Tractor Design and Testing

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Tractor Design and Testing

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Lesson 1. Hierarchical Development in Tractor Design

1. Introduction:

In 1917, Henry Ford introduced the Fordson tractor weighing one ton. The Fordson soon ruled the tractor industry, accounting for 75 percent of the U.S. market share and 50 percent of the worldwide share. Nevertheless, the tractor business remained a competitive field, at least for a few decades, and competition helped foster innovations. Tractors themselves got smaller and more lightweight and were designed with a higher ground clearance, making them capable of cultivation through the standing crop.

I. Engines:

Experiments with engines were conducted date back many centuries, but James Watt is credited with patenting the first practical steam engine in 1769 (Gray 1954b). A steam engine for agricultural work was in use by 1849 (Norbeck, 1976). It was pulled from place to place using draft animals. Development of power trains and crude steering systems transformed the steam engines into tractors that could be used for heavy drawbar work. By 1858, J. W. Fawkes had produced a steam tractor that can pull eight plows at 4.8 km/h in virgin sod (Gray, 1954b).

By 1907, tractors with internal combustion (IC) engines were beginning to appear. Competition between the two types of tractors was fierce and climaxed in the tractor trials that were held in Winnipeg, Manitoba, Canada in 1908-1911 (Goering et. al. 2003), where the limitations of the steam tractors became apparent. Steam tractors required an operating crew, including two men to run the tractor and two to haul coal and water. The firebox of steam tractors was usually fired with coal, and the open-cycle engine required periodic replenishment of the boiler water. A tractor with an IC engine required only one person to operate.

After the Winnipeg trials, steam tractors rapidly gave way to tractors with IC engines. The transition helped transform agriculture. Steam tractors were large and clumsy, lacking the versatility that tractors with IC engines provided. Steam tractors could not be used until the fire was started in the fire box and the water was brought to a boil. When the job was finished, the energy stored' in the heated water was wasted. Conversely, IC engines could be started and stopped quickly and, not having a firebox or boiler, could be made much -smaller.

II. Pneumatic Tires/Traction:

Rubber tires designed for agricultural use came along in 1933, making it much easier for tractors to function even on the roughest, muddiest ground. An Allis-Chalmers Model U tractor belonging to Albert Schroeder of Waukesha, Wisconsin, was outfitted with a pair of Firestone 48X12 airplane tires in place of lugged steel wheels. Tests by the University of Nebraska Tractor Test Laboratory found that rubber wheels resulted in a 25 percent improvement in fuel economy. Rubber wheels also mean smoother, faster driving with less wear and tear on tractor parts and the driver. Minneapolis Marine Power Implement Company even markets a "Comfort Tractor" with road speeds up to 40 mph, making it usable on public roads or hauling grain or transporting equipment and ever mindful of the power plant.

As manufacturers seek better productivity through improvements in transmissions, tires, and engine power, some tractors have become heavy again. To avoid soil compaction problems, modern tractors are sometimes '4 wheel driven' (4WD), with the weight evenly distributed over the four wheels. Dual or twin wheels are sometimes fitted to further reduce ground pressure. Four-wheel drive tractors began to appear in the 1960s. Some four-wheel drive tractors have the standard "two large, two small" configuration typical of smaller tractors, while some have four large, powered wheels. The larger tractors are typically an articulated, center-hinged design steered by hydraulic cylinders that move the forward power unit while the trailing unit is not steered separately.

III. Power Take Off (PTO):

Experimental power take-offs (PTOs) were tried as early as 1878, but in 1918, IRC was first to install a PTO on a production tractor (Goering, 2004). This option was on their Mode115-30 tractor in 1920, when it was the first tractor with a PTO to undergo a Nebraska tractor test. However, that PTO was not tested; rather, belt pulley power was measured in those days. Another early innovation, introduced by International Harvester in 1922, was the so-called power takeoff. This device consisted of a metal shaft that transmitted the engine power directly to a towed implement such as a reaper through a universal joint or similar mechanism; in other words, the implement "took off" power from the tractor engine.

An early question was whether the PTO speed should be keyed to ground speed or engine speed. In 1925, experience in rice-producing states demonstrated the wisdom of linking PTO speed, to engine speed. The rice crop was heavy and traction was poor, but the grain binders could run at full speed while travel speed was reduced to accommodate the heavy crop. In 1926, ASAE adopted the first PTO standard that specified the direction, speed, size, shape and location of the PTO shaft. The first standard speed was 536 rpm, which got rounded-off to 540 rpm. Later, when power demands rose, the 1000 rpm PTO was developed. The John Deere Company followed in 1927 with a power lift that raised and lowered hitched implements at the end of each row—a time- and labor-saving breakthrough. Engineers in the 1930s came up with diesel engines, which provided more power at a lower cost.

IV. Hydraulic System:

Irish mechanic Harry Ferguson developed a tractor that incorporated an innovative hydraulic draft control system, which raised and lowered attached implements—such as tillers, mowers, post-hole diggers, and plows are automatically adjust their needed depth.In 1917, Henry Ford had formed a company (Ford and Son) separate from his automobile business to manufacture farm tractors (Wendell, 1979). Their Fordson tractor was manufactured and sold until 1928, at which point Ford & Son was merged back into the Ford Motor Company. The David Brown Company in England was the first to build the tractor, but Ferguson also claim it to Henry Ford in the United States. With a handshake agreement, Ford manufactures Ferguson's tractor and implements from 1939 to 1948. The three point hitch was developed by Harry Ferguson by 1935, after 17 years of experimentation. In 1936; he began selling a light tractor equipped with the hitch in the British Isles and Norway. The Ferguson system included an automatic draft control system that was very effective. In 1938, Ferguson demonstrated his tractor to Henry Ford in the U.S. (Gray 1954b). A few years later Ferguson's company merged with Canadian company Massey-Harris to form Massey-Ferguson.

Tractor sales continued to climb, peaking in 1951, when about 0.8 million tractors were sold in the United States.Pulled and powered by tractors, an increasingly wide variety of farm implements were mechanizing just about every step in the crop-growing process, from seed preparation, planting of seed to the harvesting of the final seed/fruit.

Equally important developments were occurring on the other side of the hitch system. Until the three-point hitch standard was developed by ASAE in 1959, each tractor producer had a different method of attaching implements to their tractors. Typically, it was difficult or impossible to mount one manufacturer's implements on another manufacturer's tractor. A decade later, Henry Ford was ready to re-enter the farm tractor business. He liked Ferguson's three-point hitch and entered into a verbal agreement to manufacture tractors equipped with it. These Model 9N tractors entered the market in 1939 when a dispute ended the verbal agreement in 1946, Ford formed the Dearborn Motors Company to produce Ford tractors. Harry Ferguson began producing his Ferguson tractor at a new Ferguson Park plant in Detroit. In 1953, Ferguson's company merged with Massey Harris and production of the Massey Ferguson tractor began (Wendell, 1979). In the early 1950, Oliver introduced a three point hitch without draft control.

After ASAE developed their three point hitch standard in 1959, most other tractor manufacturers adopted it, as a result, it became possible to use the implements produced by any manufacturers on nearly any tractor. Development of the three point hitch also spurred the trend to larger average farm sizes. Implements fully mounted over roadways at higher speeds on road than would have been possible with pull type implements.

Open-center hydraulic systems include a fixed-displacement pump supplying an actuator through a tandem-center directional-control valve. Such systems are inexpensive and function well with a single actuator. When more than one actuator is used, the system pressure rises to that of actuator with the lowest pressure demand, which could create problems. International Harvester Company (IHC) in 1960, developed a sickle bar mower powered by a hydraulic motor. In a field test, the mower worked well in cutting heavy grass until the operator raised the hitch, at which point the mower stalled. The hitch lift cylinder had a lower pressure demand than the hydraulic motor powering the mower. Thus, the hydraulic fluid took the path of least resistance and stopped flowing to the hydraulic motor. The phenomenon is called sequencing, i.e., when two actuators have different pressure demands, the one with the heavier demand has to wait until the one with the lighter demand stops receiving hydraulic fluid. Over the years, improved hydraulic systems were developed. When John Deere introduced their "New Generation of Power" in 1960, they introduced a constant-pressure system featuring a 'variable-displacement pump that adjusted its stroke to maintain constant system pressure at a level designed to handle the heaviest load. The constant pressure systems were later succeeded by load-sensing systems. These systems include a variable-displacement pump in which a stroke control valve senses the highest pressure demand in the system and increases the pump stroke enough to meet that demand. Constant pressure and load-sensing system work, if the total fluid demand can be supplied by the pump operating at part stroke. With the touch of a lever, the operator can now control the movement of very heavy loads. When coupled with electronic system, hydraulic systems also enable automatic control of steering and other functions, control that would have been very difficult to provide without hydraulics.

V. Fuels:

One advantage of using draft animals was that farmers could grow their own "fuel," i.e., feed for the animals. With tractors, it was necessary to buy the fuel. Between 1900 and 1960, gasoline was the predominant fuel, with kerosene (the Rumely Oil Pull was the most notable of this kind) and ethanol being common alternatives. Generally, one engine could burn any of those, although cold starting was easiest on gasoline. Often, a small auxiliary fuel tank was available to hold gasoline for cold starting and warm-up, while the main fuel tank held whatever fuel was most convenient or least expensive for the particular farmer. Dieselisation gained momentum starting in the 1960s, and modern farm tractors usually employ diesel engines, which range in power output from 18 to 575 horsepower (15 to 480 kW). Size and output are dependent on application, with smaller tractors used for lawn mowing, landscaping, orchard work, and truck farming, and larger tractors for vast fields of rice, wheat, maize, soybean and other crops.

Diesel engines made an early appearance about 1930, but the required precision-made fuel metering parts made them too expensive for most farm tractors and starting was also a problem. Diesel powered tractors usually included a small, gasoline-powered "pony" motor to crank the diesel engine. Minneapolis-Moline introduced their Model U diesel tractor in 1952. The International Harvester Company (IHC) Model MD tractor used a unique starting system. A spark plug for each cylinder was in a small auxiliary chamber linked through a third valve to the main chamber.

Opening this cam-operated valve reduced the compression ratio and allowed the engine tn be started on gasoline supplied via a carburettor: the valve was closed and the carburettor bypassed to switch to diesel operation. Diesels steadily gained market share in the 1950s, and virtually all new tractors since 1976 have had diesel engines. Electrical systems had developed enough by that time to allow electric starters to replace pony motors. Diesel engines provide much higher fuel efficiency than gasoline engines. The switch to diesels had a letter effect on biofuels development, when farmers again began to grow fuel. Ethanol is not a suitable fuel for typical, unmodified compression-ignition (Cl) engines. The biofuel developed for Cl engines are calledbiodiesel, the subject of a recent ASABE lecture (Van Gerpcn et al., 2007).

VI. Safety Features:

Around 1985, it became mandatory to fit tractors with 'roll over protection structures' to lessen the high risk of fatal injury if the tractor rolled over.This basic design has remained unchanged for a number of years, but enclosed cabs are being fitted now on modern models, for reasons of operator safety and comfort.

VII. Recent Advances:

After 1994, space technology has been incorporated into agriculture in the form of GPS devices, and robust on-board computers installed as optional features on farm tractors. These technologies are used in modern, precision farming techniques. The spin-offs from the space race have actually facilitated automation in plowing and the use of light bar or autosteer systems on tractors, the idea being to neither overlap and use more fuel nor any missing when performing jobs such as cultivating. Global Positioning System (GPS) receivers on tractors to record precise locations on their farms to determine which areas need particular quantities of water, fertilizer, and pesticides.

Lesson 2. Different Type of Tractors Available in India/abroad & it'sImportance in Agriculture

1. Introduction

There are evidences of the revolution in agriculture brought by mechanization. Beginning with the internal combustion (IC) engines and moving on to rubber tires. Mechanization also improved the farm implements designed for planting, harvesting, and threshing. At the end of 20thcentury, precision agriculture became the practice, combining the farmer's down-to-earth know-how with space-based technology. Now a days tractor is the major farm power source used Worldover for different farm operations.

The name tractor came from Latin word "trahere" means to pull and latter became one word from combination of traction + motor. Tractor is a wheeled or tracked self-propelledengineering vehicle specifically designed to deliver a high tractive effort (or torque) at slow speeds as well as for the purposes of hauling a trailer or machinery used in agriculture or construction. Most commonly, the term is used to describe a farm vehicle that provides the power and traction to mechanize agricultural operations. Agricultural implements may be towed behind or mounted with the tractor and the tractor may also provide a source of power through power takeoff (PTO) or belt pulley,if the agricultural machinery is stationary.

This basic design has remained unchanged for a number of years, but enclosed cabs are being fitted now on modern models, for reasons of operator safety and comfort.

2. Development

The tractor evolved in the second half of the 19th century and first half of the 20th into its present, conventional, two wheel drive form and four wheel drive variation. This form owes much to history but also the fact that it is an inherently logical arrangement. Designers followed early tractor designs that were simply replacements for horses or other draught animals. The layout takes advantage of the transfer of weight to the main driving wheels at the rear, as the drawbar pull on the tractor increases. The layout is inherently stable in the horizontal plane because the implement commonly being pulled behind the tractor tends to follow the latter and to pull it into straight line operation. Rear mounted implements offer a minimum offset loading and moment in the horizontal plane; this contrasts with side mounted implements.

I. Type of Tractors Available in India/Abroad

Farm Tractors are classified as Follows;

(A). According to use, modern farm tractors are classified in three groups:

1. General purpose (land utility) tractors

General purpose or land utility tractors are used for major farm operations, which are common to the cultivation of most crops, such as tillage, harrowing, sowing and harvesting. These tractors are characterized by a low ground clearance, increased engine power and good traction due to their wide tyres or tracks enabling them to develop a high pull.

2. Universal row crop (row crop utility) tractors

Row-crop tractors are for the inter-cultivation operations of crops sown in rows. Inter-cultivation can take place anytime from crop germination to harvest. Several rounds of cultivation may be done over the season. A row-crop tractor essentially brings together a farm tractor and its cultivator into one machine, The earliest tractors were to mechanize agriculture to reduce the heavy efforts of plowing and harrowing before planting, which was done by humans and draft animals. Early tractors were used mainly to alleviate this drudgery, but they tended to be very big and heavy, so were not well-suited in getting into a field of already-planted row crops for weeding, spraying etc. Row-crop tractors are generally light, affordable and reliable with more ground clearance and wide wheel track that can be adjusted to suit the particular inter row distance. Modern row crop tractors have rollover protection systems in the form of a reinforced cab or a roll bar for better safety.

3. Special purpose tractors

Special purpose tractors are modification of standard land or row crop utility tractor models and are used for definite or special crops/jobs (e.g. in cotton, garden, orchard, vineyard fields) or for various jobs under certain conditions (e.g. on marshy soils, hillsides). The agricultural tractor is sometimes modified for use under special conditions where the standard type is not suitable. The narrower tractor is a basic small tractor which has been modified to pass through the rows of orchard trees and vineyards. The high clearance tractor is usually a standard tractor which has high ground clearance for spraying, fertilizer broadcasting and other operations at later stage of crop growth. High clearance tractor with air conditioner cab was developed by the PAU, Ludhiana for collection of spectral images of the crop and for intercultural operation in wide row crops (Fig. 2.1). Light, low HP, 4WD tractors work in paddy field, where the combination of light weight and 4WD is desirable. Other special purpose tractors provide engine and transmission systems for special purpose-built machines, such as for pipe laying, drainage and mechanical harvester.

Fig. 2:1 High clearance tractor in field

Garden tractors (mini tractors) are small, light weight tractors designed for use in gardens, orchards and small estates (Fig. 2.2).The engines are generally a one- or two-cylinder petrol (gasoline) or diesel engines. Typically, diesel-powered garden tractors are larger and heavier-duty than gasoline-powered unit. Tractors designed for orchards, have features suited to passing under tree branches easily. These include a lower overall profile; reduced tree-branch-snagging risk (via under slung exhaust pipes rather than smoke-stack-style exhaust, and large sheet metal cowlings and fairings that allow branches to deflect and slide off rather than catch); spark arrestors on the exhaust pipes; and often wire cages to protect the operator from snags. Recently HMT has also developed a Tranter (Transport + Tractor), which can be used for farm work as well as for the transport purposes (Fig. 2.3). It's having seating capacity for 5 peoples to sit comfortably during transportation.

Fig. 2.2: Mini tractor for garden/orchard

Fig. 2.3: Tranter type of tractor

(B). As per traction unit the tractors are divided into

1) Crawler (track laying) type
2) Semi-tracked type
3) Wheeled type

(a) 2 wheeled tractors (Power tillers)
(b) 4 wheeled, 2 wheel driven (2WD) tractors
(c) 4 wheeled, 4 wheel driven (4WD) tractors
(d) 8 wheeled, 8 wheel driven (8WD) tractors

Tracked tractors are equipped with tracks instead of wheels. They are generally used on farms where soils are difficult to cultivate, such as heavy clays, or where seasons are shorter and wet conditions predominate. More power can be transmitted to the drawbar than wheeled tractors. Maintenance costs are however higher than for wheeled tractors. Also, unlike wheeled tractors, they must be transported from field to field by a 'low loader'. Recently, a tractor manufacturer designed a high powered, high speed tracked tractor that runs on rubber tracks and can be driven on the road. This model may make the tracked tractor more popular in future. Tracked tractors have power ratings of 65-700 HP (48.47-522 kW).

Two wheeled tractors are often called 'walking tractors or power tillers. The small hand held units with rotary cultivators are usually driven by petrol engines. Larger units are often coupled to 2 wheeled trailers and driven by diesel engines. Engines of 5-15 horsepower are common for power tillers. Four wheeled, 2WD tractors are the most common type of tractor. The two rear wheels are given engine power. The front wheels are much smaller and are used for steering. Engine power ranges from 25 to 120 HP (18.64 to 89.48 kW). The 4WD tractor is similar to the 2WD tractors, but all 4 wheels of 4WD tractor are powered for better traction. The front wheels are half the size of the rear wheels. The 4WD tractors usually have power ratings of 70 HP (52.2 kW) and above, although some lower horsepower units are made for special purposes especially in Japan for wet fields. The 8WD tractors are the top of the range in terms of weight and power. There is lesser soil compaction and wheel slip by distributing weight and power over 8 wheels. They are articulated in the middle, and an axle is mounted to each of the jointed halves, with both axles driven. Each axle has 2 dual wheels at each end, or 4 wheels per axle. 8WD tractors usually have engines of 200 HP (149.14 kW) or more.

(C). As to the type of undercarriage, tractors are divided into

1) Framed
2) Semi-framed
3) Frame-less

Tractors may be framed, semi-framed or frameless. The body of framed tractors is essentially a riveted or welded frame, that of semi-framed tractors is made up of two short longitudinal beams (side members) bolted or welded to the rear axle housing, while in frame less tractors, the body is formed by bolting together the casings of individual tractor mechanisms.

(D). As indicated by 3-point linkage categories

There are five different hitch sizes, called categories (Table 2.1). The higher category hitches have sturdier lift arms and larger connector pins. There is some flexibility in the tractor hp at which one category hitch ends and the next begins.

Table 2.1: Specifications of different categories of three point linkage system

Category	Tractor HP (kW)	Top Link Pin Diameter		Lift Arm Pin Diameter	
		In	mm	Inch	mm
0	Up to 20 (10.44)	5/8	15.88	5/8	15.88
I	20 to 45 (10.44 to 33.56)	3/4	19.05	7/8	22.23
II	40 to 100 (29.82 to 74.57)	1	25.40	1⅛	28.58
III	80 to 225 (59.65 to 167.78)	1¼	31.75	1 7/16	26.99
IV	180 to 400 (134.23 to 298.28) and above	13/4	82.55	2	50.80

Category II is most widely used in india, but category I is used for many implements designed for use with small to medium tractors. Fortunately many mounted implements and machines are now designed for use with either category I or II tractors and this is point to note in selecting equipment.

3. Global Variations in Tractors:

- Rice-land tires are used in Japan.
- Power/weight ratios are greater for tractors in Japan.
- Radial-ply tires are common in Europe for better traction.
- Tractors outside of North America have up to four PTO speeds.
- In North America 4WD is used mainly tractors of over 100 kW are mainly used but in Japan tractors of 10 KW may have front wheel assisted 4WD
- In Europe and Japan, 4WD with front wheels smaller than the rear is common but in North America all 4WD tractors have equal size wheels
- Crawler tractors are more popular in Europe and UK.
- Power tillers are common in Asia.

4. Future Engine Designs

- CI engine is well established and not likely to be replaced soon.
- Ceramics materials which have high heat resistance as well as anticorrosion and anti-water properties are likely to be incorporated into designs of the future for increased operating temperature and reduced wear.
- Look for electric drives for cooling (air and water movement) and lubrication.

5. Trends in Tractor Design:

The future tractor design greatly depends on technological and social advancement in agricultural and economic sector including energy and environmental systems. Tractors continue to have a greater power/mass ratio, which results in the tractors travelling at a faster speed, since improvements in traction have not kept pace with the increase in power. It is also clear that the power output of tractors has continued to increase. The growth however in power and weight of tractors will probably not continue at the same rate as in the past. The major reason for limiting the increase in size of future tractors is increase in soil compaction affecting soil conservation as well as plant growth. However, Gohlich (1984) presents an excellent discussion on the trends of the tractor design as:

- Total weight reduction of tractor and implements: More emphasis will be concentrated on reducing the total weight of the tractor implement system in order to minimize the ground pressure and soil compaction, particularly during seed bed preparation

- Front and rear mounted implements: It will contribute increasingly to better, more convenient and more economical field operations.

- Lighter tractors will transfer power through PTO: Instead of the standard heavy tractors of today, for most of the required field operations a lighter, second tractor power unit with low pressure tires, which would transfer the majority of its power through the power take off (PTO) rather than through the ground drive may be a desirable approach on the future farm

- Power transfer will be controlled automatically: The optimization of power transfer will be facilitated by driver information displays as well as by control circuits that may eventually over take some of the present manual functions.

- Driver comfort and safety will be improved: The roll-over protection structure (ROPS), seat belt, AC Cabin etc. will be provided in all future tractors for safety and comfort of the driver.

- Introduction of information and space technologies systems like GPS devices, and robust on-board computers installed as optional features on farm tractors. These technologies are used in modern, precision farming techniques. Use of light bar or auto-steer systems on tractors, the idea being to neither overlap and use more fuel nor leave streaks when performing jobs such as cultivating.

6. Importance of Tractors in Agriculture:

Power availability coupled withother advanced technologies has linear relationship with the food grain productivity (Fig. 2.4). Power availability varying from 0.60 kW/ha in Orissa state having food grain productivity of about 1000 kg/ha as compared to the 4000 kg/ha in Punjab state having a power availability of 3.5 kW/ha. Tractor is the main power source for almost all agricultural operations. The farm tractor is used for pulling or pushing agricultural machinery for plowing, tilling, disking, harrowing, planting and similar tasks, can be used for providing rotary power to implements like rotavator, strip till drill etc. and for transportation. A farm tractor can also be used for stationary purpose like to power a pump for irrigation, to thresher etc.

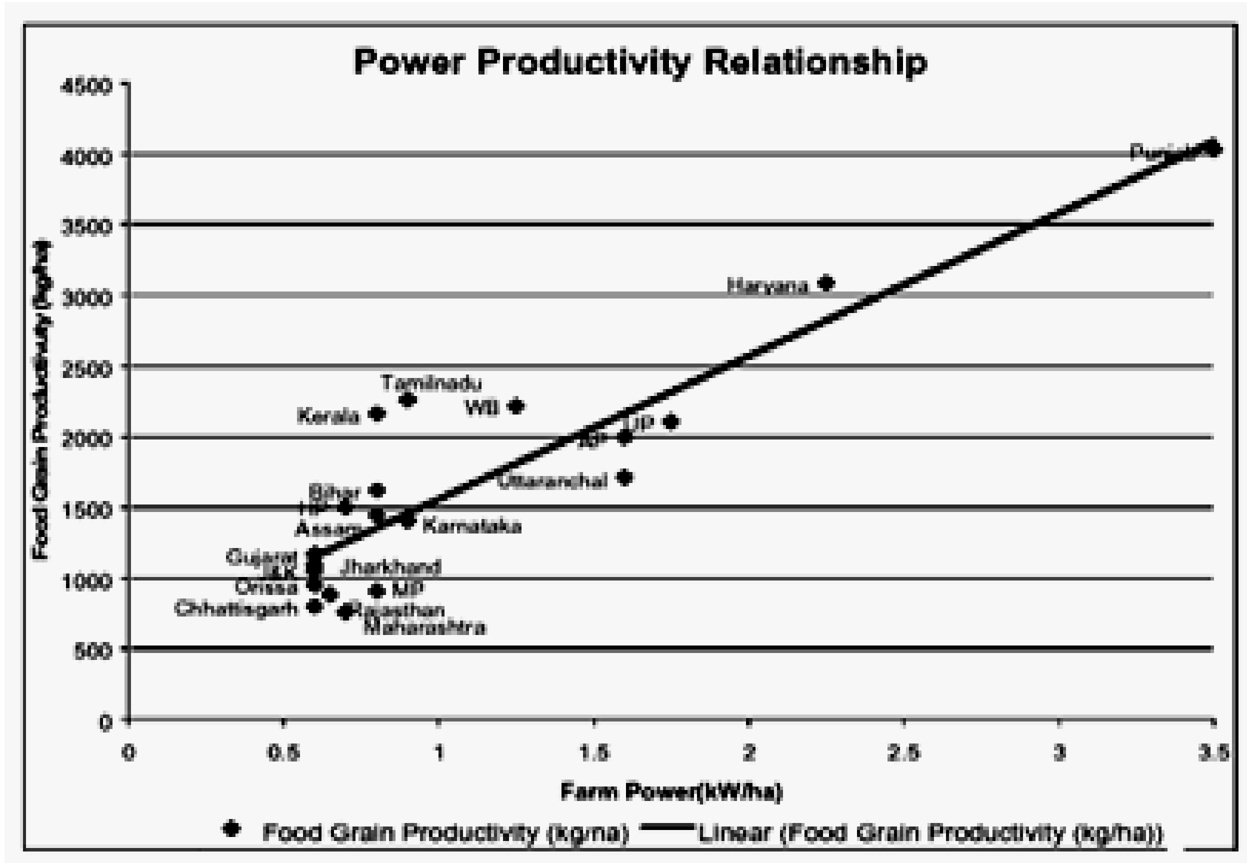


Fig. 2.4: Power availability relationship with food grain productivity in India

Although it is able to undertake a multitude of specific tasks at farms, the functions of the tractor can be reduced to the following (Reece 1971):

(i) The provision of up to full power in the form of a large drawbar pull (compared to the weight of the tractor) at low speeds. The highly variable loading that occurs in agricultural operations requires consideration of tractor performance at part load, particularly with respect to fuel consumption.

(ii) The provision of power for driving and control of a range of implements and machines performing various tasks and attached in a variety of ways.

(iii) The provision of power as the basis for a transport system in both on- and off-road conditions.

Lesson 3. Recent Trends in Tractor Design

1. Introduction

Withall the developments in the last hundred years, most tractors today still look much like small steam traction engines. The growth, however in power and weight of tractors will probably not continue at the same rate as in the past. The reason for limiting the increase in size of future tractors is due to increase in soil compaction affecting soil conservation as well as plant growth. The future will see more sophisticated tractors with greater reliability, manoeuvrability, comfort, and safety. Gradual evolution in design is more likely than radical change. Currently, more number of speeds with faster highway towing speeds, comfort, safety, more information systems are being developed for tractors. The modernfarm tractor has become a marvel of engineering with features that would be beyond the imaginations of early tractor designers. How could they have imagined a future operator sitting in an air conditioned cab, using an internet-connected computer to check crop prices while a GPS signal guided the tractor across the field. Further, the tractor has transformed agriculture. Modern tractor is made up of different systems. System wise recent trends in tractor design are explained below,

I. Power Generation System i.e. Engines:

Average power of tractor used in India is 35 HP (26.10 kW), but trend in the tractor manufacturing is that average power of the tractor is increasing. Piston engine is not likely to be replaced immediately with other types of energy conversion systems. Most of the tractor engines in India are designed with 2 to 4 cylinders. New engines for current tractor models contain changes or modifications made by improvement in design, fuels or materials to make it more efficient, economical, more durable with low exhaust emissions. Some major principles set by the French engineer for an IC engine that combustion chamber should have smallest possible surface to volume ratio, expansion process should be rapid and compression at the start of expansion should be as high as possible must be strictly followed. Average tractor engine bore ratio in India is about 1.33. There is the tendency to further reduce this stroke bore ratio hence recent engines have a smaller stroke bore ratio which allows higher engine speeds, running in more compact size and reduced vibrations.

II. Transmission:

A modern tractor drive train is a complex arrangement of several basic components that are used to control and transmit the power delivered by the engine. Most older farm tractors use a manual transmission. They have several gear ratios, typically three to six, sometimes multiplied into two or three ranges. This arrangement provides a set of discrete ratios that, combined with the varying of the throttle, allow final-drive speeds from less than one to about 40 km/h, with the lower speeds used for working the land and the highest speed used on the road. Tractor manufacturers are giving more attention so that there should be more number of speeds available on their models. In most of the Indian tractors, now available speeds are 8 or 10 (4/5 low + 4/5 high) forward with 2 reverse speeds instead of 4 or 6 forward speeds used previously. When a limited number of speeds are available on the tractor, it will not be possible to use the maximum engine power available, especially when the load is highly variable. Hence, the tractor should be provided specific speeds and the ease with which these speeds can be selected are the most important features determining that how well the transmission meets the farmer's needs. Ideally any forward speed upto 40 kmph and 15 kmph reverse speed could be selected under any load with a simple adjustment of a control lever. Previously, Tractors were with only sliding or constant mesh type gear boxes with few speeds in their transmission systems. But, now some manufacturers have incorporated partially synchronized or fully synchronized type gear boxes with many speeds for their tractors. Consequently, the transmission is a compromise between what is designed and what can be provided with available technology at a reasonable cost. Unsynchronized transmission designs were replaced with synchronization or with continuously variable transmissions (CVTs). Either a synchronized manual transmission with enough available gear ratios (often achieved with dual ranges, high and low) or a CVT allow the engine speed to be matched to the desired final-drive speed, while keeping engine speed within the appropriate speed range for power generation. Fully synchronized gear box technology was introduced by Bajaj Tempo in their OX-35 & 45 models. The advantage of a synchronized transmission is that gear changes can be made easily without damaging the transmission, even when the tractor is moving. In new Holland tractors there is the partially engaged synchronized gear box in which speed equalization occurs at higher speeds. Optional four wheel drive (4 WD) technology is also provided by some local manufacturers. Net tractive coefficient and tractive efficiency are more for a 4 WD tractor than a 2 WD tractor. Hence, four wheel drive tractors are able to produce more drawbar power. Dual clutch and live PTO are now common for the Indian tractors.

III. Chassis Design

Present non-cab design of Indian tractor generally make use of the cast iron unit frame construction. Chassis of the tractor consists of the engine, transmission system, suspension system, road wheels, steering, brakes etc. suitably mounted. Application of power systems, to drastically reduce control efforts, for brakes and steering used in tractors. Hence, instead of disc brakes available in many tractors, now hydraulic brakes are introduced in HMT 7511 and oil immersed brakes are used in the OX model of Bajaj Tempo. Hydraulic braking system are simple in construction, self-lubricating type with equal braking effort at all the wheels. There are complete water sealed brakes in HMT range of tractors suitable for paddy fields. In most of the Indian tractor models, reciprocating ball and nut type steering system was provided. Optional power steering/hydrostatic steering is also now provided by many manufacturers of India. Generally, the power steering system provides automatic hydraulic assistance to the turning effort applied to the manual steering system.

Eicher tractors introduced straight rear axle in one of their model. To increase the driver's comfort and convenience operator's seat was improved in many ways. The vehicle seat should be adjusted to provide the operator with an easy control of the steering mechanism. Deluxe and Rail Fender type seats with horizontal and vertical adjustments are now being provided by all of the tractor manufacturers. Some research studies had shown that the predominant vibrational motion of a wheel tractor is vertica1 and that the seated operator is most sensitive to vertica1 acceleration. Hence, M&M ltd. has introduced shock absorbing type suspension system to reduce the vertical vibration for tractor seat.

IV. Hydraulic Systems:

The agricultural tractor is only one half of a machine combination and cannot start to solve its purpose until the other half the implement added. Implement can be added with three point linkage systems operated hydraulically. The mounted implement, 3-point linkage and hydraulic draught controls pioneered by Ferguson are the fundamental to most of the world's tractors.The ford 9N tractor with the Ferguson three-point hitch, introduced in 1939, was equipped with a hydraulic system. Harold Brock, at the age of 93 reported on his experiences in working with Henry Ford, to develop the hydraulic system on the Ford 9N at the ASABE centennial celebration in Minneapolis.There is a continuous improvement in the hydraulic system of a tractor. Now a day, Automatic Depth and Draft Control (ADDC) system is available on all the recent models introduced by Indian manufacturers of a tractor. Bosch type control valve has been used in the hydraulic system of the OX-35 &45 models of the Bajaj Tempo.

V. Traction Improvements:

Because the drawbar is one of the most used but least efficient methods of using tractor power, traction has been the subject of much research, resulting in traction improvements. Pneumatic tires improved traction by allowing drawbar power to be developed with more speed and less pull. Added ballast reduces slip in drive wheels. When pneumatic tires were introduced in the 1930s, B.F. Goodrich discovered that use of water in the tires helped improve traction (Gray, 1954b) and calcium chloride was added to prevent freezing. Radial introduced on tractors in 1980s, tolerate lower inflation pressure and provide a bigger soil-tire footprint to improve traction. In addition, use of mounted implements rather than pull-type implements helps increase the loading on the drive wheels, thus improving traction.

Traction limits the amount of drawbar power that can be delivered by tractors driven by only rear wheels. In 1958, the Steiger tractor with four-wheel drive (4WD) and 175 kW of engine power was introduced (Larsen, 1981), and soon other companies also began producing 4WD tractors. These were unsuitable for row crop work, but in 1979, IH announced their 2+2 tractor that was a 4WD tractor capable of row crop work (Larsen, 1981). While production of 4WD tractors continues, a movement has begun toward rear wheel drive tractors supplemented with front wheel assist (FWA). The Europeans were offering FWA in the 1950s, with FWA in the American market coming later. Initially, the front wheels were driven hydrostatically, but this quickly gave way to mechanical FWA.

Crawler tractors, i.e. tractors with steel tracks, have excellent traction but have had limited success in agriculture because of their limited mobility and travel speed. They cannot be driven on highways. In 1987, Caterpillar introduced their Challenger tractor. Its rubber tracks allowed the high, ground contact area of a crawler tractor with the mobility of a wheeled tractor. In 1997, John Deere introduced a similar rubber-tracked tractor. Caterpillar sold their Challenger line of tractor to AGCO in 2002.

The steel wheels and lugs of early tractors greatly limited travel speed. Because drawbar power is the product of pull and speed, these tractors needed a lot of mass to support high pull and appreciable drawbar power. The first reported use of rubber tires on tractors was in Florida orange grooves; steel lugs were damaging tree roots, so tire casings were attached to the wheels to protect the roots. These tires had no tubes i.e., were not pneumatic (Gray, 1954b).

The higher speeds permitted by pneumatic tires helped to transform agriculture, in that higher speed allowed the average farm size to grow much larger. Thus, when farmers wanted to increase the size of their farming operations, they could include land parcels so widely separated that reaching them with steel lugged tractors would have been impractical with average farm size thus increasing, fewer people remained in farming operations, a trend that was accelerated by the use of pneumatic tires on farm tractors.

VI. Comfort and Safety:

Early tractors were not known for comfort and safety. For example, starting one of these tractors usually required turning a hand crank at the front of the tractor or spinning a flywheel at the side of the tractor. If the tractor was inadvertently left in gear and started easily, the-person starting the engine could suddenly find himself standing directly in front of a moving, tractor, with his life on the line. Tractor seats were typically of the steel pan type, with no cushioning. The logic of tractor controls varied from manufacturer to manufacturer. Some tractors had a. foot-operated clutch, while other clutches were hand-operated. Even hand-operated clutches differed; some were engaged by pushing them forward, while others were engaged by pulling them backward. An operator, moving from one tractor to another, could easily become confused and get into life-threatening situations.

The tractor PTO, if unshielded, was also dangerous. There have been numerous press reports of injury or death when people became entangled in unshielded PTO shafts. The danger was recognized early on when, in 1926, PTO Standard S203 was developed. It included a section on shielding the PTO shaft. Unfortunately, the metal cover shielding the PTO line between the tractor and implement was often discarded by farmers. It was not until decades later that the driveline safety shield was made an integral part of the driveline: and could not be discarded.

In US, tractor-related injuries account for approximately 32% of the fatalities and 6% of the nonfatal injuries in agriculture. Over 50% is attributed to tractor overturns. Early tractor owners were not enthusiastic about comfort and safety features. As Larsen (1981) pointed out, "If a farmer placed a pad on the seat or raised an umbrella to protect himself from the sun, he was generally viewed as a sissy." Consequently, tractor manufacturers gave little thought to operator comfort. The Minneapolis-Moline Comfort tractor was likely the first to cater to operator comfort. Its enclosed cab was designed to protect the operator from rain, snow, and cold weather. When that tractor was introduced in 1938, few farmers were willing to pay for the added cost of the enclosed cab, and not many Comfort tractors were sold.

Extension agricultural engineers developed scale-model tractors that could be used to show how tractors could upset when used improperly (Larsen, 1981). When John Deere introduced their New Generation of Power in 1960, the tractors included numerous comfort and safety features. Dr. Janet Travell, personal physician to President John Kennedy, helped Deere design the tractor seat. In addition, the location and operation of tractor controls were designed to reduce operator error. The control logic to achieve that result is stated in ASABE Standard S335, Operator Controls on Agricultural Equipment, i.e., "This standard is based on the principle that a given direction of movement of any control should provide a consistent and expected result." Thus, for example, moving a throttle lever forward should increase, not decrease, the engine speed. ASABE has two other related documents that help- tractor safety. These are S304, Graphical Symbols for Operator Controls and Displays on Agricultural Equipment (first adopted in 1967), and EP443, Color Coding Hand Controls (first adopted in 1984). The symbols are designed to be widely understood. For example, the turtle symbol is used to indicate SLOW, while the rabbit symbol indicates FAST. In color coding, for example, red is used only for single function engine stop controls. While John Deere was cited as an introducer of numerous comfort and safety features in 1960, other tractor manufacturers were also adding such features about the same time.

Row crop tractors necessarily have a high center of gravity, so overturns can easily occur. In the late 1960s, work was underway in Sweden on what became Roll Over Protective Structures (ROPS), (Larsen, 1981). ROPS was highly effective in preventing fatal overturn accidents. Initially, ROPs was offered as an option, but when John Deere introduced ROPS as standard equipment 'on their tractors, farmers went looking elsewhere for new tractors. The situation changed when John Deere offered their technology to other companies in exchange for an agreement to install ROPS on their tractors, and farmers began to accept tractors with ROPS (Leffingwell, 1994): While ROPS began as a roll bar, ROPS strength was later incorporated into tractor cabs. The independent left and right wheel-braking augments the steering of the tractor when only the two rear wheels are driven. This is usually done when it is necessary to make a sharp turn. The split brake pedal is also used in mud or soft soil to control a tire spinning due to loss of traction. The operator presses both pedals together to stop the tractor. For tractors with additional front-wheel drive, this operation often engages the 4-wheel locking differential (diff-lock) to help stop the tractor when traveling at road speeds.

Modern tractors have a ROPS to prevent an operator from being crushed if the tractor turns over. The ROPS does not prevent tractor overturns; rather, it prevents the operator from being crushed during an overturn. This is especially important in open-air tractors, where the ROPS is a steel beam that extends above the operator's seat. For tractors with operator cabs, the ROPS is part of the frame of the cab. A ROPS with enclosed cab further reduces the likelihood of serious injury because the operator is protected by the sides and windows of the cab.

For the ROPS to work as designed, the operator must stay within its protective frame. This means the operator must wear the seat belt; not wearing it may defeat the primary purpose of the ROPS.

A fifth pedal is traditionally included just in front of the driver's seat to operate the rear differential lock (diff-lock), which prevents wheel slip. The differential normally allows the outside wheel to travel faster than the inside wheel during a turn. However, in low-traction conditions on a soft surface, the same mechanism could allow one wheel to slip, further reducing traction. The diff-lock overrides this, forcing both wheels to turn at the same speed, reducing wheel slip and improving traction. Care must be taken to unlock the differential before turning, usually by hitting the pedal a second time, since the tractor with good traction cannot perform a turn with the diff-lock engaged. In modern tractors, this pedal is replaced with an electrical switch.

VII. Levers and switches:

Many functions once controlled with levers have been replaced with some model of electrical switch with the rise of indirect computer controlling of functions in modern tractors.

The three-point hitch was controlled with a lever for adjusting the position, or as with the earliest ones, just the function for raising or lowering the hitch. With modern electrical systems, it is often replaced with a potentiometer for the lower bound position and another one for the upper bound, and a switch allowing automatic adjustment of the hitch between these settings.

VIII. GPS/Navigation:

Space does not permit inclusion of many other parts of tractor history. Among the important omissions are lubrication systems, air cleaner, and numerous drive train variation, Other tractor improvements loom on the horizon, and only two will be mentioned. Automatic tractor guidance based on the Global Positioning System (GPS) and/or machine vision, is nearing commercial reality. In Europe, work is underway on tractors with spring-mounted cabs and/or axles to protect the operator when the tractor is used at high speeds, and such tractors are also entering the U. S. market.

The modernfarm tractor (Fig. 3.1) has become a marvel of engineering with features that would be beyond the imaginations of early tractor designers.

(Source:http://images4.wikia.nocookie.net/__cb20120621203660/tractors/images/2/2e/VTZ_504_MFWD_ (Foton) _-_2012.jpg)

Fig. 3.1 Modern farm tractor

(Source: http://daddystractor.com/category/social-studies/page/2/)

How could they have imagined a future operator sitting in an air conditioned cab, using an internet-connected computer to check crop prices while a GPS signal guided the tractor across the field? Further, the tractor has transformed agriculture. It has so improved worker productivity that now less than 2% of the U. S. population are needed to be farmers.

Module 2. Study of special design features of tractor engines and their selection

Lesson 4. Selection of engines available in the market and their performance

1. Introduction

Many sizes and types of engines are available for automobiles including engine for tractors. Selection of engine for automobiles depends mainly upon their uses. Engine used for on-road vehicles like car, trucks etc. are different than the engines used for off-road vehicles like tractors. Main emphasis will be given on the design requirement of different components of the engine and selection of engines for the tractors. Design of each part of an engine for a tractor is out of the preview of this book.

2. Difference between tractor and automobiles:

Automobile engines are generally unsuitable for tractors due to the difference in uses of both vehicles. The main design differences between tractors and automobiles are explained in Table 4.1.

Table 4.1: Main design differences between tractor and automobile:

Parameter	Automobile	Tractor
Engine type	Designed for high torque and the engine is expected to be able to produce it for longer times.	Designed to produce maximum power the engine will produce at the best speed.
Functional Design	Designed for Speed (Maximum Speed of 5000 RPM)	Designed for Brake Power or Traction (Maximum Speed of 2500 RPM)
Surface of Operation	Hard Surface like concrete being on-road vehicle	Soft and undulated terrain of soil being off-road vehicle
Weight transfer	No weight transfer being Single part system	There is weight transfer from front to rear wheels being 2-3 parts system (tractor-hydraulic unit-implement or tractor-straw reaper-trailer)
Type of Fuel	Diesel or Petrol	Mostly Diesel engine or Biodiesel
Working conditions	Better environmental conditions	Harsh conditions like dust etc.
Wheels	All four wheels of same size	All four wheels may or may not be same specially small HP tractors

3. Engine Selection:

Mostly four stroke cycle diesel engines are used for the tractors. An engine produces power by providing a rotating crankshaft which can exert a given amount of torque on a particular load and speed. The amount of torque the engine can exert usually varies with speed. Torque is defined as a force around a given point, applied at a radius from that point. The unit of torque is kg-m. To better understand, let us take an example, two cars of equal weight, one is having a 2-liter twin-cam engine that makes 300 HP (223.71 kW) at 8000 RPM (27 kg-m) and 400 HP (298.28 kW) at 10,000 RPM (29 kg-m) will run faster as compared to a 5-liter engine that makes 300 HP (223.71 kW) at 4000 RPM (54 kg-m) and 400 HP (298.28 kW) at 5000 RPM (58 kg-m). In fact, in cars of equal weight, the smaller engine will race better because it's much lighter, therefore puts less weight on the front end. and, in reality, the car with the lighter 2-liter engine will likely weigh less than the big V8-powered car, so will be a better race car for several reasons.

4. Tractor vs. Automobile Engine:

- Tractor engines tend to have longer stroke as compared to bore - than a car or pickup truck engine. Long stroke allows good low-end torque.

  Tractor engines are designed for the highest torque at low RPM's or tractors have high torque for a given horsepower or tractor produce their rated horsepower at low rpm. An auto engine might make its max rated hp at 4500 rpm where-as a tractor engine makes its max power at anywhere from 975 to 2200 rpm. Although, once it gets to the rear wheels, the engine torque is irrelevant because gear reduction has made the torque at the axle identical for the high rpm/low torque engine as for the low rpm/high torque engine.

- Tractors are made to sustain max power all day long in the field under load and will do it for years. If a car engine is run in a tractor's field under load at 4500 rpm or higher if so rated, and see how long it will move. If throttle is put back to 2000 rpm to make it last then it won't have enough torque to pull through that field or mud.

- A car engine is designed to have great reserve power for just short spurts when needed it and the rest of the time it "loafs". Tractor engines are made to work all day and car engines are made to loaf all day unless needed to get through a yellow light or occasional drag race.

- Torque is a more important part for the loads on a tractor as compared to power relates to speed in a car engine. A car engine only makes good power at high RPM's. Different engines use their available horsepower as cars uses only 30%, the road trucks use 60% and Tractors use 90% of their available power.

- Tractor engines are subjected to usually large and fluctuating loads during most field operations. The important engine parts including castings like cylinder blocks, heads, crankshaft, connecting rods, piston, valves and other parts are heavier and stronger than automotive engines, as in a tractor, weight is not an issue in fact a heavier engine would add ballast to the machine.

- Mostly, tractor engines have replaceable cylinder liners (sleeves) that, theoretically, allow an engine block to be overhauled an unlimited number of times and on each overhaul the engine will be brought back to original factory specifications.
- Tractor engine are often part of the tractor frame. They have bolt holes in the side of the lower front part of the engine block. Some manufacturers attach the front axle mounting brackets directly to the front of the block, thus eliminating the need of a frame. Generally smaller tractors are frameless
- A tractor with 4 cylinder engine give 90 HP(67.11 kW) and a car with 2 cylinder engine give 120 hp. It depends upon the cylinder capacity as more cylinder capacity means more fuel will enter as more fuel will enter in engine, output will be more. Hence, bigger size of cylinder will produce more power not the number of cylinders. Suppose 4 cylinders are sucking 50 mg fuel at one stroke and one cylinder consuming 100 mg will produce more power.

5. Power and Torque for an Engine:

Torque and speed are measured but power is calculated. A dynamometer measures the power produced by applying a load to the engine output shaft by means of a water brake, a generator, an eddy-current absorber, or any other controllable device capable of absorbing power. The dynamometer control system causes the absorber to exactly match the amount of torque the engine is producing at that instant. Torque and RPM of the engine shaft are measured and from those two measurements, it calculates observed power. Various factors like air temperature, barometric pressure, and relative humidity are measured in order to correct the observed power to be measured at standard atmospheric conditions, called corrected power.

Force (F) = Torque (T) ÷ Radius (R) ... (4.1)

Distance per revolution = 2 π R

Distance per minute = 2 π R x RPM

Power (P) = F x Distance per minute

P = (T ÷ R) x (2 π R .RPM)

P = 2 π T. RPM

As 1 HP = 75 kg-m/sec or 4500 kg-m/min

Or HP = 2 π T. RPM ÷ 4500

HP = Torque x RPM ÷ 5252 (Torque is in pounds-ft) (1HP = 33000 pounds-ft/sec)

It means if torque is measured in pounds-ft/sec then HP will be equal to torque at engine speed of 5252 rpm.

HP = Torque x RPM ÷ 716.5 (Torque is in kg-m) (1 HP =75 kg-m/sec) ... (4.2)

But if torque is measured in kg-m then HP will be equal to torque at engine speed of 716.5 rpm

The modern diesel engine for tractor has every advantages as regards convenience of operation, being a reliable starter, lower fuel consumption and immediately ready for hard work. Its good torque characteristics' are widely appreciated. The measure of tractor's power or capacity for field work are the net engine power and draw bar horse power. The net power of an engine or tractor is the power that anengine can deliver for the performance of work at the crankshaft.

6. Power and Torque Curve for an Engine:

For measuring the power developed at various speeds and loads, the engine is first started with no load, and the speed of the shaft is measured by tachometer. The load is then increased in stages. At each stage, the speed and the torque are recorded by dynamometer. Beyond a certain limit, it will be found that additional loads reduce the speed of the engine to such an extent that it is in the danger of stalling. When this point has been reached, no further load should be applied. By plotting the values of the power for various speeds or loads, a curve indicating the maximum power is obtained.

In order to design an engine for a particular application, it is helpful to plot out the optimal power curve for that specific application, then from that design information, the torque curve is determined which is required to produce the desired power curve. Typically, the torque peak will occur at a substantially lower RPM than the power peak. The reason is that, in general, the torque curve does not drop off (% wise) as rapidly as the RPM is increasing (% wise). For a race engine, it is often beneficial (within the boundary conditions of the application) to operate the engine well beyond the power peak, in order to produce the maximum average power within a required RPM band.

An example of that concept is shown in Fig.4.1. The three dashed lines represent three different torque curves, each having exactly the same shape and torque values, but with the peak torque values located at different RPM values. The solid lines show the power produced by the torque curves of the same color.

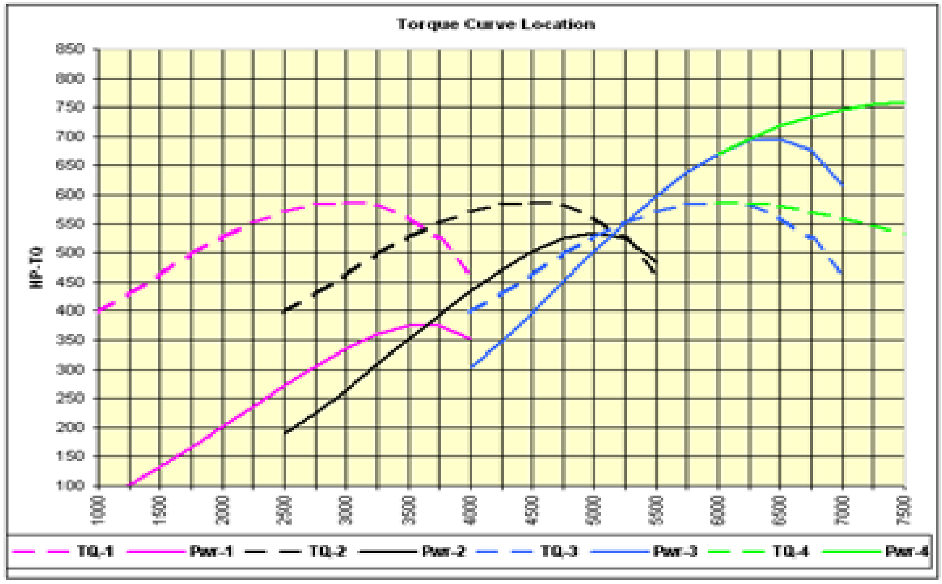


Fig. 4.1: Power and Torque curve for different engines

Note that, with a torque peak of 587 lb-ft (795.86 N-m) at 3000 RPM, the pink power line peaks at about 375 HP (375.63 kW) between 3500 and 3750 RPM. With the same torque curve moved to the right by 1500 RPM {black, 587 lb-ft (795.86 N-m) torque peak at 4500 RPM}, the peak power jumps to about 535 HP (398.95 kW) at 5000 RPM. Again, moving the same torque curve to the right another 1500 RPM {blue, 587 lb-ft (795.86 N-m) torque peak at 6000 RPM} causes the power to peak at about 696 HP (519 kW) at 6500 RPM.

Using the black curves as an example, note that the engine produces 500 HP (372.85 kW) at both 4500 and 5400 RPM, which means the engine, can do the same amount of work per unit time (power) at 4500 as it can at 5400. However, it will burn less fuel to produce 450 HP (335.56 kW) at 4500 RPM than at 5400 RPM, because the parasitic power losses (power consumed to turn the crankshaft, reciprocating components, valvetrain) increases as the square of the crankshaft speed.

The RPM band within which the engine produces its peak torque is limited. You can tailor an engine to have a high peak torque with a very narrow band, or a lower peak torque value over a wider band. Those characteristics are usually dictated by the parameters of the application for which the engine is intended.

As shown in figure, blue torque curve has been altered (as shown by the green line) so that it doesn't drop off as quickly. Note how that causes the green power line to increase well beyond the torque peak. That sort of a change to the torque curve can be achieved by altering various key components, including (but not limited to) cam lobe profiles, cam lobe separation, intake and/or exhaust runner length, intake and/or exhaust runner cross section. Alterations intended to broaden the torque peak will inevitable reduce the peak torque value, but the desirability of a given change is determined by the application.

The torque exerted by an engine is a measure of the moment which it can continuously exert. For a given gear ratio in the transmission of a tractor, any increase in load on the engine calls for a corresponding increase in engine torque. If the maximum torque available is insufficient, the engine will stall. Because tractors are designed to operate in widely varying load conditions, it is essential for satisfactory performance that maximum torque should be developed at a lower engine speed than that corresponding to maximum power. Torque and power curve of a tractor engine are shown in Fig. 4.2. It is indicated that peak torque i.e. 810 lb-ft (1098.21 N-m) of engine was available at an engine speed of 1500 rpm of the engine. But peak power was 130 hp (96.94 kW) at 2200 rpm of engine, at that speed the torque was 650 pound-ft (881.28 N-m). The peak torque at 1500 rpm is about 25% more as compared to the torque at peak power position.

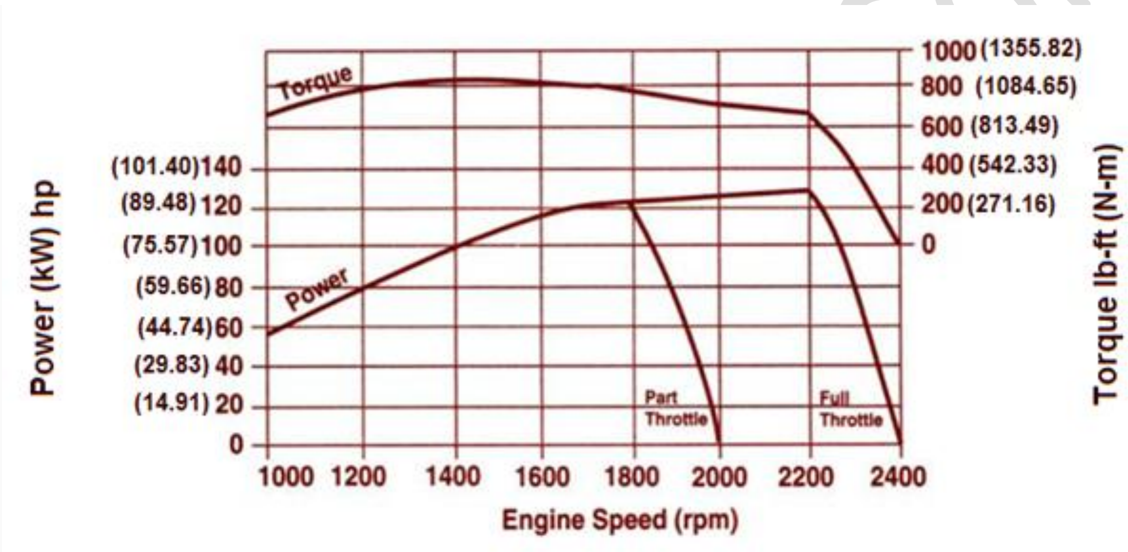


Fig.4.2: Power and Torque curve for Tractor Engine

If another engine is having flat torque speed curve having maximum torque only 4% higher than at maximum power. In the field if 10% overload occurs, the first engine will slow down and the driver has time to change down to a lower gear if desired, the engine is capable of taking the tractor. But the second engine will cause the tractor to stall with very little warning. An engine with a considerable reserve of torque is particularly useful for agricultural works specially operation of combine/forage harvester, where a troublesome blockage occurs if the engine stalls.

Lesson 5. Design requirements for tractor engine components and systems.

1. Introduction

New engines correspond essentially to current models but contain changes or modifications made possible by improvement in design, fuels, lubricants or materials. The first step of any design problem is to select the speed, type, number and size of cylinders and the arrangement of the cylinders for the required output. The second step is to calculate the sizes and materials of the parts to withstand the stresses.

As yet, there appears no alternate to the CI engine for tractors and the diesel will continue be the main source of engine fuel. Piston engine is not likely to be replaced immediately with other types of energy conversion systems. Tractor engines are designed for a high load factor, that is, the power output may be 85 to 90% of the maximum brake power at rated speed and the engine is expected to be able to produce this power for long periods of time.

Most of the tractor engines in India are designed with 2 to 4 cylinders (Table 2). Single-cylinder engines are now used in large numbers on power tillers or on lawn and garden tractors. New engines for current tractor models contain changes or modifications made by improvement in design, fuels or materials to make it more efficient, economical, more durable with low exhaust emissions. Maximum engine speed for tractor is generally between between 2000-2500 rpm. Average hp of tractor used in India is 35 hp (26.1 kW) but trend in the tractor manufacturing is that average hp of the tractor is increasing, hence manufacturers are introducing tractors upto 75 hp (55.93 kW) having displacement volume of about 4000 cc. with 4 cylinders. In some cases like for larger areas and competitive agricultural conditions where farmers seeks more power, tractor manufacturers are increasing engine displacement, use higher engine speeds and other systems to increase power.

2. Stroke-Bore Ratio:

Major principles set by a French Engineer for an IC engine that combustion should have smallest possible surface to volume ratio, expansion process should be rapid and compression at the start of expansion should be as high as possible must be strictly followed. Stroke-bore ratio in engines is a design consideration because higher compression ratios are generally permissible with small bores and higher thermal efficiencies may be attained with the higher compression ratios. However, assuming equal compression ratio and displacement per stroke, a cylinder with a large stroke-bore ratio will have a higher surface to volume ratio. Obviously, a decrease in the length of the stroke necessitates an increase in the bore in order to maintain the same displacement. This larger surface ratio permits more heat transfer to the combustion chamber walls, resulting in a decreasing efficiency. The short stroke engine having less piston travel has lesser friction. The breathing capacity or volumetric efficiency of high speed engines can be improved by decreasing the stroke bore ratio, which permits the use of larger or multiple valves. This ratio for tractors tested at Nebraska in 1982, the average stroke to bore ratio in tractor engines was decreased to 1.01 from 1.29 in the year 1920. Average stroke-bore ratio of the tractor engine in India was about 1.33 in 2001 (Table 2). There is the tendency to further reduce this stroke-bore ratio hence recent engines have a smaller stroke-bore ratio which allows higher engine speeds, resulting in more compact size and reduced vibration. One model Swaraj 744 and three models of Escorts range of tractor viz. Farmtrac 45, 50 & 55 have stroke-bore ratio equal to one (Table 2). Even in one model of Escort, this ratio is less than one i.e. 0.95. Technology of turbocharging the engine has also been introduced recently in the Indian tractors.

3. Specific Fuel Consumption (SFC):

Fuel efficiency is becoming an increasingly important factor in farm economics. Obviously, tractors with the lowest SFC are the most efficient. There is the continuous effort by all the manufacturers to reduce the SFC for their newly introduced models. Among the six major players of tractor in India, the Mahindra 575DI has the lowest SFC at max. power i.e. 233 g/kWh. It is clear from the table 2 that wt/power ratio of the tractors in India is being reduced, which results in the tractors travelling faster, since improvements in traction have not kept pace with the increase in power. Efforts are needed to improve the traction of the tractor. Indian manufacturers have vastly improved the weight to power ratio of their prime mover by either the slimming process on castings derived through CAD/CAM designs or by change of designs to accommodate higher break mean effective pressures reaching peak values close to 23 bars.

4. Compression Ratio:

The thermal efficiency of an engine does not approach the theoretical efficiency of an Otto cycle engine as is given by

$$\text{Efficiency} = 1 - \frac{1}{r^{n-1}} \qquad \text{... (5.1)}$$

Where

r = Compression ratio

n = C_p/C_v (Ratio of specific heat of air at constant pressure and constant volume)

Hence, it is apparent that the efficiency of an ideal otto cycle increases as the compression ratio increases.
There are many reasons why the actual efficiency is substantially below the theoretical efficiency. Some of the discrepancies can be accounted for by the following factors

1. The compression and expansion of gases is not adiabatic
2. There are friction losses in the engine
3. Work is required to draw in and exhaust the gases

4. For a free breathing engine (not supercharged) the volumetric efficiency will be less than 100%
5. Complete combustion does not occur

Large changes in the compression ratio of diesel engines are not practical. Most diesel engines have compression ratios that range from 16:1 to 22:1

5. Design of Combustion Chamber:

The shape and size of the combustion chamber has a decided effect upon the proper mixing of the fuel and air and also upon the fuel detonation. In general the combustion chamber is designed to create turbulence of the mixture for better combustion and greater flame propagation velocity, thereby decreasing the combustion time and improving antiknock characteristics. A short and compact combustion chamber generally requires lesser time for combustion and improves the antiknock characteristics of fuel There are many variations in the design of combustion chamber of diesel engines fitted in the tractors. Some variations are due to the different methods of starting the combustion chamber process in the cylinder. Because the fuel to air ratio is very low as the fuel is first injected into the cylinder, ignition will not begin until the ratio is in the combustible range. Thus if the fuel were injected directly into the combustion chamber, there would be an unnecessarily long delay before ignition begins, resulting in a very high initial pressure. Four types of combustion chambers are used in diesel engines namely direct injection (DI), pre, swirl or turbulence and auxiliary combustion chambers. Most common method of diesel injection is the direct-injection (Dl) in which combustion chamber generally employs a concave piston head. M&M ltd. has to introduce in tractor engines to increase the thermal efficiency, results to lower the fuel consumption claimed this method of injection first. In DI engines there is also tine atomisation of the fuel in the combustion chamber. Two manufacturers HMT and Eicher have claimed the turbulence or swirl combustion chamber in their tractor engines. Due to turbulence or swirl action in these type of combustion chamber there is a greater utilisation of air therefore higher mean effective pressure is attained at the clean exhaust from the engine. These engines are also called indirect injection (IDI) engines. IDI engines are also quieter than the DI engines and can be run on fuel with a lower cetane number. In the swirl combustion chamber, burning of fuel-air mixture is caused by swirl action thereby improving the mixing and subsequent combustion in the main combustion chamber. The swirl chamber contains from 50 to 90% of the compressed volume when the piston is on top dead center (TDC). Eicher ltd. gave the term Ricardo type engines to these IDI engines, since Ricardo first used that design. With the better swirl control in these engines, noise level was also reduced in greater extent. Some of the models of different tractor with their specifications shown in Table 5.1.

6. Fuels:

Almost all of the fuels commonly used in farm tractors are products of crude petroleum. Crude petroleum is made of combined carbon and hydrogen in approximately the proportion of 86% carbon and 14% hydrogen. The atoms of carbon and hydrogen may be combines in many ways to from many different hydrocarbon compounds from crude oil. The two grades of diesel fuels commonly used in US are Grade No. 1-D and 2-D. Grade no. 1-D diesel fuel is volatile fuel is applicable for use in engines used for relatively wide variations in loads and speeds. Grade No. 2-D type fuels are lower volatile used for the engine used relatively at high loads and uniform speeds or in engines not requiring fuels having the higher volatility. Fuel quality is specified because engine design and operation affect the type of fuel best suited for an engine.

I. Cetane number:

The ignition quality of diesel fuel is determined by its cetane number/index. In general, high cetane fuels permit an engine to be started at lower air temperatures, provide faster engine warm-up without misfiring or producing white smoke, reduce the formation of varnish and carbon deposits and eliminate diesel knock. Generally diesel fuels marketed in USA have a range from 33 to 64 cetane numbers but for tractor diesel fuels having 38 to 52 cetane numbers are generally used.

Proper viscosity or resistance to internal flow of the diesel fuel is required. The injector pumps perform best when the fuel has proper viscosity. If the viscosity is too low, more frequent maintenance and repair of injection system may result. If the viscosity is too high, excessively high pressures may result in the injection system. The desired kinematic viscosity for diesel fuel is 1.5 (Min) to 4.0 (Max) centistokes at 40^{o} C temperature.

A diesel fuel often has a tendency to form carbon deposits in the engine. Carbon residue tests are very effective in predicting carbon formation of base fuels, but they may be in error when the fuels contain additives such as ignition improvers like hexyl nitrates. Carbon residue in diesel fuel generally ranges from 0.15 to 0.35%.

II. Flash point:

The flash point is not directly related to engine performance. It is however of importance in connection with legal requirements and safety precautions involved in fuel handling and storage and is normally specified to meet insurance and fire regulations.

Diesel engine injectors are precision made and therefore are quite sensitive to any abrasive material in the fuel. Since the ash content is directly related to wear of the injection system, it must be kept low. Diesel fuel has a maximum allowable ash content of 0.01%.The additives in diesel fuel are for engine protection and to improve engine performance. Antioxidants, metal deactivators and corrosion inhibitors are used in diesel fuels.

III. Biodiesel:

As fossil fuels become scarce, other fuels like bio-diesel will have to be used. There are many factors that must be considered in the selection of an alternative fuel. Some of these factors are cost per unit of work done, availability, compatibility with the engine, safety, storage, management and convenience.Biodiesel is a clean, oxygenated fuel made from renewable agricultural resources such as Jatropha, soybeans, rapeseeds etc.. It is simple to use, biodegradable, and free of sulfur. Using biodiesel fuel reduces particulate emissions, as well as decreases dependence on crude oil. It can be used as blend with diesel as B2 fuel (2 percent biofuel and 98 percent diesel). John Deere has approved B5 fuel for tractor engines and many other manufacturers in the industry are following the lead. The technical problems often reported include excess carbon deposits on pistons and exhaust valves, fuel filter cogging and engine oil dilution with the use of plant oils for IC engines. These problems must be solved before plant oils can become a viable alternative fuel.

IV. Fuel Injection Systems:

Generally three types of fuel injection systems used in tractors are: individual or in-line type, distributor type and unit injector type (Fig. 5.1). In function the distributor system and inline or individual pump systems are the same. The difference is that the distributor system replaces the individual pumps with a single pump plus a distributor rotor. Because of compact nature of the distributor type pump, its principle of operation is more difficult. The distributor pump performs the different functions like metering the quantity of fuel determined by the governor, delivering the fuel at high pressure in the range from 10000 to 20000 kPa to the injectors and timing of the fuel injection that is the function of engine speed. Unit injector combines the function of high pressure pump and injector into one unit. One advantage of such a system is that there is no high pressure line to complicate the timing and metering of the fuel. The unit injector is commonly driven by a separate cam shaft. TAFE and New Holland have introduced rotary type FI pump in the fuel injection system of their tractors.

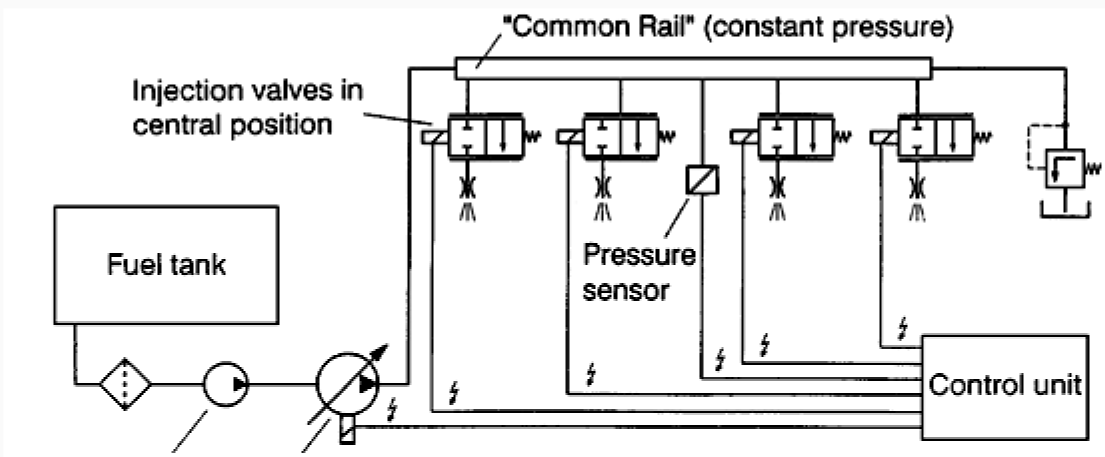


Fig. 5.1: Fuel injection system
(Source: CIGR Handbook of Agricultural Engineering Volume III)

7. Air Cleaning System:

Dust entering a tractor engine is often the principal cause of wear. The location of the air inlet affects the quantity of dust to be removed by the air cleaner. The dust concentration was highest near the engine and lowest in the region directly above the engine. For this reason, tractor designers usually select an air inlet above or near the top of the engine housing. Dry type and wet type or oil bath type air cleaners are generally used for the tractors (Fig.5.2 and 5.3). Efficiency of dry type air filters exceeds that of the oil bath type. Because a tractor operates most of the time at less than full load, the relative cleaning efficiency at one half load is significant. At less than rated airflow the efficiency of the oil bath cleaner tends to decrease, whereas that of the dry type filter remains high. Almost by all the manufacturers 3-stage air cleaning first by pre-cleaner followed by oil bowl and paper element has been introduced for tractor engines.

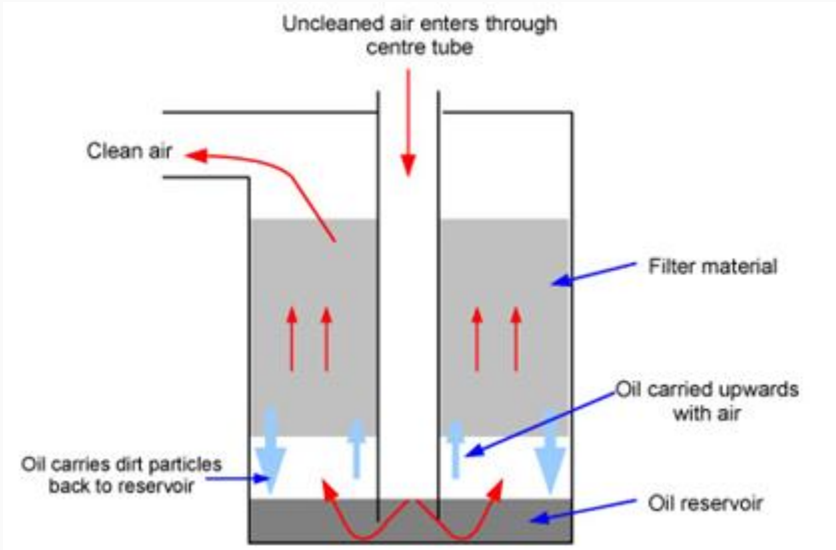


Fig. 5.2: Oil bath type air cleaner

(Source: http://vintagetractorengineer.com/2009/01/oil-bath-air-cleaners-for-tractors/)

Fig. 5.3: Oil bath type air cleaner assembly
(Source: http://www.metlonics.com/images/TRACTOR/L7.jpg)

8. Cooling System:

The proper design and maintenance of a cooling system (Fig. 5.4) are extremely important because the amount of heat to be dissipated is high. The heat rejected to the cooling water by a diesel engine at 2000 rpm is approximately 0.58kW for each kW of output. Because a tractor usually operates at a high load factor, a relatively large cooling capacity must be supplied compared to that for an automobile. Water flow for the cooling system ranges from 0.7 to 1.4

l/kW of engine output and pumps are usually selected to deliver 25 to 90 ml/s per kW. Fan power is normally 5 % of gross engine power, with a range of 2.5 to 10%. Radiator frontal areas of 19 to 29 sq.cm/kW engine power output. Temperature drop through the radiator can be assumed to be 5.5 to 8.5 Degree C.

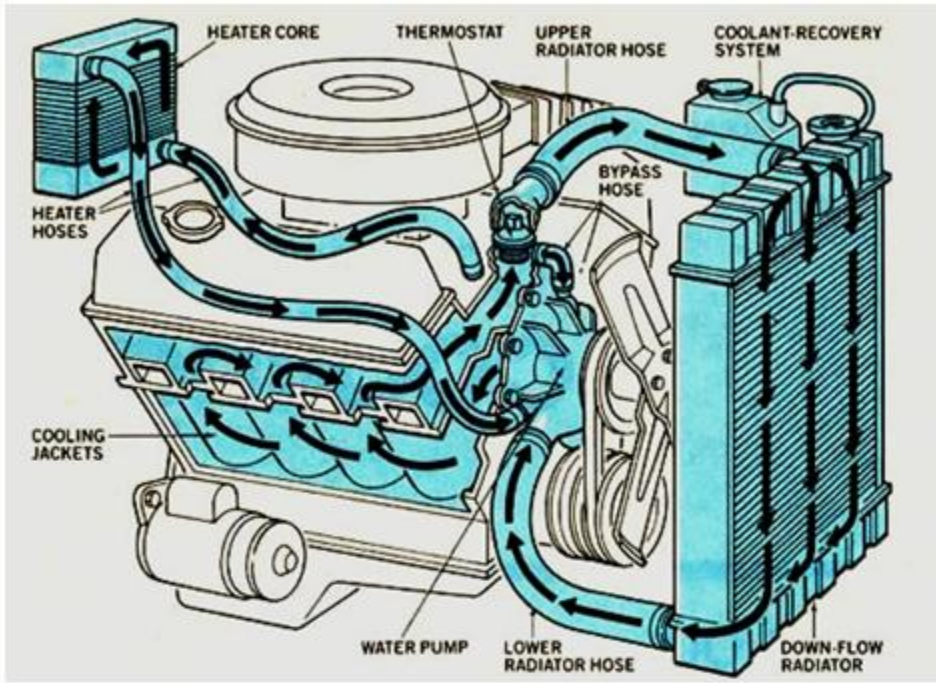


Fig. 5.4: Cooling system
(Source: http://www.crankshaftcoalition.com/wiki/File:Engine-cooling-system.jpg)
(http://web.utk.edu/~tprather/FoothillsTractorClub/TechTips/cooling.gif)

9. Governing System:

The engine control device is called a governor. The governor can be mechanical or an electronic device. In general, governors for IC engines are of the centrifugal-force, spring loaded type.

A good governor for agricultural tractor engines is taken to be one giving performance such that the difference between no load speed and maximum load speed is less than 100 rpm. The maximum load and no, load are at maximum governor settings on both sides. As with the increase of load the crankshaft torque rises to a peak and that maximum torque is developed at a speed well below governed speed and therefore well below the speed at which maximum power is obtained. It is an important phenomenon. When the engine is operating at the full throttle, its speed and power are controlled solely by load and some reserve is provided by governor in order to cope with sudden increase of load. If at any particular speed of engine set by the operator, the increase or decrease in load will decrease or increase the speed is regulated by the governor without changing the gear. But a tractor fitted with a suitable diesel engine having more than 500 rpm in reserve that is the difference in maximum power speed and maximum torque speed, will possess good slogging ability.

Lesson 6. Engine design changes for emission reduction

1. Introduction

The technology absorption process move towards lower polluting emissions is gathering momentum with all tractor manufacturers. Three years back Kirloskar started designing and developing a modem 3-cylinder 100-mm bore engine for Punjab Tractors Ltd. (PTL). The cost-effective design was tailored to meet the Indian tractor users and satisfy Indian pollution norms and regulations. Main pollutants coming in engine exhaust gases are Oxides of Nitrogen (NOx), Carbon mono-oxide (CO), Oxides of Sulfur (SOx), Hydro-carbon (HC) and Particulate matter (PM). All these pollutants are polluting the environment as;

NOx – Oxides of nitrogen, which react in the atmosphere with hydrocarbons to form particulate matter

CO – Carbon monoxide, a product of incomplete combustion

SOx – Oxides of sulfur, which contribute to acid rain

HC – Hydrocarbons, another product of incomplete combustion

PM – Particulate matter, a non-gaseous product of combustion and atmospheric reactions

2. Emission Standards:

The different emission norms Bharat (Trem) for stage I, II and III for diesel agricultural tractors in India are given below in Table 6.1.

Table6.1. Bharat (Trem), Emission standards for diesel agricultural tractors in India

Engine Power	Date	CO	HC	HC+NO_x	NO_x	PM
kW		g/kWh				
All	2005.10	5.5	-	9.5	-	0.80
Bharat (Trem) Stage III A						
P < 8	2010.04	5.5	-	8.5	-	0.80
8 ≤ P < 19	2010.04	5.5	-	8.5	-	0.80
19 ≤ P < 37	2010.04	5.5	-	7.5	-	0.60

37 ≤ P < 75	2011.04	5.0	-	4.7	-	0.40
75 ≤ P < 130	2011.04	5.0	-	4.0	-	0.30
130 ≤ P < 560	2011.04	3.5	-	4.0	-	0.20

Emissions are tested over the ISO 8178 C1 (8-mode) cycle. For Bharat (Trem) Stage III A,the useful life periods and deterioration factors are the same as for Bharat (CEV) Stage III, Table 6.2.

Table 6.2: Bharat (CEV) stage III with useful life periods

Power Rating		Useful Life Period
		Hours
< 19 kW		3000
19-37 kW	constant speed	3000
	variable speed	5000
> 37 kW		8000

3. Engine design changes for Emission Reduction:

Reduced emissions don't have to come at the expense of engine performance. Engineers utilize a combination of innovative engine design and new technologies to improve fuel economy and performance while meeting emissions regulations.Available technologies for reducing emissions include:

- Charge air cooling
- In-cylinder solutions
- Exhaust gas recirculation
- Turbocharging
- Fuel injection systems
- Full authority electronic controls
- After-treatment

I. Charge air cooling.

Keeping air intake temperatures as low as possible controls NOx. Air-to-air charge air cooling not only reduces NOx, it also improves engine durability and increases low-speed torque and power density. It is the most efficient method of cooling intake air to help reduce engine emissions while maintaining low-speed torque, transient response time, and peak torque. Charge air cooling enables an engine to meet emissions with better fuel economy and lower installed costs.

II. In-cylinder solutions.

i. Combustion bowl and piston ring design.

Particulate emissions have been reduced by increasing injection pressure and improving the shape of the combustion bowl at the top of the piston. A reduced lip radius on the re-entrant bowl piston increases turbulence and air fuel mixing, helping burn all available fuel during combustion. The addition of valve guide seals limits particulates by reducing oil consumption. Directed top-liner cooling reduces oil consumption and enhances combustion efficiency by reducing wear in the top ring turnaround area and improve piston ring performance.

ii. Premixed compression ignition (PCI).

In traditional diesel combustion, the burning occurs in the rich regions of the spray resulting in high temperatures and high NOx. With premixed compression ignition (PCI), multiple fuel injection strategies are used to lower temperatures. This technique reduces NOx without using exhaust gas recirculation.

iii. Exhaust gas recirculation (EGR).

The lower an engine’s peak combustion temperature, lesser the amount of NOx created. EGR is an effective method of reducing peak combustion temperature and reducing NOx. The concept is simple, during certain conditions of engine operation, the EGR valve opens and measured amounts of exhaust gas are routed back into the intake manifold and mixed with the incoming fresh air. Since this process removes some oxygen from the air, the exhaust temperatures in the combustion process are lowered and the levels of NOx are reduced. Cooled EGR, as used in John Deere Power Tech Plus™ engines, increases the effectiveness of NOx reduction, while enhancing engine efficiency and power density (similar to charge air cooling).

III. Turbocharging.

i. Standard or wastegated turbocharger.

A turbocharger is an engine supercharger driven by exhaust gas turbine. Exhaust gases from the engine enter the turbine housing radially and drive the turbine wheel, which drives the compressor wheel. Both being mounted on the same shaft. Turbocharging increases the density of the air delivered to the cylinder thus making its volumetric efficiency 100% well above that available in natural aspiration. It allows the engine to burn more fuel and in turn develop more power.

Depending on the power rating, standard or wastegated turbochargers are precisely matched to the power level and application. Transient smoke is controlled by using higher-boost turbochargers, including using wastegated turbos that increase low-speed torque and prevent over-boosting at high speed.

ii. Variable geometry turbocharger (VGT).

Variable geometry turbocharger, which helps drive exhaust gas recirculation. The VGT tailors the amount of recirculated exhaust gas that mixes with the fresh air. This is accomplished through the engine control unit, which changes the pitch of the VGT vanes in order to maximize power and efficiency. The amount of cooled EGR required is determined by load and engine speed. When the exhaust flow is low, the vanes are partially closed. This increases the pressure against the turbine blades, making the turbine spin faster and generating more boost.

The VGT minimizes the impact on engine envelope size and provides excellent performance across the entire operating range of the engine, including transient response and fuel economy. It is also a highly effective approach to meeting Stage III A regulations and allows a wider power range using common engine performance hardware — reducing the number of engine configurations.

IV. Fuel injection systems.

i. High-pressure common rail fuel injection system.

For middle range engines, the high-pressure common rail fuel injection system provides constant control over fuel injection variables such as pressure, timing, duration, and multiple injections. It delivers higher injection pressures, up to 1600 bar, for more efficient combustion.

ii. Electronic unit injector (EUI).

For the larger size engines, the EUI fuel injection system is used to increase fuel pressure for more efficient combustion. This helps reduce NOx and PM.

iii. Mechanical fuel system.

To meet many emission regulations for smaller engines can be done by making improvements to the mechanical fuel system. Newer mechanical fuel systems are able to generate higher injection pressures for more efficient combustion.

V. Full authority electronic controls.

Another key component in emissions reduction is the engine control unit (ECU). It uses sensors and models to control fuel quantity, injection timing, air-to-fuel ratio, multiple fuel injections, amount of cooled EGR, and a host of other control parameters to deliver peak engine performance and fuel economy. Integrating electronic controls between the engine and the entire vehicle also reduces emissions and improves performance.

VI. After Treatment.

i. Selective catalytic reduction (SCR).

SCR is an aftertreatment option that requires a urea-based additive to reduce NOx emissions. When ammonia in urea is mixed with engine exhaust in a catalytic converter, a chemical reaction takes place and the NOx in the exhaust is converted to oxygen, nitrogen, and water. This method adds costs because of the extra tank, pump, associated components, and the SCR additive – but it provides better fuel efficiency than other NOx-reducing methods.

ii. Lean-NOx catalyst.

There are two types of Lean-NOx catalysts with different methods of regenerating. The DeNOx catalyst is a precious metal-based system that reduces hydrocarbons in an oxygen-rich exhaust stream. Without using electronic controls, the catalyst's efficiency for reducing NOx is less than 10 percent. When electronic controls are used, the efficiency is still less than 30 percent – with a substantial fuel economy penalty. A more effective Lean-NOx catalyst is the NOx adsorber (NAC), or sometimes called the Lean-NOx trap (LNT). It must be regenerated in an oxygen-deficient environment, requiring more sophisticated controls. When the unit is clean, it can reduce NOx by 90 percent. However, it is very sensitive to fuel sulfur levels and can lose efficiency quickly (to near zero) when exposed to high-sulfur fuels. When that happens, sulfur has to be removed from the catalyst. This process of sulfur removal is called desulfation. It requires very sophisticated controls and exposes the engine to high thermal stress while running at a significant fuel economy penalty. By using electronic engine controls with this type of catalyst, efficiency can be maintained greater than 60 percent over the life of the engine.

iii. Diesel oxidation catalyst (DOC).

The diesel oxidation catalyst (DOC) doesn't reduce NOx, but it is effective at reducing carbon monoxide, hydrocarbon, and some particulate matter. The flow-through oxidation catalyst oxidizes both gaseous (volatile) hydrocarbons and the semi-volatile portion of PM known as the volatile organic fraction (VOF). At higher exhaust temperatures, DOCs can also oxidize sulfur in the exhaust to form sulphate precipitated material. Catalyst manufacturers have been able to achieve the needed VOF reduction while minimizing sulfate formation. DOCs operate at peak efficiency when the sulfur concentrations in the fuel are 0.05 percent or lower. DOCs typically reduce emissions of particulate matter by 20 percent. DOCs also reduce emissions of hydrocarbons by 50 percent and carbon monoxide by 40 percent.

iv. Active diesel particulate filter (DPF).

DPFs (or particulate traps) will likely to be one of the options used to meet particulate matter reductions in Stage III B and Final Tier 4/Stage IV. Manufacturers are working hard to reduce the cost and optimize the size of these aftertreatment devices. The DPF traps and holds particulates in the exhaust. Exhaust gas flows through channels with porous walls that allow exhaust to escape, but traps soot and particulates. Then, with the help of a catalyst, the DPF regenerates by burning the collected soot.

Because high exhaust temperatures are required for this regeneration to take place, the challenge is to design DPFs that provide consistent regeneration at all levels of engine operation. "Active" diesel particulate filters solve this problem, by raising the exhaust temperature based on particulate filter backpressure. Manufacturer's working to develop active DPF systems that would regenerate in low-load and normal operating conditions.

Metals and ash found in lubricating oil can become trapped in the DPF as well. Since ash and metals cannot be burned off during soot regeneration, they are left in the filter. The buildup can eventually clog the filter and may require maintenance and cleaning. The use of lubricating oil with low ash can help alleviate this issue.

Module 3. Study of basic design parameters for traction,mechanics of chassis 39 and stability of tractors

Lesson 7. Soil machine systems for off-road vehicles

1. Introduction

The agricultural tractor is one of the class of mobile machines that involves the 'traction' process. The word 'traction' and name 'tractor' come from the word to 'draw' or 'pull' so a tractor is basically a machine for pulling off-rod; other mobile machines such as locomotives are in the same class. Vehicles like trucks and even motor cars, which are essentially vehicles for carrying loads are also involve the on road traction process. The tractor is also in the class of machines that involves operation under what are known as 'off-road' conditions. Others in this class include machines used for earth moving, mining and military work.

The tractor tyres have the function of supporting the tractor and of converting rotary motion of the engine to linear motion of the tractor.

The wheels must be chosen to:

1. Support the weight of the tractor (together with any transferred weight by attached implements) while limiting the sinkage into the soil surface and the resultant rolling resistance.

2. Engage with the soil (or surface) and transmit the traction, braking and steering forces (reactions) while limiting relative movement and the resultant slip, skid etc.

3. Provide ground following ability together with some springing and shock absorption.

The important variables in relation to the tyres include:

1.Size (diameter and width) which determines their tractive capacity and rolling resistance.

2.Strength, expressed in terms of ply rating, which in turn determines the pressure that can be used and hence the weight that the tyre can carry; this in turn also determines the tractive capacity and the rolling resistance.

3.Tread pattern which, together with the surface characteristics, determines the contact with the surface.

The losses in power at the wheel-surface interface are often great, particularly on soft surfaces (i.e., their tractive efficiency is low), hence the power available at the tractor drawbar may be much less than the power of the engine. Therefore the choice of the tyres and the weight on them is crucial in determining the overall performance of the tractor.

Various types of tyres may be used on the tractor, depending mainly on the surface on which it is working. For the following conditions, the tyres or wheels indicated in Fig 7.1 are recommended.

Fig. 7.1: Different types of tyres for different conditions

(a) Large area, shallow tread with 'high' pressure: Hard surfaces such as roads

(b) Intermediate depth tread: Normal agricultural work, dry soil

(c) Deep tread: Soft, wet agricultural soils

(d) Wide low pressure: Lawns/desert where low sinkage is required

(e) Tracks as on a crawler tractor: Dry soil, heavy loads as in earthmoving

(f) Metal cage, with angled lugs, alone or as extensions to normal tyres: Saturated, puddled soils

2. Definitions:

Rolling (motion) resistance, R is the force opposing motion of the wheel that arises from the non-recoverable energy expended in deforming the surface and wheel. It is convenient to consider this force as acting in the horizontal direction.

Tractive force, H is the horizontal reaction on a driven wheel by the soil in the contact area; it is equal and opposite to the horizontal force generated by the wheel on the soil.

Drawbar pull, P is the horizontal force at the axle generated by a driven wheel; it may be assumed that:

Drawbar pull (P) = Tractive force (H) - Rolling resistance (R) ...(7.1)

Towing force is the force to move a freely rolling wheel over the surface and is equal and opposite to the rolling resistance.

3. Operational states of a wheel

The operation of a wheel can be classified into one of the following states; each occurs within the tractor or other machines under some conditions and each has a particular unknown parameter associated with it.

(a) Braked: Here the wheel is towed against an opposing, external torque as when being braked or when it is used to generate a torque to operate a 'ground-driven' machine such as a seed drill; the unknown parameter is the wheel slip. The extreme case is where the wheel does not rotate, but just skids across the surface.

(b) Towed: Here the wheel, such as the front wheel of the tractor or the wheel of an agricultural implement, is towed with zero opposing external torque; the unknown parameter is the rolling resistance. Towed wheel is a special case of the braked wheel, with zero braking torque. A towed wheel is subject to some negative wheel slip.

(c) Driven: Here the wheel is driven with an external input torque and is required to develop a drawbar pull as in the drive wheel of a tractor; the unknown parameter is the wheel slip. The extreme case is where the wheel slips, but does not move forward. These operational states of a wheel in which input and output torque and input and output force (towing force or drawbar pull) are shown plotted against wheel-slip. From this it will be seen that:

(d) Self-propelled: Here the wheel is driven with an external input torque to overcome its own rolling resistance and to propel it across the surface without developing a drawbar pull. This approximates to the drive wheel of a tractor with no drawbar pull (if we neglect the rolling resistance of the front wheels); the unknown parameter is the rolling resistance. Self-propelled wheel is a special case of the driven wheel, with zero drawbar pull. Self-propelled wheel is subject to some positive slip

4. Tractor Performance Analysis:

Thus, if we neglect losses in forward motion due to wheel slip and in drawbar pull due to rolling resistance, all of the power from the engine is available at the drawbar. .But this is the ideal situation which might apply approximately to the tractor working on hard surfaces with small drawbar pulls and small wheel slips.

However, in many agricultural situations, wheel slip is significant, hence the travel speed of the tractor will be lesser than the ideal value. Also, much of the torque on the rear wheels goes to drive the tractor forward against the rolling resistance of both the driving and the rolling wheels. Hence the drawbar pull will also be lesser than the ideal value.

Although the tractor is moving, the equations of equilibrium can be applied to it because it is assumed that there is no acceleration. Force and torque acting on tractor are shown in Fig. 7.2.

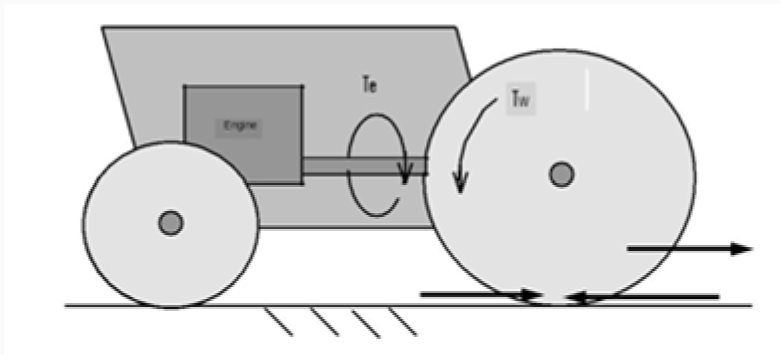


Fig 7.2: Mechanics of the tractor

5. Speed analysis:

Drive wheel diameter = D

Engine speed = Ne

Drive wheel rotational Speed = Nw

Overall transmission ratio r = Ne/Nw

If we assume that there are no losses in motion due to slip between the wheel and the surface:

Travel speed, Vo = Linear speed of wheels= $\pi D Nw = \pi D Ne / r$

This analysis shows that the travel speed depends directly on the engine speed and inversely on the gear ratio.

If the tractor is now moving with a speed V (lesser than the ideal travel speed, Vo above),

We can then define wheelslip as:

Wheelslip, s = Vo - V/Vo

Where, Vo = theoretical travel speed

V = actual travel speed

$$V = Vo\,(1 - s) = \pi D\, Ne.(1 - s)/r \quad \text{... (7.2)}$$

6. Torque / force analysis

Engine torque = Te

Drive wheel torque, Tw = r Te

Equilibrium requires that this torque is equal and opposite to the moment of the soil reaction, H on the wheel:

$$H.D/2 = Tw = r.Te$$
$$H = 2\,r\,Te/D$$

If we assume that there are no other horizontal external forces acting (such as rolling resistance, aerodynamic forces), equilibrium also requires that:

Drawbar pull, P = Soil reaction, H

$$P = 2\,r\,Te/D$$

This analysis shows that the drawbar pull depends directly on the torque generated by the engine and on the gear ratio. This assumes that the wheel / ground contact can generate the reaction to P.

A rolling resistance force (∑R for all wheels) which is assumed to act horizontally on the wheels at the wheel- ground contact patch, opposes motion of the tractor,

For equilibrium of the external horizontal forces acting on the tractor:

$$H = P + \sum R$$
$$P = 2\,r\,Te/D - \sum R \qquad \text{... (7.3)}$$

7. Power analysis

Considering power transmission at the wheels,

Output power = Input power - Power loss

i.e., Drawbar power = Wheel power - Power loss

Hence, Power loss = Wheel power - Drawbar power

$$= 2\pi\,Tw\,Nw - P\,V$$
$$= 2\pi\,(H.D/2).(Vo/\pi D) - P\,V$$
$$= H\,Vo - P\,V$$
$$= H\,Vo - (H - \sum R)\,V = H\,(Vo - V) + \sum R\,V$$
$$= H.Vo\,s + \sum R\,V$$
$$= H\,Vs + \sum R\,V \qquad \text{... (7.4)}$$

Here Vs is the slip velocity, i.e., the velocity of the wheel relative to the surface at the surface-wheel contact.

Total power loss = Power loss due to slip + Power loss due to rolling resistance

Minimizing the total power loss thus is matter of minimizing the sum of the loss due to slip and that due to rolling resistance. This is a complex problem when it is realized, for example, that the effect of weight on the driving wheels is to decrease the slip loss and increase rolling resistance losses.

8. Tractor Performance Efficiencies:

(a) Tractive efficiency (TE):

TE = Output power/Input power

= Drawbar power/Wheel power

$$= P.V/H.Vo$$
$$= (H - \sum R)/H.(1 - s)$$
$$= (1 - \sum R/H)(1 - s) \text{ or } P/P + R.(1 - s) \qquad \ldots (7.5)$$

The tractive efficiency that appears here contains two terms:

P and (P+R) which represents a 'force' efficiency; thus when there is no rolling resistance (R = 0) this factor in the tractive efficiency = 1.

(i) (1-s) which represents a 'speed' efficiency; again when there is no wheelslip (s = 0), this factor in the tractive efficiency = 1.

It might be thought that the tractive efficiency, which is one of the most important measures of tractor performance, could be determined on the basis of above mentioned equation.

However, the major difficulty with this approach is that, in practice, it is not possible to determine a relationship between rolling resistance and slip or, in general, to determine rolling resistance when a wheel is undergoing a slip. Hence, it is necessary to determine the tractive efficiency by measuring drawbar and wheel power directly by following relation;

$$TTE = P\,V/2\pi\,Tw\,Nw \qquad \ldots (7.6)$$

Drawbar pull, P, with a tension load (force) cell between the tractor and a load vehicle or implement

Travel speed, V, by timing over a known distance

Wheel torque, Tw , with a torque load cell in the transmission to the driving wheels

Wheel speed, Nw , by counting wheel revolutions over a known time period

(b) Transmission efficiency (TME)

TME = Power to wheels/Power from engine

$= 2\pi \ Tw\ Nw/2\pi\ Te\ Ne$ ... (7.7)

The maximum transmission efficiency is dependent on the design and the quality of the transmission elements.

For good quality gears the maximum efficiency is about 98% per pair of gears; hence with, say, 3 pairs of gears in the transmission and another 2 pairs in the differential / final drive, the maximum efficiency will be 0.98x0.98x0.98x0.98x0.98 = 90%.

Little improvement in efficiency can be obtained by more accurate or elaborate gearing; other types of transmission will be no more efficient.

(c) Engine efficiency(EE):

EE= Power from engine/Power in fuel

$= 2\pi\ T e\ Ne/1000.FC.C$ ...(7.8)

Where,

FC = fuel consumption rate, kg/min

C = calorific value of the fuel, kJ/kg

The maximum value for engine efficiency is dependent on and strictly limited by the thermodynamics of the engine processes. A maximum value of about 35% for a diesel engine can be expected; other types of engine will, in general, be less efficient.

(d) Overall efficiency (OE):

= Drawbar power/Fuel power

= Engine power/Fuel power. Wheel power/Engine power. Drawbar power/Wheel power

= Engine efficiency. Transmission efficiency. Tractive efficiency

Consider typical maximum values for these variables: $\eta_o = 0.35 \times 0.90 \times 0.75 = 22\ \%$

Because the maximum tractive efficiency is low and highly variable and the other efficiencies like transmission efficiency or strictly limited efficiency of engine, any significant increase in the overall efficiency of tractor performance will be achieved by increasing the tractive efficiency. Research into an understanding of the traction process and into more efficient traction devices are needed.

9. Tractive coefficient (TC):

The performance of a tractor depends to a significant degree on its weight and, in particular, on the weight on the driving wheels. It is therefore useful to define a non-dimensional drawbar pull - weight ratio termed:

Tractive coefficient (TC)= Drawbar pull/Weight on driving wheels

The tractive coefficient is a number which characterizes the interaction between the wheel and the surface in an analogous way to which coefficient of (sliding) friction characterizes the interaction between one body sliding on another. Where a different wheel and surface may be considered similar to those for which the tractive coefficient is known, then for the same wheelslip:

Drawbar pull = Tractive coefficient x weight on wheel

Where a tractor operates on a slope the tractive coefficient should logically be based on the total force parallel to the ground, ie, on the drawbar pull plus the component of the weight of the tractor down the slope. Where a four-wheel tractor is considered, and with other tractors also, the weight used may be the total weight on all wheels. In quoting values of tractive coefficient, it is therefore necessary to state which weight has been used.

Lesson 8. Traction mechanics and its prediction

1. Introduction

The study of traction mechanics includes soil - implement and soil - vehicle mechanics in general. Two approaches can be used for traction prediction

(a) Empirical

Here experimental data on the drawbar pull and rolling resistance of various wheels together with a single soil parameter (the cone index obtained by measuring the force to push a cone penetrometer into the soil) are used to predict drawbar pull and rolling resistance on a purely empirical basis (Wismer and Luth, 1974). Such an approach provides a ready and useful means of performance prediction but it is not suitable as a basis for understanding the traction process;

(b) Theoretical

Theoretical approach uses classical soil properties like cohesion, angle of internal friction and some semi - empirical parameters to develop a model for the prediction of the tractive force (soil reactions) and drawbar pull. This approach provides the best understanding of the traction process and an appropriate introduction. The theoretical / predictive approach provides the best basis for understanding tractive performance and will be emphasised here; the other approaches may be more readily used for the immediate determination of wheel performance.

The usual approach is by considering the prediction of tractor performance is to begin with the study of the performance of single wheel. The performance of the tractor is then understood as the combined interaction and performance of two or more such wheels. The traditional four-wheel tractor is a combination of driven (or braked) wheels at the rear and free rolling, towed (pushed) wheels at the front.

2. Tractive Performance

The early study of the performance of tractors was limited to the experimental measurement of travel speed and wheel slip at various drawbar pulls on soils. The results were intended to provide an understanding of the principles involved and a basis for comparing the relative performance that farmers might expect from the various tractors in the field. Rolling resistance of wheels was measured by equating it to the towing force required to move different types of (mainly transport) wheels across visually described surfaces, eg. road (hard), stubble (firm), cultivated soil (soft) etc.

The theoretical prediction of tractive performance has involved the separation of the problem into two parts, viz,the prediction of:

(i) Tractive force, H

(ii) Rolling resistance, R

Using this approach it is assumed that the drawbar pull (P) is what remains of the tractive force after the rolling resistance has been overcome, ie:

$$P(s) = H(s) - R \qquad \text{... (8.1)}$$

Where,

P(s) implies that P will be determined as a function of slip

H(s) implies that H will be predicted as a function of slip

While R is also a function of slip, this function is not known and hence the value for R is that measured under the towed condition or predicted, both of which assume zero slip. Clearly this is only approximate because the rolling resistance under finite slips will be greater than the value measured or predicted with zero slip. The generation of a tractive force by the tractor requires an equal and opposite horizontal reaction by the soil against the driving wheels in the contact area. This reaction force, which in effect determines the tractor performance, is predicted on the basis of the soil strength parameters (c and f) and the soil deformation corresponding to various wheelslip values.

The support of the tractor requires a vertical reaction on the wheels which causes vertical deformation of the soil in the contact area. Equating the energy to deform the soil (ie. to make the rut) to the work done by the rolling resistance force provides a basis for calculation of the latter. The process is modelled by the pressure – sinkage relationship for a plate pressed into the soil; slip is considered to be zero.

i. Measurement of Rolling Resistance:

The rolling resistance of a wheel is, in general terms, the force opposing the motion of the wheel as it rolls on a surface. This force arises from the energy losses that occur due to

- The elastic but non-ideal deformation of the wheel
- The inelastic and non-recoverable (plastic) deformation of the surface
- Friction in the wheel bearings (usually assumed to be negligible)

From this it will be clear that the rolling resistance of a wheel will be a function of the strength deformation properties of the surface and the size and deformation characteristics of the wheel. For wheels with tyres, the secondary factors include the air pressure, the structure of the tyre carcass (radial or bias ply) and the tread pattern. For speeds used with agricultural tractors, rolling resistance is relatively independent of the speed of deformation of the soil and the tyre, hence of the travel speed.

The ideal is a perfectly rigid wheel rolling on a perfectly rigid surface. This defines the kinematics of the rolling wheel. Hard wheel on a hard surface, this is approximated to by an elastic steel wheel rolling on an elastic steel track as in a railway.Hard wheel on soft surface. Here most of the deformation and energy loss occurs in the surface which yields plastically but does not recover. Tractor front wheels and implement wheels with 'high' pressure tyres, operating on soft agricultural soil, are of this type.Soft wheel on hard surface. Here most of the deformation and energy loss occurs in the wheel and appears as heat. Tractor driving wheels and vehicle wheels both operating on road surfaces are of this type.Soft wheel on soft surface. Here both the wheel and the surface deform significantly as in the tractor rear wheel operating on soft soil. Energy loss occurs mainly in deforming the soil.

One major aspect of understanding and predicting tractor performance is that of determining the rolling resistance of a wheel as it is towed without slip over the surface. The problem of determining the rolling resistance of a driving wheel, when slip is present, is more complex. When a wheel rolls over a soft surface it makes a rut or compacted track. The simplest basis for the prediction of its rolling resistance is to therefore assume that the work done against the rolling resistance is the work done in compacting the soil. Bekker (1956) assumed that the wheel was equivalent to a plate continuously being pressed into the soil to a depth equal to the depth of the rut produced by the wheel.

ii. Maximum Tractive Force:

The horizontal force transmitted between a machine and the soil has a limiting value which depends on both the soil strength and machine design parameters. The contact area of a driving tire is approximately flat as shown in Fig.8.1, within certain limits of soil stiffness and tire inflation pressure which will be explained later. The magnitude of the area of all driving wheels can be estimated as:

iii. Estimation of Contact Area:

A very rough approximation of the contact area is given by

$$A = 0.78 \sum (bL) \quad \text{... (8.2)}$$

But, a flexible tire has a smaller contact area on hard surfaces than it does on soft ground. A rule of thumb which can be used for the estimation of tire contact area is shown in Fig. 8.1.

$A = bL$

Where,

b = tire section width

$L = d/4$ on a hard surface

$L = d/2$ on a soft surface (tire sinkage $z > 0.05\ d$)

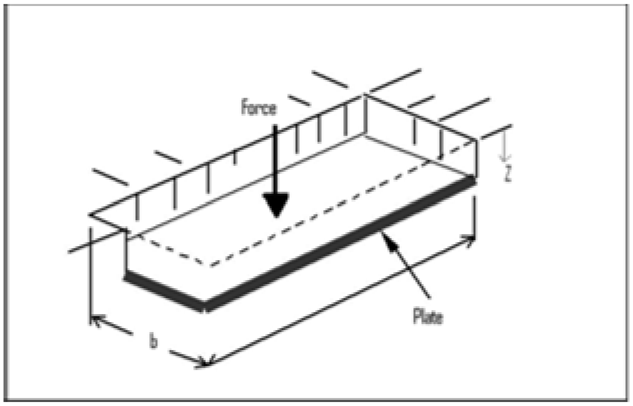


Fig. 8.1: Plate being pushed into the soil as tractor tyre to calculate the contact area and pressure

In addition Wong (1978) and Bekker (1985) gave an approximate method to calculate length from the maximum tire deflection δ_t

$$L = 2\,(d.\delta t - \delta_t^{\,2})^{\left(\frac{1}{2}\right)} \qquad \text{... (8.3)}$$

iv. Maximum Shear Strength of Soil:

Coulomb (1776) noted that there appeared to be two mechanical processes in action which determine the ultimate shearing strength of soil-tool interaction. One process is called friction(internal angle of friction Ø) and the other cohesion (c). The total material shear strength is the sum of these two components as follows

$$S = c + p\ \tan Ø \qquad \text{... (8.4)}$$

Where p is the normal pressure acting on the internal shear surface in question

The lugs on tires penetrate the soil surface, unless it is very hard in order to hold soil among them and to cause the development of soil to soil strength on the horizontal tractive surface.

The maximum force value, is the summation of the soil shear strength over the total contact area of all the driving tires

$$H = \int \sum A\,(c + p\ \tan Ø).dA = c\sum A + \sum V.\tan Ø \qquad \text{... (8.5)}$$

In which, ΣA = The sum of contact areas of all driving wheels of tractor

ΣV = The sum of vertical forces on all the driving wheels of tractor

The machine design specifications which can be changed to alter the maximum traction force are the driver contact area and the weight on the drivers. On a course granular material which is cohesion less, it is only the increase in vehicle weight that can improve the traction effort. When the soil is a wet fine grained material with a small total angle of internal friction, it is the contact area which should be enlarged for better traction and this is the reason for the popularity of wide tires large diameter tires or duel or even triple tire sets on tractors which operate on clayey terrain.

v. Soil Deformation and Slip:

Because soil is not a perfectly rigid material, it deform under the action of stresses. The horizontal deformation of the soil surface in reaction to a traction force of low pressure tire is very similar to that observed in the rectangular shear plate soil strength test by Coulomb. Bekker(1956) suggested that the horizontal deformation versus shear stress response of a plastic soil, such as sand or wet clay is observed to be close to an exponential curve of the following form

Horizontal shear stress will be

$$\tau = S\left(1 - e - \frac{X'}{K}\right) \quad \text{...(8.6)}$$

Where,

S = Soil shear strength = c + p tanØ

X' = Horizontal deformation of the soil surface

K = a soil stiffness coefficient

The final or maximum horizontal deformation of the soil surface will be X'm, which can be related to wheel slip (s) and contact length (L) of a tire, assuming that the tire maintains a relatively rigid length

$$X'm = sL$$

Soil deformation X', varies along the contact length and the shear stress between soil and machine will also vary according to the equation for a plastic soil. The total traction thrust can be calculated by integrating the shear stress distribution over the contact area.

$$H_t = b\int_0^L \tau . dX = bS\int_0^L \left(1 - e^{\frac{-X'}{K}}\right). dX = bS\int_0^L (1 - e^{\frac{-SX}{K}})$$

$$H_t = H\{1 - \frac{K\left(1-e^{\left(\frac{-sL}{K}\right)}\right)}{sL}\} \quad \text{... (8.7)}$$

Bekker (1960) and Wong (1978) have shown that one can develop some more complicated stress deformation relationships for soils which suffer some loss of strength with extensive shearing. They also pointed out the importance of the length of a tire contact area in the traction phenomenon.

vi. Work done to deform soil:

a) Sinkage in Soil:

The stress distribution in a soil under an object having a vertical load is more complex than the horizontal thrust strength relation. Penetration into the soil begins at small loads with accompanying shear strains, which are less than those required to develop failure. After local shear failure has occurred, a wedge of soil beneath the sinking structure continues to descend, but an increasing penetration load is needed in order to 1ft (30 cm) larger depths of "surcharge soil above and to the sides of the object.

Natural soil exhibits a gradual change in load required for the transition between two states and a smooth variation with increasing penetration force is observed. Bernstein (1913) and Goriatchkin (1937) (cited by Bekker, 1956) and the following equation was proposed to describe it.

$$p = k.\, Z^n \qquad \text{... (8.8)}$$

where,

p = vertical average contact pressure

k = a soil stiffness constant for sinkage

z = sinkage distance into the soil

n = a soil constant

The principal deficiency of this equation for prediction of machine sinakge and performance was found to be the variability of the soil stiffness constant, k with the size of the object on the soil.

For a plate, length l, width b, being pressed into the soil, as in Fig.8.2, Bekker suggested that the pressure, p under such a plate is given by:

$$p = \left(\frac{K_c}{b} + k_{\varnothing}\right) z^n \qquad \text{... (8.9)}$$

where,

z is vertical soil deformation (sinkage)

K_c and $K_{\varnothing}$ are soil stiffness or sinkage constant

n is soil sinkage exponent

b is the smaller overall dimension (width of rectangular plate or radius of circular disc) of the plate

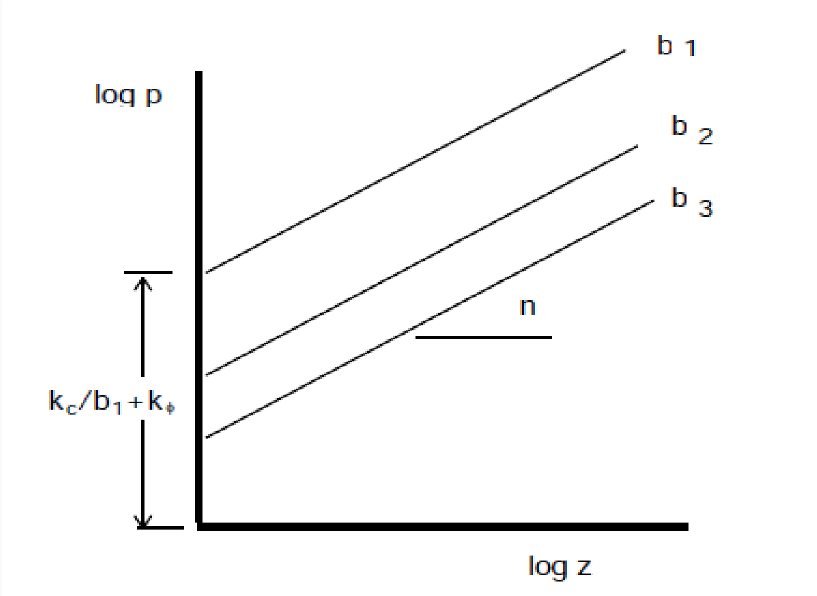


Fig. 8.2: Plotting to calculate slopes and intercept for different plates with different widths

b) Measuring soil parameters

Because the work to compact the soil is used as the basis of prediction of rolling resistance, the force to push a plate into the soil and the associated sinkage is chosen as an appropriate method of determining the soil parameters for the calculation of rolling resistance.

To obtain the parameters, a series of plates of different widths, b1, b2, b3 are pushed into the soil while the force and corresponding sinkage are measured.

$$\log p = \log\left(\frac{k_c}{b} + k_{\emptyset}\right) + n \cdot \log z \qquad ...(8.10)$$

When, log p is then plotted against log z, we get a series of straight lines of slope 'n' and intercept on the log p axis = (K_c / b + K_f) as shown in Fig. 8.2. Further if the intercepts are then plotted against 1/b the slope of this line is and the intercept at 1/b is kf.

vii. Rolling Resistance:

Rolling resistance is the force opposing horizontal motion on a deformable surface or on flexible tires.It can be considered as a rate of energy loss to the soil and /or tires. It has been known in practice that the rolling resistance of a tire increases both with the vertical load on the wheel and with the sinkage of the tire into the soil. Industry rules of thumb are available for approximate calculations for earthmoving tires in a range of outside diameters from 150 to 300 cm are shown in Table 8.1.

Table 8.1: Coefficient of rolling resistance (R/N) on soils of different stiffness (Caterpillar, 1968)

Surface	Sinkage, cm	Coefficient of Rolling Resistance (R/N)
Hard smooth roadway	0	0.02
Firm dirt roadway	slight	0.035
Dirt roadway	2.5-5	0.05
Rutted dirt roadway	10-15	0.075
Soft muddy road or sand	20	0.1-0.2

Generally, with the increase in tire diameter, the rolling resistance decreases in tilled loam soil or sand type soils. Tire inflation has also amarked effect on rolling energy requirements, depending on the type of surface upon which the tire travels. On soft surfaces such as loose sand or tilled loam, a higher inflation pressure results in an increased rolling resistance force. On the other hand, larger inflation pressures reduce the rolling resistance of a tire travelling on surfaces which are more firm such as sod or concrete.

A further factor which can influence the effort required to move wheels on soil is the arrangement of two or more wheels on a vehicle. Another set of experiments conducted by Mckibben and Davidson (1940) indicated that a different result is caused by placing the dual wheels, side by side or a tandem configuration in which one wheel follows the other (Table 8.2)

Table 8.2: Rolling resistance coefficient (R/N) of 15.2-40.6 cm tires in different arrangements under a vertical load N of 4.5 KN per tire and at an inflation pressure of 138 kPa (Mckibben and Davidson, 1940).

Tire arrangement	Coefficient of rolling resistance (R/N)		
	Bluegrass pasture	Tilled loam	Loose sand
Single	0.06	0.319	0.338
Dual, 20 cm center	0.061	0.278	0.342
Dual. 30 cm center	0.059	0.290	0.308
Dual, 40 cm center	0.061	0.305	0.313
Tandem, following	0.057	0.223	0.223

There was 26-32% reductions in rolling resistance coefficient for the second trial of a wheel in the same track on tilled loam and sand surfaces. While the reduction in motion resistance, resulting from tandem wheel arrangement and trailer wheels following tractor tires, may offer savings in machinery operation energy, there can be an offsetting price to pay elsewhere i.e. compaction of soil at about the same rate as does increased contact pressure on a single wheel.

It means that tandem wheels or a trailed machine in the same tracks, will double the soil compaction effect of each individual wheel under the same weight. If a machine has wheels arranged side by side, or a trailer has wheels in tracks to the side of tractor tracks, then less intensive compaction occurs in the soil, although admittedly a larger area of a field will be compacted.

i. Soft wheel on soft surface

Here the wheel (or a track) is assumed to impose a uniform pressure on the soil which deforms uniformly over the contact area as shown in Fig 8.3 until the contact area times the pressure at the tyre surface is equal to the weight on the tyre. This pressure may be assumed to be made up of the pressure equivalent to the stiffness of the tyre carcass and the internal pressure of the air (and the water if used).

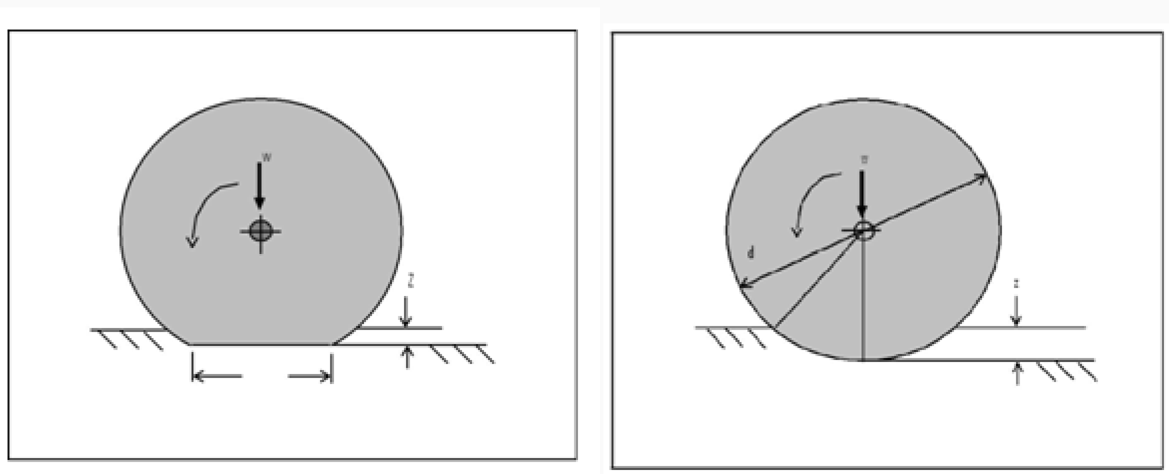


Fig. 8.3: Sinkage and deflection for soft and hard wheel and on soft surface

Then the vertical work to press such a plate into the soil:

$$\text{Work} = bl \int_0^{Z_0} P\,dz$$

$$= bl\left(\frac{k_c}{b} + k_\emptyset\right)\int_0^{Z_0} Z.\,dz$$

$$= \frac{l(k_c + bk_\emptyset)(Z_0)^{n+1}}{n}$$

But for a weight, N on the plate, at maximum sinkage ,

$$N = bl\, p_{max}$$
$$= bl\left(\frac{kc}{b} + k_{\emptyset}\right)(Z_0)^n$$
$$= l\,(k_c + b\,k_{\emptyset})\,(Z_0)^n$$

$$Z_0 = [\frac{N}{l(Kc + bk\emptyset}]^{1/n}$$

$$Work = \frac{l(K_c+bk_{\emptyset})}{n+1}[\frac{N}{l(Kc+bk\emptyset}]^{n+1/n}$$ ...(8.11)

Before considering the two types of wheel / surface that have been analysed on this basis we need to show how the soil parameters can be measured.

Consider the work done in towing such a wheel a distance, l against the rolling resistance, R. In simple terms, if this is equal to the work done on forming the rut as calculated for the plate, length l , width b pressed into the soil, as in (a) above:

$$Rl = \frac{l(K_c + bk_{\emptyset})}{n+1}[\frac{N}{l(K_c + bk_{\emptyset}}]^{n+1/n}$$

$$Rl = \frac{l(K_c + bk_{\emptyset})}{n+1}[\frac{N}{l(K_c + bk_{\emptyset}}]^{n+1/n}$$

$$R = \frac{b}{(n+1)\left(\frac{Kc}{b} + k\emptyset\right)^{\frac{1}{n}}}[\frac{W}{l}]^{\frac{n+1}{n}}$$

$$Pressure\ p = \frac{N}{bl}$$

$$R = \frac{b}{(n+1)\left(\frac{Kc}{b}+k\emptyset\right)^{\frac{1}{n}}}[p]^{\frac{n+1}{n}}$$ ... (8.12)

This simple analysis suggests that rolling resistance depends directly (but not necessarily proportionally) on the weight of the wheel W, and inversely (but not necessarily proportionally) on the length of the contact area l but not the diameter of the wheel except in so far as it affects l. It also depends in a complex way on the width of the contact area, b. For n = 1, which might be considered typical for an agricultural soil (Dwyer, 1984), this equation can be put in the form of a coefficient of rolling resistance:

$$R = \frac{b}{2}\cdot\left(\frac{Kc}{b} + K\emptyset\right).p^2$$

$$\frac{R}{p} = \frac{b}{2}\left(\frac{Kc}{b} + k\emptyset\right).p$$

$$R.\frac{bl}{N} = \frac{b}{2\left(\frac{Kc}{b} + k\emptyset\right)}.p$$

$$\frac{R}{N} = \frac{1}{2}l\left(\frac{Kc}{b} + k\emptyset\right).p \qquad ...(8.13)$$

This equation suggests that the coefficient of rolling resistance will be proportional to the ground pressure and inversely proportional to the length of the contact area. Hence, for example, improved traction will be achieved on sandy soils if p is small and l is large, ie, by the use of low pressure tyres.

Another approach to develop a predictive formula for rolling resistance was proposed by Mckyes(1978). It was based on the assumptions that rolling resistance is proportional to the wheel load, the sinkage in the soil and the inverse of tire outside diameter, a component is added to account for tire deformation and resistance on hard surfaces, as follows

$$R = \left[\frac{z + \delta t}{d}\right].N \qquad ...(8.14)$$

Where,

$\delta_t = 0.02$ d for off-road truck tires

$\delta_t = 0.04$d for low pressure tires ($p < 100$ kPa)

$$z = (p/k)1/n = (N/blk)1/n$$

$$z = [1/d\{(N/blk)1/n\} + \delta t/d].N$$

$$z = Nn + 1/n/d(blk)1/n + \delta t.N/d$$

The first part of the above equation involving soil stiffness actually becomes identical to the above equation if

$$l = d/(n+1)$$

If on the other hand, the tire contact length l is assumed to be one half of the tire diameter, d then

l = d/2 (for soft surface like soil)

$$z = Nn + 1/n/dn + 1/n\ (bk/2)1/n + \delta t.N/d$$

$$z = (N/d)\ n + 1/n/(bk/2)1/n + \delta t.N/d$$

$$z = b(N/bd)\ n + 1/n/(k/2)1/n + \delta t.N/d$$

$$z = b(N/2bl)\ n + 1/n/(k/2)1/n + \delta t.N/d$$

$$z = b(p)\ n + 1/n/2.(k)1/n + \delta t.N/d \quad \text{... (8.15)}$$

The equation shows that rolling resistance increases with normal force, soil stiffness (1/k) and width at constant contact pressure (p). Resistance also decreases with the tire diameter

Lesson 9. Mechanics of tractor chassis and stability analysis

1. Introduction

The term 'mechanics' here refers to an analysis of the forces that act on the tractor chassis. The major force is that of gravity and is known as the weight. This is sometimes given in units of mass (kg); in engineering analysis (concerned with statics) all such 'weights' should be converted to force units (kN).

I. Centre of gravity

The centre of gravity is the point at which the whole of the mass and the weight of the tractor may be considered to act. Its location depends on the disposition of the various masses that comprise the tractor. Any analysis of the tractor chassis requires the location of the centre of gravity to be known. It is usually specified in relation to the rear axle as shown by point G in Fig. 9.1.

i. Longitudinal location:

The location of the centre of gravity in the longitudinal (X) direction may be found by measuring the weight on the front (Wf) and rear (Wr) wheels.
Application of the force equilibrium condition gives the tractor weight, W:

$$W = W_f + W_r \qquad \text{... (9.1)}$$

Application of the moment equilibrium condition gives the required longitudinal location, Xr as shown in Fig. 9.1.

For the tractor take moments about O:

$$W.X_r = W_f.X$$

$$X_r = W_f \frac{X}{W} \qquad \text{... (9.2)}$$

The wheel base (X) between the front and rear axles is usually given in the manufacturer's specification or can be measured directly.For most common rear wheel drive tractors Xr is approximately 30 % of X; this is also the % of the static tractor weight that is on the front wheels.

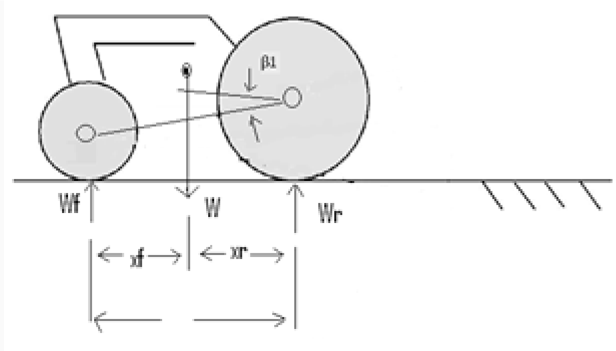


Fig. 9.1: Location of front and rear wheel location along with CG of a tractor

ii. Vertical location:

The location of the centre of gravity in the vertical (Y) direction is more difficult. The common method is to lift the front (or rear) of the tractor as shown in Fig. 9.2 and measure the weight on the front wheels (W'f) in the raised condition. The following is similar to Barger et. al.,(1952).

Application of the moment equilibrium condition gives the required vertical location, Yg.

For the tractor take moments about O:

$$X'_r = \frac{W'_f}{W} X''$$

The geometry of the positions of the centre of gravity gives:

$$z = \frac{X'_r}{\cos ß}$$

$$Y_g = \frac{X_r - z}{\tan ß}$$

Substituting for z gives

$$Y_g = \frac{\left\{Xr - \frac{X'r}{\cos ß}\right\}}{\tan ß} \quad \ldots (9.3)$$

$$ß = ß_1 + ß_2$$

$$ß = a\tan\frac{(Rr - Rf)}{X} + a\tan\frac{(y' - Rr)}{X''} \quad \ldots (9.4)$$

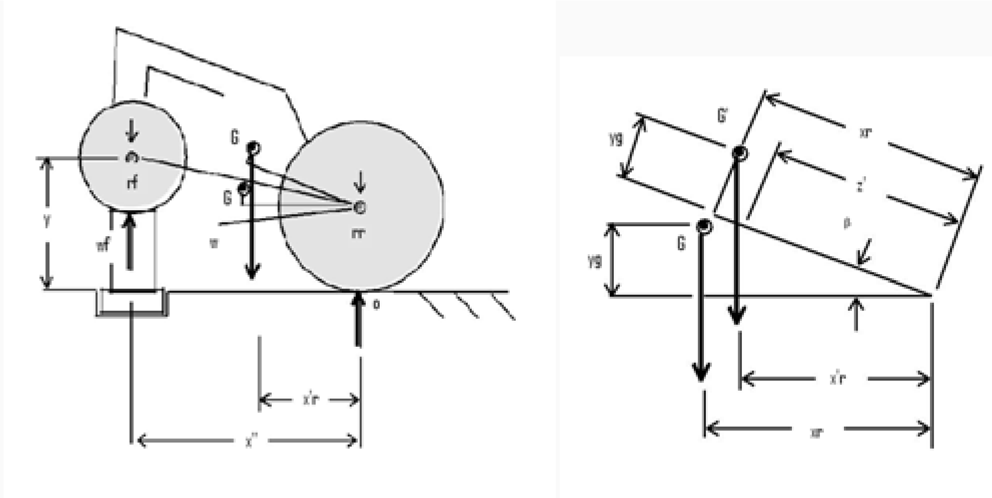


Fig 9.2: Tractor in raised position

II. Issues in chassis mechanics

Two aspects of the mechanics of the tractor chassis, which are of importance to the performance of the tractor, can be identified:

i. Weight transfer:

For a tractor under dynamic or in operating conditions, the weight on the wheels be different from the static values. These changes are termed as 'weight transfer' or the changes in the vertical longitudinal plane, ie, from front to rear because these have the greatest influence on tractor performance. Weight transfer is a normal outcome of the action of the forces generated on the tractor chassis by the ground and by the implement. It occurs whenever and how the tractor is loaded, including the 'no' load case where there is some weight transfer due to the torque on the rear wheels required to propel the tractor against the rolling resistance of all the wheels. It is also normally a desirable outcome because the tractor is designed to take advantage of it by having at least some of the driving wheels at the rear where, for normal forward operation, the increase in rear wheel weight is proportional to the drawbar pull. In reverse gear and in the 'over-run' condition, (the implement pushing the tractor) the forces toward the front of the tractor transfer weight from the rear wheels to the front wheels, a fact which affects the performance of the tractor in this type of work and when braking.

ii. Instability:

Instability occurs when the weight transfer is sufficient to cause the tractor to tip over rearwards. Impending instability (where the front wheels leave the ground and the tractor is on the point of becoming unstable) is considered because it is a limiting case of the weight transfer and hence of tractor operation. It is an undesirable situation because it represents loss of steering control and may lead on directly to actual instability. Such a situation is partly avoided by inherent features of the design of the tractor-implement system and partly by its operation in a way that avoids reaching that condition. Usually the wheels slip before instability occurs. An understanding of the actual process of tipping over in the vertical longitudinal plane which may require more complex dynamic analysis that also includes, inertia of the tractor chassis and of the implement, also the inertia and stiffness of the transmission to the rear wheels.

iii. Analysis and Assumptions

The following analysis of the tractor in the longitudinal, vertical plane is limited to the calculation of wheel weight during steady state operation in normal work and to the prediction of the conditions for impending instability. Although the tractor and implement are moving, the assumption of steady state operation implies that there are no inertia forces; the forces are doing external work but are not causing any acceleration. Hence the principles of statics and the conditions for static equilibrium of rigid bodies can be applied.

Three independent equations of equilibrium can be written:

- Sum of the forces in any two perpendicular directions are zero. The two directions usually chosen are those parallel to and perpendicular to the ground surface.
- Sum of the moments about any two points in the vertical longitudinal plane are zero. The two points usually chosen are the wheel- ground contact points or the centres of the wheels.

In simple situations it may be sufficient to consider the whole tractor as a rigid body. Where the external forces are known the weights on the wheels can be calculated directly. However it is sometimes convenient to consider the tractor as composed of two rigid bodies. One the drive wheels, rotate about a centre located in the other - the chassis of the tractor. This occurs under the action of the torque acting on them which is internally produced by the engine.

- Any such analysis must apply appropriate constraints ie, that the forces and moments on each are equal and opposite. In this analysis and the worked examples, the following simple assumptions are made:
- forward motion is uniform; this assumes constant implement forces and no acceleration
- Lines of forces on wheels are either tangential or radial or may be resolved as such;
- Sinkage and tyre distortion (but not normal tyre deflection) are neglected
- Tractor is symmetrical about the longitudinal vertical plane; all the forces and moments may be considered to act in this plane
- Other forces, such as the change in position of the fuel and oil in the tractor on sloping ground, air resistance and other minor forces are neglected

1) Weight Transfer

Consider rear wheel drive tractor on a slope as shown in Fig. 9.3.

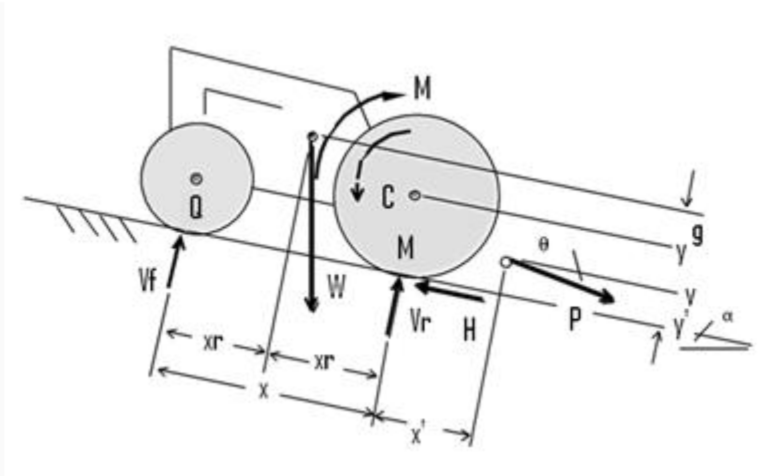


Fig. 9.3: Tractor for weight transfer analysis

The implement force P acts through the point (x', y') at an angle Φ to the ground surface.

For the tractor, take moments about C:

$$V_f.X + Y_g\,W \sin\alpha + X'P\sin\theta + M = X_r\,W\cos\alpha + Y\,P\cos\theta$$

$$V_f = \frac{X_r}{X}W\cos\theta + \frac{Y}{X}P\cos\theta - \frac{W}{X}Y_g\sin\alpha - W\frac{X_r}{X}\cos\alpha + P\frac{Y}{X}\cos\theta \quad \text{... (9.5)}$$

For the wheels, take moments about C: M = H. r

Resolve parallel to the slope: H = $W\sin\alpha + P\cos\theta$

Substitute for M and H above:

$$V_f = W\frac{X_r}{X}\cos\alpha + P\frac{Y}{X}\cos\theta - W\frac{Y_g}{X}\sin\alpha - P\frac{X'}{X}\sin\theta - W\frac{r}{X}\sin\alpha - P\frac{r}{X}\cos\theta$$

Combining:

$$V_f = W\frac{Xr}{X}\cos\theta - W\frac{Yg + r}{X}\sin\alpha - P\left(\frac{r - Y}{X}\right)\cos\theta - P\frac{x'}{X}\sin\theta$$

$$V_f = W_f - P\left(\frac{y'}{x}\right)\cos\theta - W\left(\frac{Yg + r}{x}\right)\sin\alpha - P\frac{x'}{x}\sin\theta \quad \text{...(9.6)}$$

Similarly weight on the rear wheels (Vr) perpendicular to the slope is given by:

$$V_r = W_r + P\left(\frac{y'}{X}\right)\cos\theta + W\left(\frac{Yg+r}{x}\right)\sin\alpha + P\left(\frac{X+X'}{X}\right)\sin\theta \qquad ...(9.7)$$

The terms in Equations can be identified as follows:
W_f, W_r are the static weight on the wheels when the tractor is on the slope

$W\frac{Yg+r}{x}\sin\theta$: The moment effect of the weight component down the slope, decreasing the front wheel weight and increasing the rear.

$P\left(\frac{y'}{X}\right)\cos\theta$: The moment effect of the implement force component down the slope, decreasing the front wheel weight and increasing the rear.

$P\frac{x'}{X}\sin\theta$: The moment effect of the implement force component perpendicular to the slope, decreasing the front wheel weight.

$P\frac{X+x'}{X}\sin\theta$: The direct (P SINΘ) and the moment effect $(P\frac{x'}{X}\sin\theta)$ of the implement force component perpendicular to the slope, increasing the rear wheel weight.

Referring to the Equations, moment effect of the component of the drawbar pull down the slope $P\cos\theta$ has two effects:

$P\frac{Y}{X}\cos\theta$: increases and decreases with moment arm y

$P\frac{r}{X}\cos\theta$: decreases and increases with moment arm r

The net effect of $P\cos\theta$ is therefore the difference between these two, i.e.,

$$P\left(\frac{r-Y}{X}\right)\cos\theta$$

$$= P\frac{y'}{X}\cos\theta$$

This fact gives rise to the idea that if the drawbar pull acts below the rear axle, its moment, $P\,Y\cos\theta$., increases V_f and holds the front of the tractor down. While this is true, it omits the more important, unrecognised aspect that a usually larger moment, $P\,r\cos\theta$, tends to decrease the weight on the front wheels.

The following special cases are of interest:

1. If y' increases, i.e., the point of action (i.e., the drawbar) is raised, Y decreases and the weight transfer, $\frac{P(r-Y)}{x}\cos\theta$ increases; the tractor may reach the condition of impending instability when $V_f = 0$

2. If y' = 0, the point of action (the drawbar) is at ground level, Y = r; there is no weight transfer due to P.

3. If y' is negative, the point of action is below ground level (i.e., as is possible with a three point linkage or with the drawbar in a trench), Y is greater than r, the term $P\frac{y'}{x}\cos\theta$ becomes positive and negative ie, weight is transferred from the rear to the front wheels.

4. If θ = 0, ie, the implement force is parallel to the ground

$$V_f = W_f - P\left(\frac{y'}{x}\right) - W\left(\frac{Yg + r}{x}\right)\sin\theta$$

$$V_r = W_r + P\left(\frac{y'}{x}\right) + \frac{W(Yg + r)}{x}\sin\theta$$

5. $I\alpha = 0,$ i.e., the ground is horizontal

$$V_f = W\left(\frac{X_r}{x}\right) - P\left(\frac{y'}{x}\right) = W_f - P\left(\frac{y'}{x}\right)$$

$$V_r = W\frac{X_f}{x} + P\left(\frac{y'}{x}\right) = W_r - P\left(\frac{y'}{x}\right)$$

6. If also, P = 0, ie, there is no implement force

$$V_f = W\frac{X_r}{x} = W_f$$

$$Vr = \frac{WX_f}{x} = W_r$$

2) Weight Transfer with Rolling Resistance:

The above analysis neglects any effect of rolling resistance. However, this can be included by introducing force acting along the slope (opposite the direction of motion) as a further force to be overcome by the tractor.

The rolling resistance may be expressed in terms of a coefficient (ρ) as

$$\text{Rolling resistance} = \rho.\text{Weight on wheel}$$

Here the weight will be the wheel weights perpendicular to the slope, ie, V_f and V_r as given in by equations above. The rolling resistance for the tractor may be estimated by combining the effect on the front andrear wheels by considering a coefficient for the tractor as a whole.

$$R = \rho(V_f + V_r) = \rho.(W\cos\alpha + P\sin\theta)$$

The total tractive force

$$H = W\sin\alpha + P\cos\theta(W\cos\alpha + P\sin\theta) \quad \text{... (9.8)}$$

Tractive force required (for a rear wheel drive tractor) in terms of the gross tractive coefficient.

$$\Psi' = \frac{\text{Tractive force}}{\text{Rear wheel weight}}$$
$$= \frac{W\sin\alpha + P\cos\theta(W\cos\alpha + P\sin\theta)}{W_r + w\frac{(r+Yg)}{x}\sin\alpha + P\frac{y'}{x}\cos\theta + P\frac{(x+x')}{x}\sin\theta} \quad \text{.... (9.9)}$$

3) Weight Transfer with Different Hitching Systems:

Considering the three common hitching systems, evaluation with respect to weight transfer can be donei.e., the increase in the weight on the rear wheels as a result of the implement forces. This analysis does not take into account the weight of the implement, which is more significant for the mounted and semi-mounted systems than for the trailed. However, it provides a valid comparison of the relative advantages of weight transfer of the three systems on the basis of the soil forces and of the conditions under which these advantages will be achieved.

Different type of hitch systems for a tractor are:

(i) Trailed on its own wheels

(ii) Semi-mounted on the lower links of the tractor and a rear wheel

(ii) Fully mounted on the three-point linkage.

to the ground surface as shown, is assumedfor each. θIn order to compare them it is necessary to determine the dynamic weight on the front and rear wheels of thetractor for each system; the same soil force S, acting at an angle

(I) Trailed type hitch system

Tractor with trailed type hitch system is shown in Fig. 9.4.

Resolving horizontally:

$P = S \cos \theta$

Moments about Q for the tractor:

$$V_r . X = W X_f + P . y'$$

$$V_r = Wr + S \frac{y'}{X} \cos\theta \qquad \ldots(9.10)$$

And

$$V_f = W_f - \frac{y'}{X} S \cos\theta \qquad \ldots(9.11)$$

Weight transfer will occur if $V_r > Wr$ ie, if y' is positive, ie, if the drawbar is above ground level; it will be increased by increasing the drawbar height, y'.

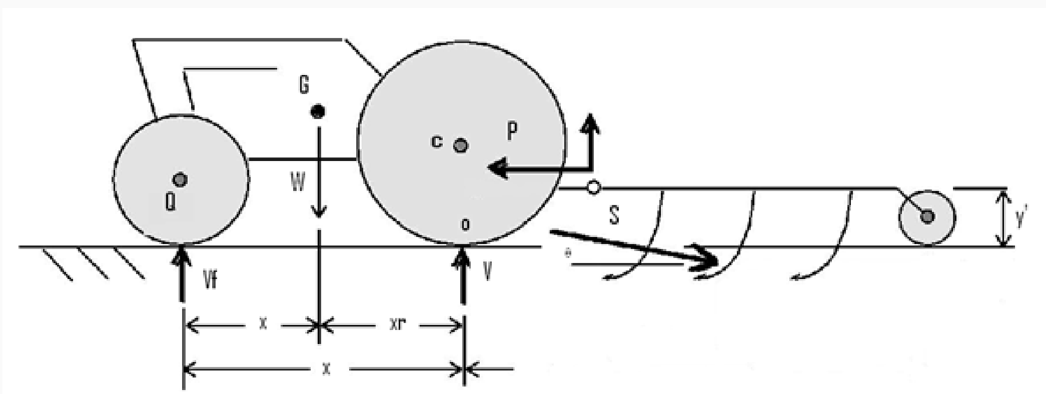


Fig. 9.4: Tractor with trailed type hitch system

(II) Semi-mounted type hitch system

Tractor with semi mounted hitch system is shown in Fig. 9.5.

Resolving horizontally:

$P = S \cos \theta$

The dynamic weight T on the tractor drawbar is given by moments about A for the cultivator:

$$T a = S(a - b) \sin\theta + P y' + S Z\cos\theta$$

Where b gives the horizontal location of the soil force.

Substituting for P

$$T = S\frac{(a-b)}{a}\sin\theta + S\frac{(z+y')}{a}\cos\theta$$

The dynamic weight on the rear wheels is given by moments about Q:

$$V_r X = W X_f + P y' + T(X+X')$$

Substituting for T and P:

$$V_r X = W X_f + S y'\cos\theta + S\frac{(a-b)(X+X')}{a}\sin\theta + S\frac{(z+y')(X+X')}{a}\cos\theta$$

$$V_r = W_r + S\frac{(a-b)(X+X')}{aX}\sin\theta + S\frac{y'}{X}\cos\theta + \frac{(z+y')(X+X')}{aX}$$

$$Vr = W_r + \frac{S(a-b)(X+X')}{aX}\sin\theta + S\cos\theta\frac{ay' + (z+y')(X+X')}{aX}$$

Similarly is given by;

$$V_f = W_f - S\frac{(a-b)x'}{aX}\sin\theta - S\frac{(ay'+z+y')x'}{aX}\cos\theta \quad \dots (9.12)$$

Weight transfer will occur if Vr > Wr which will always occur unless one of the following terms is negative and greater in magnitude than the other.

The first term will be negative if b > a, i.e., the soil force is behind the wheel. The second will be negative if y' is negative (below ground level) and greater than z or z is negative (above ground level) and greater than y'. All of these conditions are unlikely to occur for a semi-mounted implement, hence weight transfer will always occur.

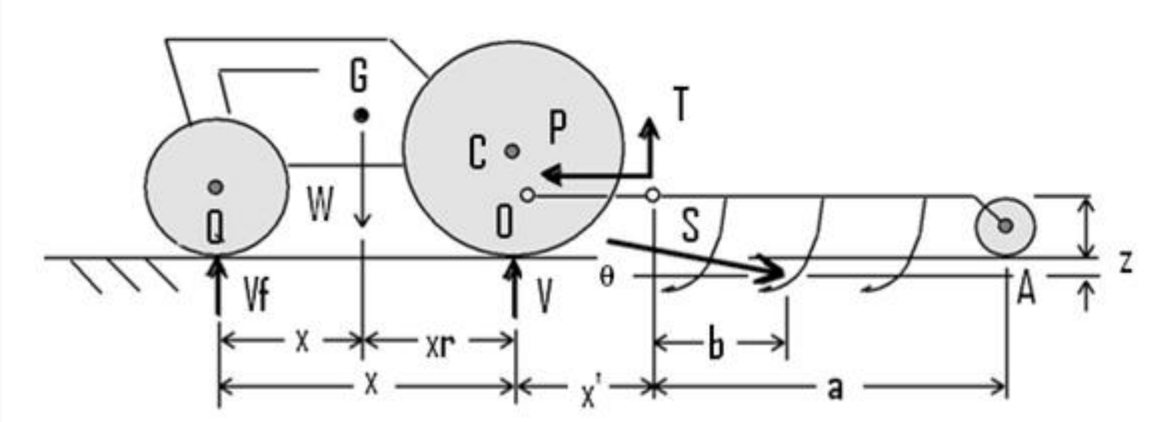


Fig. 9.5: Tractor with semi mounted hitch system

(III) Mounted type Hitch System:

Tractor with mounted hitch system is shown in Fig. 9.6.

The dynamic weights V_r on the rear wheels is given by moments about Q for the tractor / implement system as a whole:

$$Vr\,X + S\,z\cos\theta = W.X_f + S\,(X + X' + b)\sin\theta$$

$$Vr = W_r + S\frac{(X + X' + b)}{X}\sin\theta - S\frac{z}{X}\cos\theta \quad \text{... (9.13)}$$

The dynamic weight Vf on the front wheels is given by moments about O for the tractor / implement system as a whole:

$$WXr + S\,z\cos\theta = V_f\,X + S\,(x' + b)\sin\theta$$

$$V_f = W_f - S\frac{(X' + b)}{X}\sin\theta + S\frac{z}{X}\cos\theta \quad \text{... (9.14)}$$

Increasing the length of mounted implements (hence increasing b) will increase the weight transfer to the rear wheels due to the direct effect $(S\sin\theta)$ and the moment effect $(S\frac{x'+b}{X}\sin\theta)$ from the front wheels. The limit will be the length and weight that will still allow the tractor to lift the implement without itself tipping up; weights may be added to the front of the tractor to avoid this.

Weight transfer will occur if:

$$V_f > W_f$$

$$S\frac{X + x' + b}{x}\sin\theta > S\frac{z}{X}\cos\theta$$

$$\tan\theta > \frac{z}{X + x' + b}$$

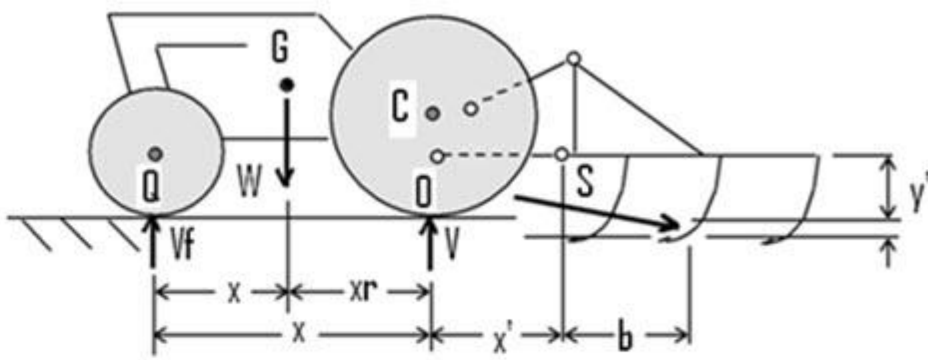


Fig. 9.6: Tractor with mounted hitch system

This implies that weight transfer to the rear wheels will occur if the soil force passes above the front wheel / ground contact point.

to the rear wheel weight. Another measure associated with weight transfer from the front wheels in the mounted system is the condition that)θThe above includes the contribution of the vertical component of the soil force (S sin

$$V_f < W_f$$

$$S\frac{x' + b}{X}\sin\theta > S\frac{z}{X}\cos\theta$$

$$\tan\theta > \frac{z}{x' + b}$$

This implies that weight transfer from the front wheels to the rear will occur if the soil force passes above the rear wheel / ground contact point. Further, weight transfer will increase as b increases, ie, the implement gets longer.

Module 4. Selection of different mechanical power transmission units of 71 Agril. Tractor

Lesson 10. Tractor clutches and brakes

1. Introduction

Power transmission system is the gear and/or hydraulic system having different components that transmits mechanical power from a prime mover (which can be an engine or electric motor), to some form of useful output device.

The power transmission system consists of:

(a) Clutches and Brakes

(b) Transmission gears

(c) Differential

(d) Final drive

(e) Rear axle

(f) Rear wheels

I. Clutches:

Clutch is a device, used to engage and disengage the tractor engine from the transmission gears and drive wheels. Clutch transmits power by means of friction between driving members and driven members (Fig. 10.1).

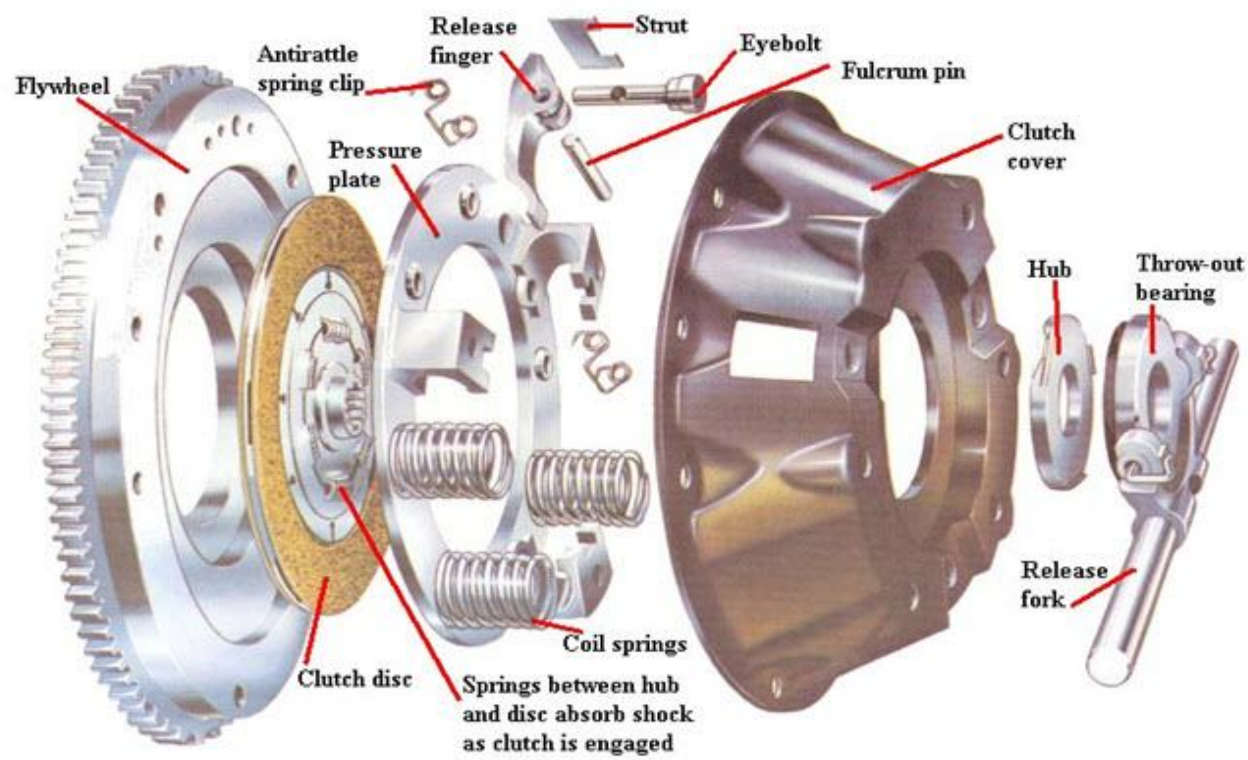


Fig. 10.1: Clutch

(Source: http://www.motorera.com/dictionary/pics/c/coil-spring_clutch.jpg)

Functions of a clutch:

- The internal combustion engine as used in a tractor must be cranked manually or by a special starting mechanism. For cranking, the engine is disconnected from the rest of the transmission unit by a suitable clutch. After starting the engine, the clutch is engaged to transmit power from the engine to the gearbox. This type of engine must attain a certain speed before it will have any power.

- Changing the transmission gears must be permitted for the purpose of securing different traveling speeds. The gearbox must be kept free from the engine power, otherwise the gear teeth will be damaged and engagement of gear will not be perfect. This is done by clutch.

- Stopping the belt pulley must be permitted without having to stop the engine. This is done by placing a clutch between the engine and the transmission gears and belt pulley.

II. Requirements of clutch:

- It should have good ability of taking load without dragging, grabbing and slipping.

- It should have higher capacity to transmit maximum power without slipping.

- It should be convenient, accessible and easy to operate, adjust and repair.

- Friction surface should be highly resistant to heat effect. The control by hand lever or pedal lever should be easy.

III. Types of clutch

Clutches are mainly of three types:

i. Friction clutch

ii. Dog clutch

iii. Fluid coupling

i. Friction clutch

A clutch in which one part turns the other by the friction between them. Friction clutch produces gripping action, by utilizing the frictional force between two surfaces. These surfaces are pressed together to transmit power.

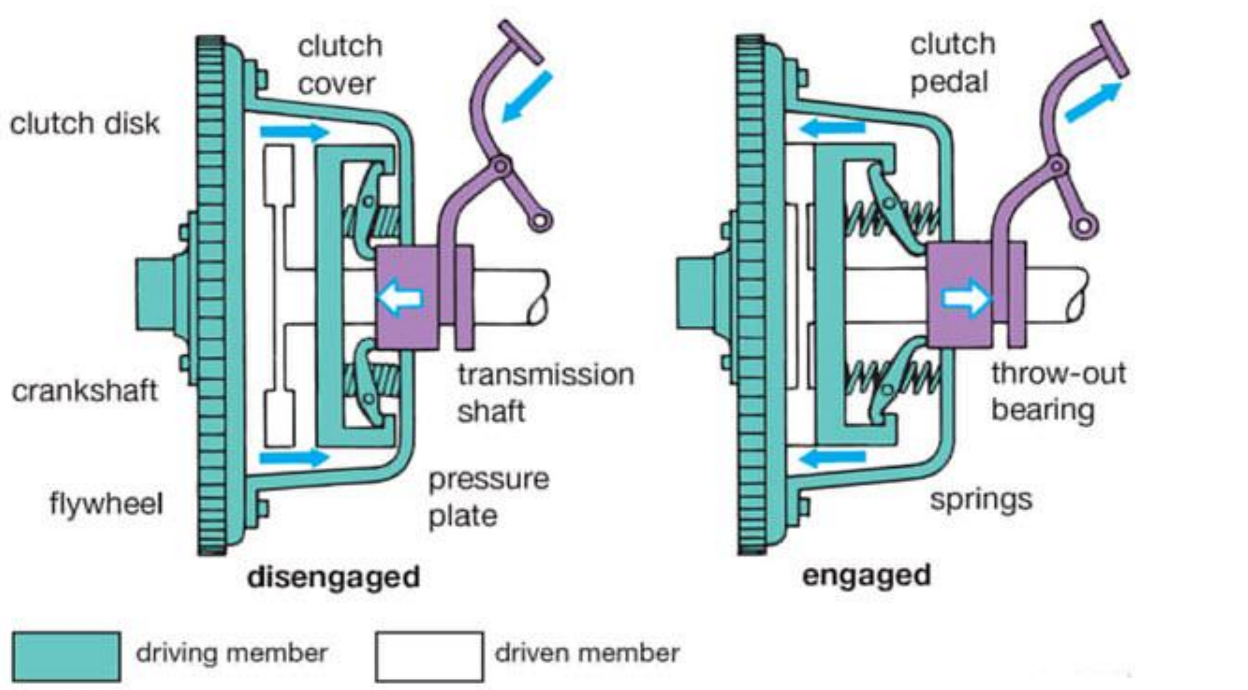


Fig. 10.2: Principle of friction clutch

(Source: http://media.web.britannica.com/eb-media/41/104141-004-5B075D35.gif)

(http://www.brickengineer.com/pages/anims/mechanisms/clutch-animation.gif)

While starting the engine, the clutch pedal is depressed. After the start of the engine, the clutch pedal is slowly released to increase the pressure gradually on frictional surface until there is no slip. Thus the driven plate is gripped firmly to the driving plate. Transmission of power depends upon the kind of material used for the friction members and intensity of the force, pressing them together.

Friction clutch is most popular in four wheel tractors (Fig. 10.2). Fluid clutch is also used in some tractors these days. Dog clutch is mostly used in power tiller.

Friction clutch may be subdivided into three classes:

i. Disc/Plate clutch

a. Single plate clutch or single disc clutch

b. Multiple plate clutch or multiple disc clutch

ii. Cone clutch

Frictional clutches are most commonly used because of following advantages:

Advantages of Friction Clutches:

1. Slips during engagement help the drive to pick up and accelerate the load with minimum shock.
2. They need not to be unloaded before engagement.
3. These can be used at high engagement speeds.
4. Slip under momentary shock loads, provides cushioning.

a) Single plate clutch:

This may be called single disc clutch.

It consists of:

1. Pressure plate
2. Clutch plate
3. Springs
4. Release fingers

The single disc clutch is a plate type of clutch in which a single thick iron plate is coated with friction material on both sides (Fig. 10.3). There is only one clutch plate in this type. The clutch plate is pressed against the flywheel of the engine by the spring loaded pressure plate. The pressure produced by a number of springs, located between the pressure plate and the housing, which is bolted to the flywheel, holds the friction surfaces firmly in contact. When the pedal of the clutch is depressed, the pressure plate is pushed back by the release fingers.

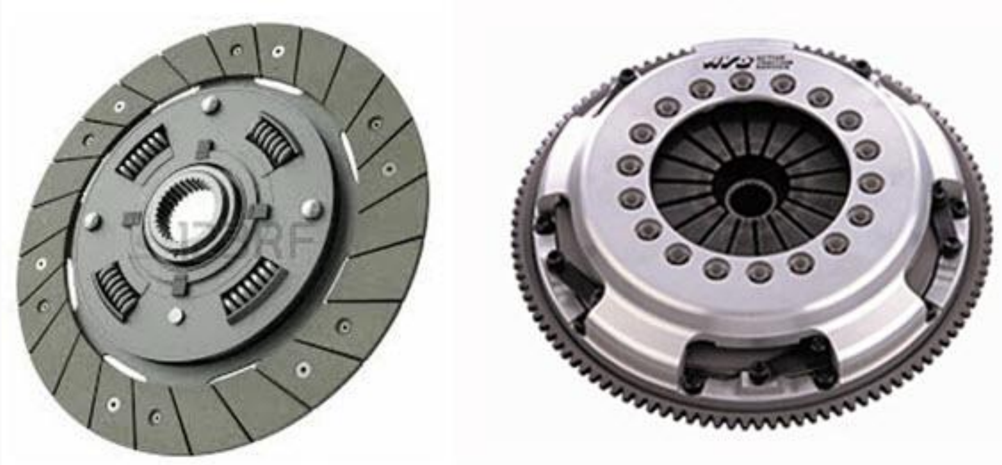


Fig. 10.3: Single plate clutch

(Source:https://encrypted-tbn3.gstatic.com/images?q=tbn:ANd9GcRIAStEDErjAEpXqDn-5zQTLPIbKN6yLbp8mS0kOwNkDwsRQgBzOsp4mnKX)

This releases the pressure from the clutch plate and disengages the clutch. Then the clutch plate stops rotating but the fly wheel continues to rotate. When the clutch pedal is released, the pressure plate forces them to turn together as one unit. Thus the power of the engine goes to the gear box for onward transmission to rear wheels. This type of tractor clutch plate is usually foot operated.

b) Multiple plate clutch:

This may be called multiple disc clutch. It can be twin-disk or three-plate type of clutch (Fig. 10.4). It differs from single-plate clutch in that the flywheel rims does not serve as a friction surface. It may also got a number of thin metal plates, arranged alternately to work as driving and driven members. One set is attached to the fly wheel and the other set is attached to the clutch shaft. If the plates are pressed together, the clutch is said to be engaged and the power is transmitted from the engine to the gear box for onward transmission to the rear wheels. This pressure is obtained by a set of heavy springs, fitted together in a housing.

Fig. 10.4: Multiple plate clutch

(Source:http://www.upgrademotoring.com/performance/os_giken/osgiken.multiplateclutch.jpg)

Engagement and disengagement of this type of clutch is very smooth due to larger surface area of friction members.

IV. Design of Disc Type Clutch:

There is a relationship between following parameters in a disc clutch:

- Dimensions of disc.
- Pressure applied to the friction surface.
- Coefficient of friction and
- Torsional moment developed.

Mathematically,

$$M_t = \tau = P \, x \, \mu \, x \, r_m \, x \, N \qquad \dots (10.1)$$

Where, M_t or τ = clutch torque, kg-cm or N-cm

P = normal force, kgf or Newton (i.e. axial force)

μ = coefficient of friction

N = no. of friction plates

r_m = effective radius of friction plates. Its value depends on design of plate which is based on

(i) Uniform pressure

(ii) Uniform axial wear

(i) Uniform pressure: When the friction surface is new and unworn and rigidly mounted, it is assumed that the normal force P is uniformly distributed over the entire area of clutch. And r_m is taken as :

$$r_m = \frac{2}{3} \times \frac{r_0^3 - r_i^3}{r_0^2 - r_i^2} \qquad .. (10.2)$$

Where,

r_o = outside radius of friction plate.

r_i = inside radius of friction plate.

(ii) Uniform axial wear: The clutch is subjected to wear due to sliding friction and after the running in wear is ended, the wear will be uniform. The mean radius r_m of the clutch is given by

$$r_m = \frac{(r_o + r_i)}{2} \qquad .. (10.3)$$

When equal importance is given to durability and torsional moment, then

$$\frac{r_i}{r_o} = 0.5 \; to \; 0.7 \qquad ..(10.4)$$

When high torsional moment capacity is needed and wear is not a serious problem, then

$$\frac{r_i}{r_o} = 0.748 \qquad ...(10.5)$$

Where wear is a problem, then

$$\frac{r_i}{r_o} = 0.479$$

V. Cone Clutch:

The principal member of the cone-clutch assembly is a metal disk with a conical peripheral surface that engages with a similarly shaped recess in the flywheel (Fig. 10.5). The cone is faced with ordinary brake lining. A heavy spring placed behind the cone, exerts sufficient pressure to insure its positive engagement. A sleeve fastened to the cone extends back and is bolted to the transmission shaft. Therefore, the engagement if the clutch connects the gears with the engine. Disengagement is produced by sliding the cone and sleeve backward on the flywheel shaft extension against the spring pressure.

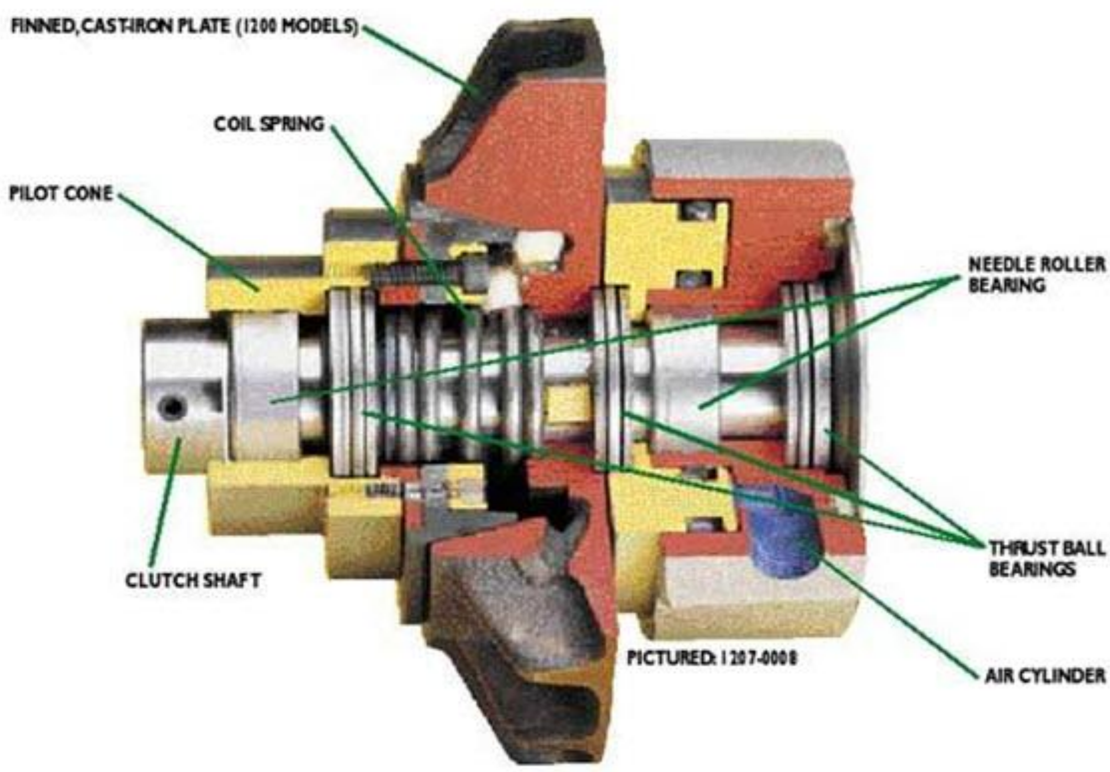


Fig. 10.5: Cone Clutch

(Source: http://www.tolomatic.com/files/image/products/large/DCCFeatures.jpg)

i. Advantages for cone clutch:

1. Force is concentrated at a large diameter.
2. Sufficient friction surface width is provided for durability.
3. A full 360° of lining material is available.
4. It is comparatively powerful for a given outside diameter and axial energizing force

ii. Design of Cone Clutch

The torsional moment developed by cone clutch is a function of

- Inner radii of functional surface
- Outer radii of frictional surface
- The cone angle, θ
- The force of engagement
- Coefficient of friction of the contact surface

$$M_t = \frac{\mu \times F_a \times r_m}{\sin\theta}$$

And,

$$r_m = \frac{(r_o + r_i)}{2}$$

Therefore,

$$M_t = \frac{\mu \times F_a \times (r_o + r_i)/2}{\sin\theta}$$

And, axial force F_a is given by

$$F_a = F_n (\sin\theta + \mu \cos\theta)$$

It has been found that the term μcosθ is only 25% effective.

Therefore,

$$F_a = F_n (\sin\theta + \mu \cos\theta/4) \qquad ..(10.6)$$

As $\theta \rightarrow 0$ $M_t \rightarrow$ to infinity

At $\theta = 0$ the cone becomes a drum and

At $\theta = 90^o$ the cone becomes a single face disk clutch

Generally the value of θ varies from 7.5 to 30^o depending on clutch facing material and type of disengagement required.

iii. Heat generated in clutch (Q)

The heat generated (Q) in a clutch is given by

$$Q = \frac{T \times N_s \times t}{9.5493} \quad \text{... (10.7)}$$

Where, Q = heat generated in the clutch due to slippage, J

T = Average slip torque, N.m

N_s = Average slip RPM

t = Total slip time for the clutch, s

iv. Temperature of heat absorbing element of clutch (T)

The temperature of heat absorbing element of clutch (T) is given by

$$T = \frac{Q}{m \times C_p} + T_o \quad \text{.... (10.8)}$$

Where, T = average bulk temperature of clutch, ^oC

Q = heat generated in clutch, J

M = total mass of heat absorbing element of clutch

C_p = specific heat of heat absorbing element, J/kg-^oC

T_o = Bulk temperature before engagement of clutch, ^oC

v. Rate of energy generation in clutch (E)

The rate of energy generation in clutch is given by

$$E = \frac{T \times N_s}{9.5193\ a} \quad \text{... (10.9)}$$

Where, E = rate of energy generation in clutch, w/mm^2

N_s = Average slip of clutch, RPM

T = Average slip torque in the clutch, N-m

a = Total facing area of clutch, mm^2

VI. Dog clutch:

It is a simple clutch having square jaws, which are used to drive a shaft in either direction. It is mostly used in power tillers (Fig. 10.6). A dog clutch is a type of clutch that couples two rotating shafts or other rotating components not by friction but by interference. The two parts of the clutch are designed such that one will push the other, causing both to rotate at the same speed and will never slip. Dog clutches are used where slip is undesirable and/or the clutch is not used to control torque. Without slippage, dog clutches are not affected by wear in the same way that friction clutches are. Dog clutches are used inside manual automotive transmissions to lock different gears to the rotating input and output shafts. A synchromesh arrangement ensures smooth engagement by matching the shaft speeds before the dog clutch is allowed to engage.

Fig. 10.6: Dog clutch

(Source: http://www.vannattabros.com/20073rd/koehring12.jpg)

(http://www.hbm.com/uploads/RTEmagicC_testmeasurement_zeroshift2.gif.gif)

A good example of a simple dog clutch can be found in a Sturmey-Archer bicycle hub gear, where a sliding cross-shaped clutch is used to lock the driver assembly to different parts of the planetary geartrain.

VII. Fluid coupling:

Fluid coupling consists of a driving member and a driven member - an impeller with radical vanes, housed in a suitable casing (Fig. 10.7). A coupler is mounted on the engine crankshaft and is 3/4th filled with suitable oil. A spring loaded sealing ring is provided to make the driven shaft oil tight. At the rotation of the crankshaft, the oil is thrown out by centrifugal force from the center to the outer edge of the impeller, increasing the velocity and the energy of the oil. It then enters the runner at the outer portion and flows towards the center, causing rotation to the runner unit. As long as impeller and runner rotate at different speeds, the oil continues to circulate uniformly but when the impeller and runner start running at same speed, the circulation of oil stops. The coupling does not increase the applied torque but only transmits the torque in an uniform manner.

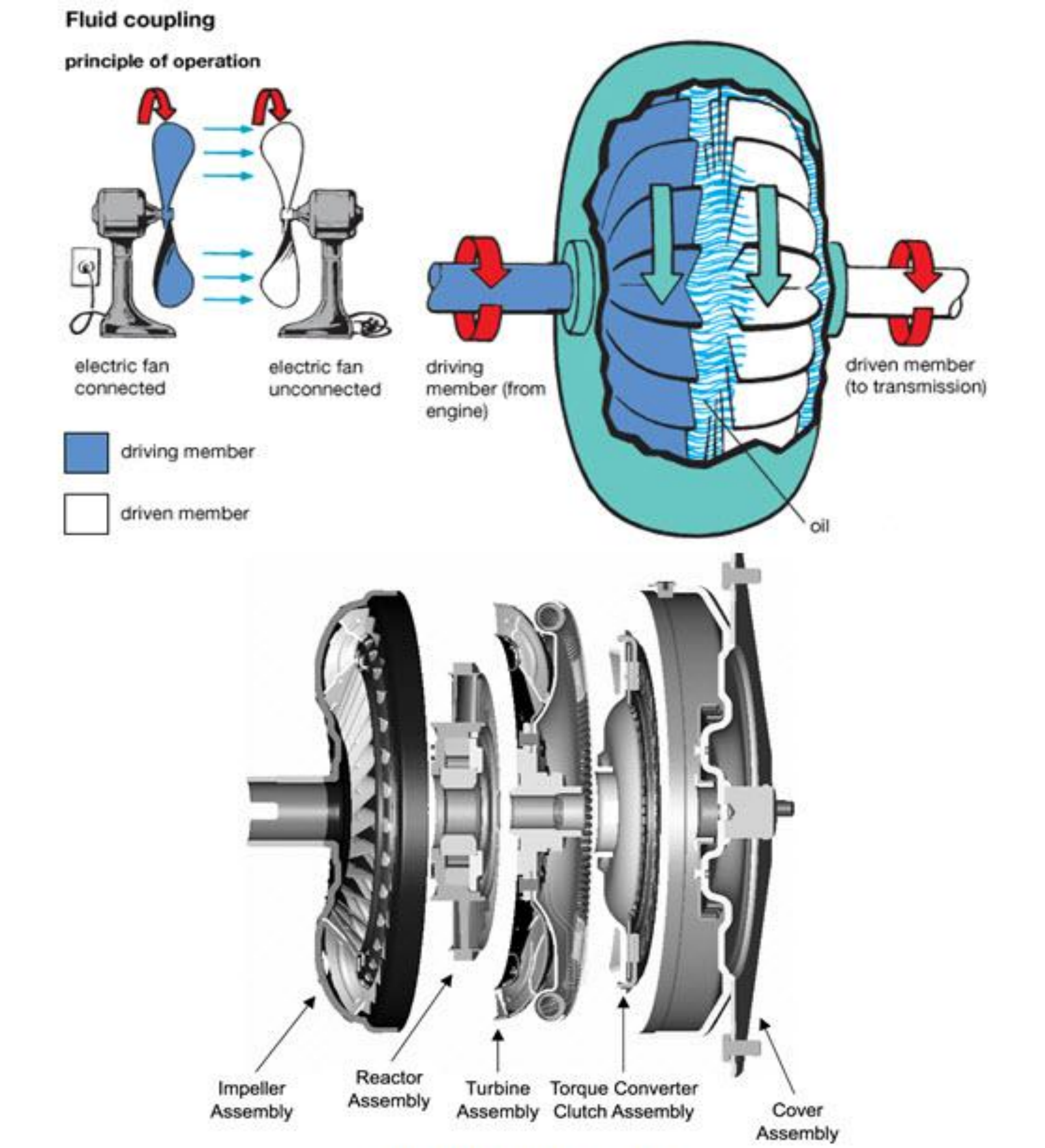


Fig. 10.7 Fluid coupling

(Source: http://media.web.britannica.com/eb-media/42/104142-004-F6E0F6F3.gif

http://www.firstgencamaro.com/torqueconverterpics/torqueconverter.png)

The main features of fluid coupling are:

1. Absorption of shock and vibration
2. Smooth starting and
3. Easy operation

VIII. Brakes:

Brakes are classified as either external, internal or bond brakes. External shoe brakes are further classified into single and double block shoe brakes. External shoe brakes consist of shoes or blocks which are pressed against the rotating surface of the brake drum. Fig. 10.2 shows a schematic representation of an external single shoe brake. The design of internal shoe brakes largely depends on force, torque, coefficient of friction and the radius of the rotating drum. Fig. 10.3 shows a schematic representation of an internal shoe brake.

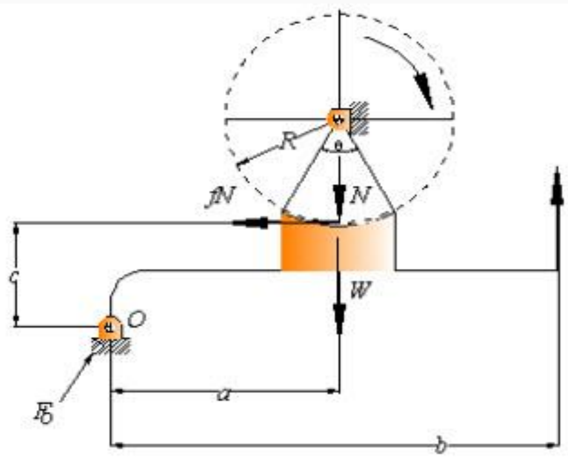


Fig. 10.2:
A schematic representation of an external single shoe brake

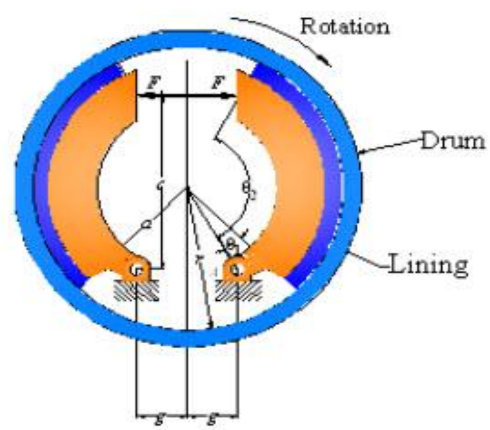


Fig. 10.3:
Schematic diagram of internal shoe brake

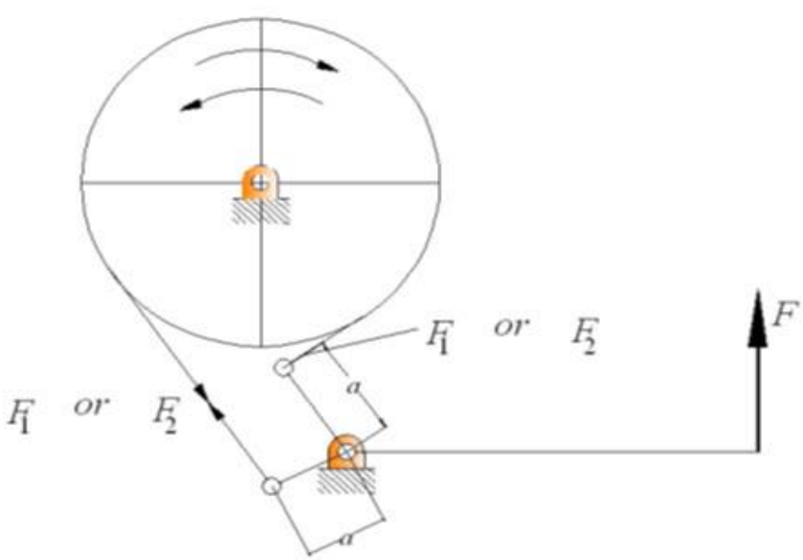


Fig. 10.4: A simple two way band brake

Band brakes are flexible bands wrapped partly around the drum. Pulling the band tightly against the drum actuates them. The design of band brakes is dependent on force, angle of wrap, coefficient of friction, pressure on the shoes and radius of the drum. A diagram of a simple two way band brake is shown in fig. 10.4.

i. Heat Generated

When the brake is actuated, energy is absorbed, which in turn is dissipated as heat energy. This design is dependent on pressure, area of contact, peripheral velocity, coefficient of friction, potential energy, and kinetic energy, coefficient of heat transfer and area of the radiating surface.

Lesson 11. Different types of gear and power transmission systems in tractors.

1. Introduction

Transmission is a speed reduction mechanism, equipped with several gears. The simplest transmissions, often called gearboxes, provide gear reduction sometimes in conjunction with a right-angle change in direction of the shaft. It may be called a sequence of gears and shafts, through, which the engine power is transmitted to the tractor wheels. These are often used on PTO-powered agricultural equipments. The complete path of power from the engine to the wheels is called power train (Fig. 11.1)

The purpose of transmission is to reduce the engine speed and increase the torque available at the rear wheels of the tractor because

HP = T.N

Where,

T is torque (kg-m) and N is rev/min.

If the engine hp is constant, it is obvious that for higher torque at wheels, low speed is required and vice-versa. So the gear box is fitted between engine and rear wheel for variable torque and speed. This is done by suitable design of gear and shafts.

The transmission uses gears to make more effective use of the engine and keeps the engine operating at an appropriate speed. Transmission's primary job is to allow engine to operate in four or five different speeds. Today's four- and five-speed automatic transmissions need torque converters with coolant, radiators and hoses — all of which cause loss of power and efficiency.

Speed varies according to the field requirements and so a number of gear ratios are provided to suit the varying conditions.

I. Function of transmission system:

- To transmit power from the engine to the rear wheels of the tractor.
- To make reduced speed available, to rear wheels of the tractor.
- To alter the ratio of wheel speed and engine speed in order to suit be field conditions.
- To transmit power through right angle drive, because the crankshaft and rear axle are normally at right angles to each other.

II. Transmission Gears

A gear is a toothed wheel designed to transmit torque to another gear or toothed component. The teeth (or cogs) of a gear are shaped to minimize wear, vibration and noise, and to maximize the efficiency of power transmission.

Different-sized gears are often used in pairs for a mechanical advantage, allowing the torque of the driving gear to produce a larger torque in the driven gear at lower speed, or a smaller torque at higher speed. The larger gear is known as a wheel and the smaller as a pinion. This is the principle of the automobile transmission, allowing selection between various mechanical advantages. A gearbox is not an amplifier or a servomechanism. Conservation of energy requires that the amount of power delivered by the output gear or shaft will never exceed the power applied to the input gear, regardless of the gear ratio. There is actually some loss of output power due to friction.

III. Types of gear:

a) Spur gears:

These are Flat with teeth projecting radially in the plane of the wheel, "straight-cut gears". These gears can be fitted only to parallel axles (Fig. 11.2).

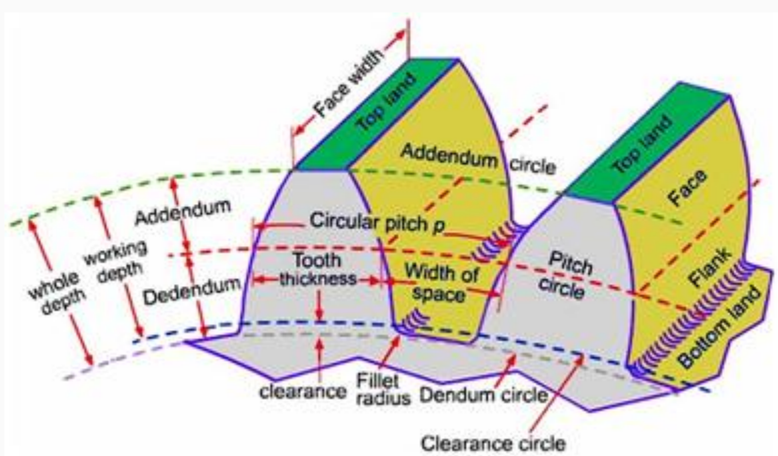


Fig. 11.2: Spur gear
(Source: http://www.micro-machine-shop.com/gear_nomenclature_1.jpg)
(http://www.wmberg.com/images/gear.gif)

a. Spur gear design

1) Gear tooth loads

The load on the gear tooth is given by

$$F_t = \frac{2T}{D} = \frac{19.1 \times 10^6 \times kW}{DN} = \frac{4500 \times HP}{\pi DN} = \frac{4500 \times HP}{V_m} \quad \ldots (11.1)$$

Where, T = torque transmitted, N-m

D = pitch diameter, mm or m

N = RPM of gear or shaft

V_m= pitch line velocity, mpm

2) Bending strength of gear tooth

The bending strength (σ) of gear tooth is given by

$$\sigma = \frac{6M}{bh^2} = FB/b \times 6t/h^2 = \frac{6F_B t}{bh^2} \quad \ldots (11.2)$$

Sector gear is merely a segment of a spur gear, such as one half or one quarter of the circumference, but still attached to the axle in the normal fashion. Rack and pinion allows torque to be converted to linear force. The pinion is a spur gear, and mates with a toothed bar or rod that can be thought of as a spur gear with an infinitely large radius of curvature. Such a mechanism is used in automobiles to convert the rotation of the steering wheel into the left-to-right motion of the tie rod(s).

b) Helical gears:

A refinement over spur gears (Fig. 11.3). The teeth are cut at an angle, allowing for more gradual, hence smoother meshing between gear wheels, eliminating the whine characteristic of straight-cut gears. - Double helical gears - Also known as herringbone gears. These gears have teeth that are 'V' shaped. Each gear in a double helical gear can be thought of as two standard, but mirror image, helical gears stacked. This cancels out the thrust since each half of the gear thrusts in the opposite direction. They can be directly interchanged with spur gears without any need for different bearings.

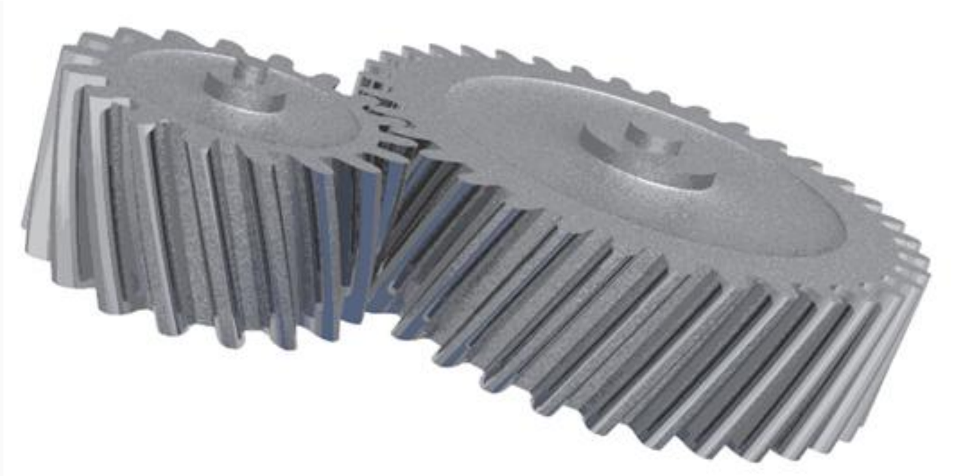


Fig. 11.3: Helical gear
(Source:http://www.flohmueller.de/pov_anim/engineering/Cog_Wheel_Helical22_5_100_50c.gif)

b. Design of Helical Gears

The forces acting on helical gear

1) Tangential Force (F_t)

The tangential force (F_t) is given by

$$F_t = \frac{2T}{D} = \frac{2M_t}{D} = \frac{19.1 \times 10^6 \times kW}{DN} = \frac{4500 \times HP}{\pi DN} = \frac{4500 \times HP}{V_m}$$

2) Separating Force (Fr)

The separating force (F_r) is given by

$$F_r = Ft \tan \Phi$$

Thrust Force (F_a)

The thrust force (F_a) is given by

$$F_a = Ft \tan \alpha$$

Where, ϕ = Pressure angle measured in a plane perpendicular to the axis of gear

α = Helix angle measured from the axis of gear

Worm gears is gear that resembles a screw, with parallel helical teeth, and mates with a normal spur gear. The worm gear can achieve a higher gear ratio than spur gears of a comparable size.

c) Bevel gears:

These gears allow to change the operating angle. However one wheel of such gear is designed to work with it's complementary wheel and no other (Fig. 11.4). Four bevel gears in a square make a differential gear, which can transmit power to two axles spinning at different speeds, such as those on a cornering automobile.

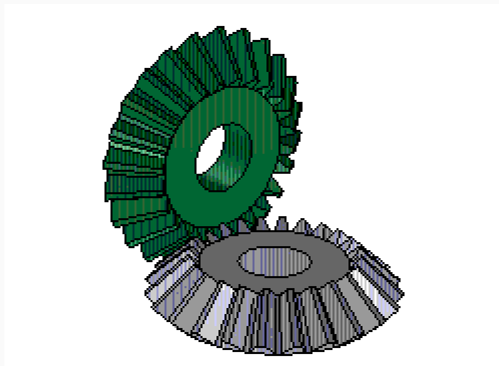


Fig. 11.4 Bevel gear
(Source: http://hgp.hdsb.ca/Grade4/FOV1-000C664C/S08AB36D9.4/bevel%2520gear.gif)

c. Design of bevel gears

1) Forces in bevel gears

$$F\,t_m = \frac{2T}{d_m} \quad \text{... (11.3)}$$

2) Axial Force (Fn)

$$F_n = F\,t_m \tan\phi \sin\delta \quad \text{... (11.4)}$$

3) Radial Force (FR)

$$F_R = F\,t_m \tan\phi \cos\delta \quad \text{... (11.5)}$$

Where, ϕ = Angle between F t_m and F_n, and

δ = Cone angle of bevel gears.

d) Planetary gear unit

The details of planetary gear unit shown in Fig. 11.5.

Gear ratios of planetary sets:

(i) Planet stationary sun rotating

$$r_g = \frac{RPM_S}{RPM_R} = \frac{S_S}{S_R} = -\frac{G_r}{G_s} \qquad ...(11.6)$$

(ii) Ring stationary sun rotating

$$r_g = \frac{RPM_S}{RPM_c} = \frac{G_r}{G_s} + 1 \qquad ... (11.7)$$

(iii) Sun stationary ring rotating

$$r_g = \frac{RPM_r}{RPM_c} = \frac{G_r}{G_c} + 1 \qquad ... (11.8)$$

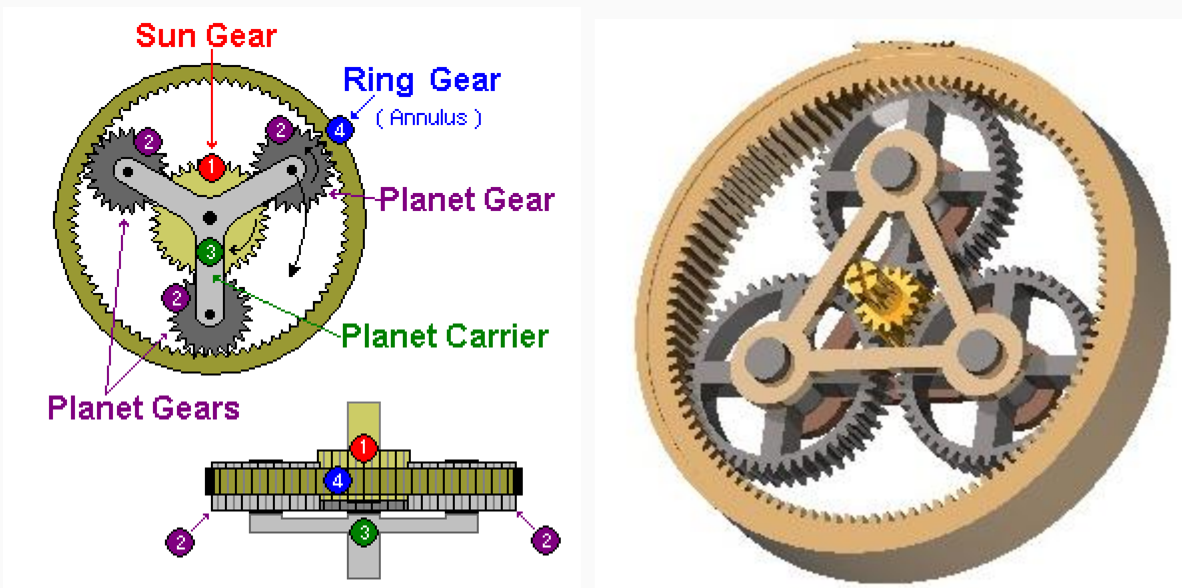


Fig. 11.5 Planetary gear unit
(Source:http://www.beam-wiki.org/w/images/1/16/Epicyclical(Planetary)_Gear_Train.GIF)
(http://www.hhbearing.com/images/Planetary_Gears.gif)

Crown gear is a special form of bevel gear which has teeth at right angles to the plane of the wheel; it meshes with a straight cut spur gear or pinion on a right-angled axis to its own, or with an escapement such as found in mechanical clocks

IV. Tractor Transmission Types

Tractors are to be used for heavy field works especially tillage operations that require maximum tractive power and P.T.O work where correct P.T.O speed is essential. At rated engine speed of tractor correct P.T.O speed should be available for getting maximum P.T.O power from the tractor. Most of the field operations for crop cultivation need forward speeds between 3-6 km/hr. Therefore, selection of suitable speed ratios in this range for different types of field works is of vital importance. In tractor the rear drive wheels require power at lower speed and high torque whereas its engine runs at higher speed and low torque. Therefore, the purpose of gearbox transmission is to provide speed reduction and multiply the torque received from the engine. Main principle of gear train transmission is given by the following relationship.

$$\frac{N_{driver}}{N_{driven}} = \frac{T_{driven}}{T_{driver}} \text{ or } N_1 \times T_1 = N_2 \times T_2 \qquad \ldots (11.9)$$

Where,

N_{driver} (N_1) = speed of driving gear, rpm

N_{driver} (N2) = speed of driven gear, rpm

T_{driver} (T_1) = number of teeth in driving gear

T_{driver} (T_1) = number of teeth in driven gear

i. Transmission Systems:

Most common type of power transmission used in tractors are as under:

a) Manual Transmission

1. Sliding gear
2. Constant mesh
3. Synchronized or Synchromesh
4. Power shift

b) Automatic Transmission

c) Hydrostatic

d) Hydro-dynamic

a) Manual Transmission

A manual transmission is a type of transmission used in automotive applications. Manual transmissions often feature a driver-operated clutch and a movable gear selector, although some do not. If you have a manual transmission, you have to shift the gears yourself, usually with a stick located on your console and the clutch pedal. Manual transmissions are characterized by gear ratios that are selectable by engaging pairs of gears inside the transmission. Manual transmissions are generally available with four to six forward gears and one reverse gear, although manual transmissions have been built with as few as 2 and as many as 7 gears. Some manuals are referred to by the number of forward gears they offer (e.g., 5-speed) as a way of distinguishing between automatic or other available manual transmissions. Manual shift transmissions, while not as user-friendly as some of the other types, tend to have cast iron durability. It has no synchronizers thus one have to stop and clutch for each gear change. One can't shift on the go without grinding gears. Its usually have 6-8 forward gears and 1-2 reverses.

Manual transmissions are of these types:

It is the plain old standard shift transmission. The two most popular styles of manual shift transmissions are the sliding gear, and the collar shift. In the sliding gear style, the gears are splined to the main shaft, and gear selection is made by actually moving the gears, via shift forks, into the appropriate location.

a) Sliding gear transmission:

Basic gear type transmission is sliding gear transmission (Fig. 11.5). Consists of input shaft and output shaft parallel to each other inside housing or case. Third shaft called idler shaft reverses power to output shaft. Idler shaft parallel to input shaft. One pair gears provides each forward speed. In each gear pair, one gear located on input shaft, other on output shaft. Gears on input shaft solidly attached to shaft by splines or keys. Gears on output shaft slide so can move to engage mating gear on input shaft. Reverse occurs when sliding gear engages idler gear.

Most basic gear type transmission is sliding gear transmission. Common in farm and industrial machines, as well as compact equipment. These transmissions simple to operate and repair and provide variety speeds.

Sliding gear transmissions contain simple arrangements spur gears and shafts. Usually contain input shaft and output shaft held parallel to each other in housing or case. Third shaft called idler shaft reverses power to output shaft. Idler shaft held parallel to input shaft.

Sliding spur gears arranged to mesh to provide changes in speed or direction. One pair gears provides each forward speed. In each gear pair, one gear on input shaft, the other on output shaft. Gears on input shaft solidly attached to shaft by splines or keys. Gears on output shaft slide to engage mating gear on input shaft. Reverse occurs when sliding gear (usually first gear) engages idler gear.

Transmission also has neutral and reverse. In neutral, transmission drive gear and countershaft drive gear mesh. Power flows into transmission through clutch shaft and countershaft turns, but none gears on countershaft in mesh with gears on output shaft. As result, output shaft doesn't turn and no power flows out transmission to drive components.

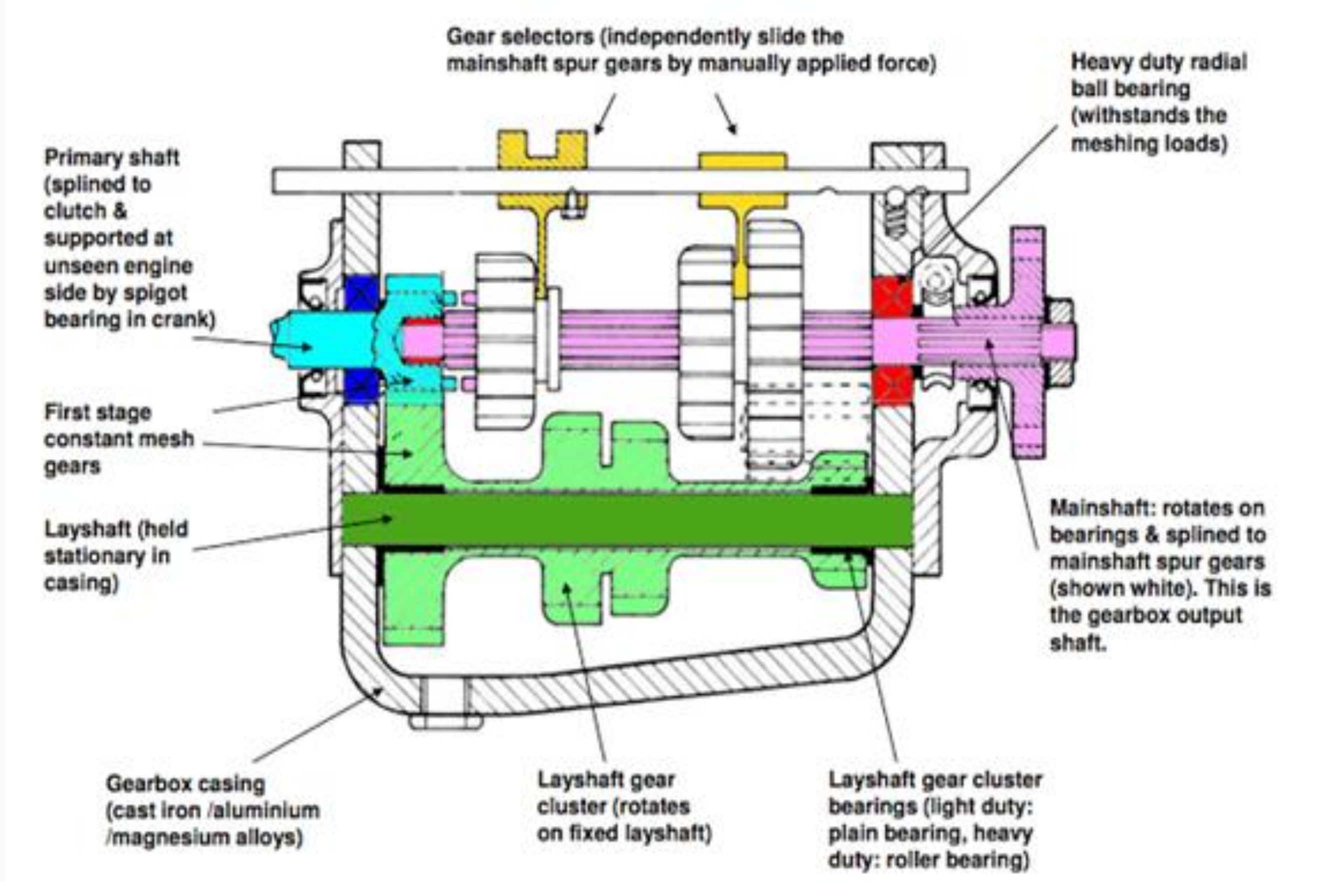


Fig. 11.5: Sliding gear transmission
(Source:http://motorsportengineering.blogspot.in/2010/12/basics-of-sliding-mesh gearbox.html)
(http://0-media-cdn.foolz.us/ffuuka/board/wsg/image/1339/10/1339105312472.gif)

b) Constant mesh type:

These gears are always in mesh. Usually the gears are helical in shape. The transmission is put into operation by engagement of shifting couplings, which slide along the splines on the counter-shaft and the output shaft of the gear box (Fig. 11.6).

c) Simple unsynchronized systems:

In this system, gears are spinning freely and their relative speeds must be synchronized by the operator to avoid noisy and damaging "clashing" and "grinding" when trying to mesh the rotating teeth (Fig. 11.7). It required skills of timing and careful throttle manipulation when shifting, so that the gears would be spinning at roughly the same speed when engaged; otherwise the teeth would refuse to mesh.

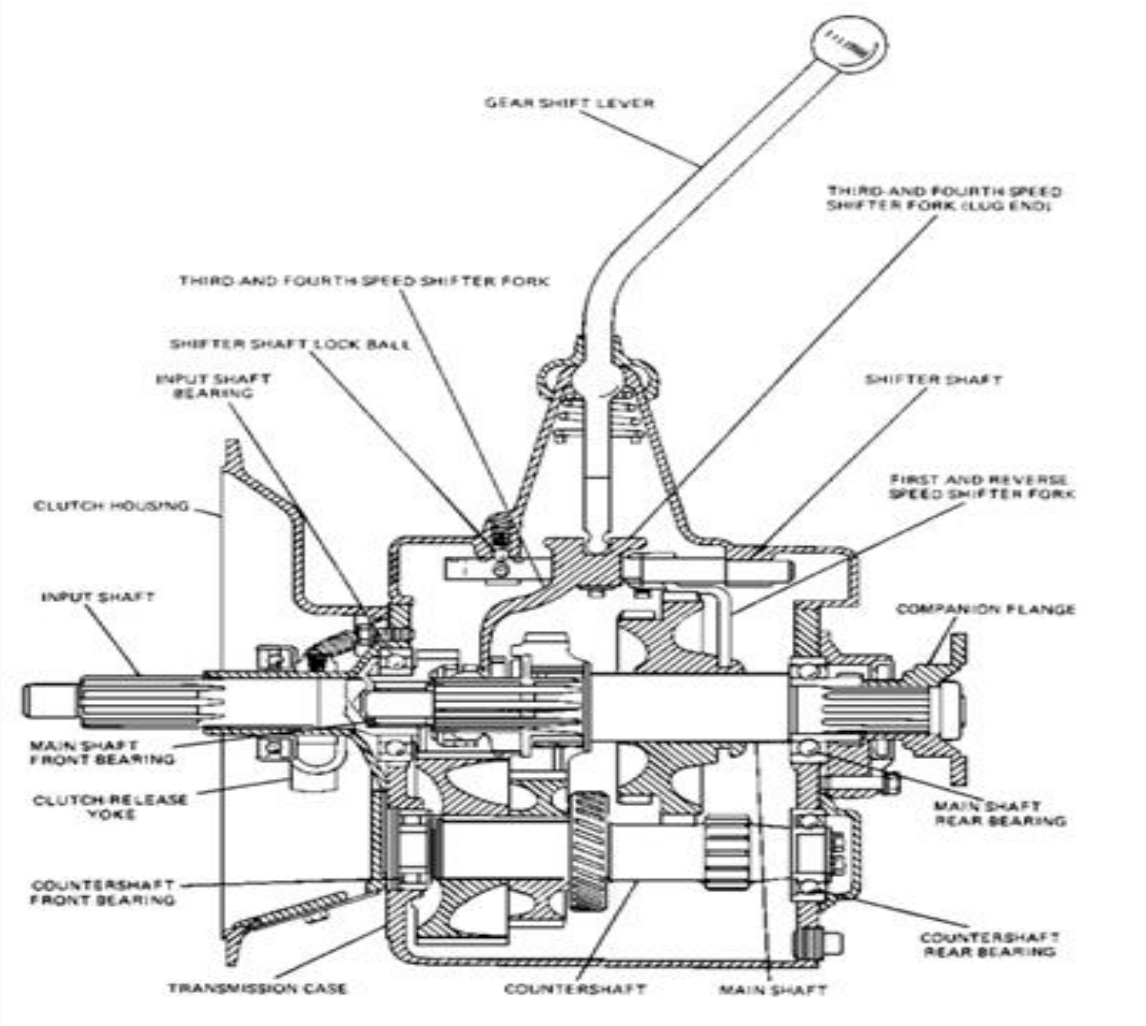


Fig. 11.6: Constant mess transmission system
(Source: http://topmech.narod.ru/Output/files/tnmfiles/OD1005/ch3.htm)

Fig. 11.7: Simple unsynchronized systems
(Source:http://wikicars.org/images/en/thumb/c/c8/Gearbox_diagram.JPG/400px-Gearbox_diagram.JPG)

For the collar shift style, the gears are built up into a stack. The gears do not slide back and forth. These gears are not splined to the main shaft but are free to rotate when not engaged.

There is a shift collar in between each gear pair, i.e. 1st & 2nd or 3rd & 4th. This collar is splined to the main shaft, and is the movable component when a speed change is called for.

d) Synchronized systems:

In the system, the gearbox is of constant mesh type, in which all gears are always in mesh but only one of these meshed pairs of gears is locked to the shaft on which it is mounted at any one time, the others being allowed to rotate freely; thus greatly reducing the skill required to shift gears (Fig. 11.8). These systems that will automatically "mesh" while changing gears. Basically the same as the manual shift except it has synchronizers and can be shifted on the go. The clutch should always be used for starts, stops as well as shifting. It usually has 6-8 forward gears and 1-2 reverses.

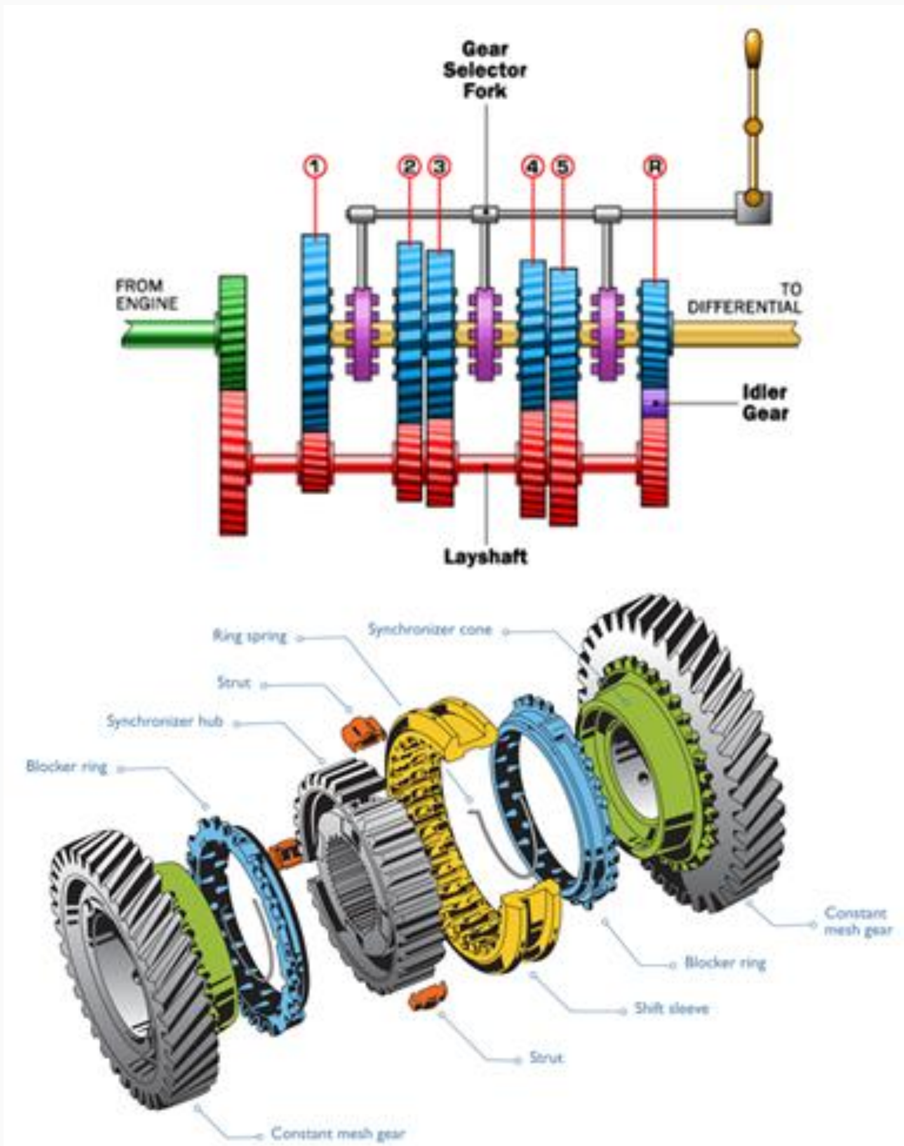


Fig. 11.8: Synchronized systems

(Source:http://static.ddmcdn.com/gif/transmission-5speed-gears.gif)

Let's suppose our transmission is synchronized between 3rd and 4th gears. We'll start out in 3rd gear, and then shift into 4th. As we shift, the first occurrence in the chain of events is that we move the transmission out of 3rd gear, and into neutral. As we continue moving the shift lever towards 4th gear, a brass cone applies friction to 4th gear, increasing or decreasing it's speed to match that of the rotating collar. Once the speeds have equalized, the gears still may not be lined up with each other, so there are little triangular shaped teeth around the outer circumference of the brass cone, which serve to ever so slightly rotate the shift collar teeth and the gear teeth into perfect alignment. This whole process occurs rapidly, usually allowing a straight-through shift, directly out of one gear and into the next. Synchro transmissions range from simple, where only a single pair of gears are synchronized, on up to full synchronization of all speeds, including forward and reverse

c) Hydrostatic Transmission:

Hydrostatic transmissions transmit all power with hydraulics i.e. with the power of oil.. One half of the transmission is a variable displacement pump and the other half is a hydraulic motor. A movable swash plate controls the piston stroke to change the pump's displacement. A hydrostatic transmission works as being a variable-displacement hydraulic pump, driving a fixed-displacement hydraulic motor (Fig. 11.9).

The greatest advantage of a hydrostatic transmission is the ability to infinitely vary the ground speed and quickly change directions. Another advantage is reliability. This transmission is self-protecting from operator abuse. Also, on foot pedal controlled transmissions, there is a built in safety factor in that you need only lift your foot from the pedal, to bring the tractor to a controlled stop. Their disadvantages are high cost, sensitivity to contamination and a slight loss of power at the PTO shaft. You must also remember to apply the parking brake when you park the tractor on a slope.

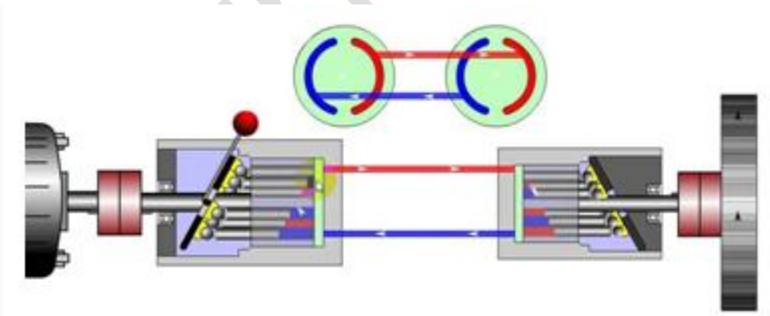


Fig. 10.9: Hydrostatic transmission

(Source:http://www.google.co.in/imgres?imgurl=&imgrefurl=http%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DqxZFSNITK&h=0&w=0&sz=1&tbnid=4Ga0WJ9zO7jx9M&tbnh=168&tbnw=299&zoom=1&docid=YODn5B0eKQyyFM&ei=6MPTUuT5GYLVrQe_i4GwBQ&ved=0CAIQsCUoAA)

Hydrostatic is, by far, the best choice for turf mowing applications or for any tasks that require constant speed and direction changes within a small area. They are used in the drive train of riding lawnmowers and lawn tractors and applications requiring continuously variable control.

A hydraulic automatic transmission consists of the following parts:

- **Fluid coupling or Torque converter:** A hydraulic device connecting the engine and the transmission. It takes the place of a mechanical clutch, allowing the engine to remain running at rest without stalling. A torque converter is a fluid coupling that also provides a variable amount of torque multiplication at low engine speeds, increasing "breakaway" acceleration.
- **Planetary gear set:**A compound planetary set whose bands and clutches are actuated by hydraulic servos controlled by the valve body, providing two or more gear ratios.
- **Valve body:**A hydraulic control center that receives pressurized fluid from a main pump operated by the fluid coupling/torque converter. The pressure coming from this pump is regulated used to run a network of spring-loaded valves, check balls and servo pistons. The valves use the pump pressure and the pressure from a centrifugal governor on the output side (as well as hydraulic signals from the range selector valves and the throttle valve or modulator) to control which ratio is selected on the gear set; as the car and engine change speed, the difference between the pressures changes, causing different sets of valves to open and close. The hydraulic pressure controlled by these valves drives the various clutch and brake band actuators, thereby controlling the operation of the planetary gear set to select the optimum gear ratio for the current operating conditions. However, in many modern automatic transmissions, the valves are controlled by electro-mechanical servos which are controlled by the Engine Management System or a separate transmission controller.

d) Continuously variable Transmission:

A different type of automatic transmission is the continuously variable transmission or CVT, which can smoothly alter its gear ratio by varying the diameter of a pair of belt or chain-linked pulleys, wheels or cones. Some continuously variable transmissions use a hydrostatic drive consisting of a variable displacement pump and a hydraulic motor to transmit power without gears. CVT designs are usually as fuel efficient as manual transmissions in city driving, but early designs lose efficiency as engine speed increases.

A slightly different approach to CVT is the concept of toroidal CVT or IVT (from infinitely variable transmission). These concepts provide zero and reverse gear ratios.

V. Tractor Transmission Performance:

The relationship between engine brake power and power in the drive wheels of tractor are discussed below.

i. Engine Brake power

The engine brake power (W) is given by the following equation

$$W = \frac{2\pi N_e T_e}{6 \times 10^4} \quad \text{... (11.10)}$$

Where, W= engine brake power, kW

N_e = engine RPM

T_e = engine torque, N-m

Or $$W = \frac{2\pi N_e T_e}{4500}$$ ... (11.11)

Where, W= engine brake power, HP

N_e = engine RPM

T_e = engine torque, Kg-m

ii. Power in the drive wheels of tractor

The power in the drive wheels of tractor is given by

$$W_w = \frac{2\pi T_w N_w}{6 X 10^4}$$ ... (11.12)

Where, W_w = power in drive wheels of tractor, kW

T_w = drive wheel torque, N-m

N_w = drive wheel RPM

Based on torque speed relationship of tractor power transmission as given in eqns. 8.2 and 8.3, the transmission efficiency (η_t) is given by the following equation.

$$T_e N_e \eta_t = T_w N_w = \text{Constant}$$ ... (11.13)

Where, T_e = engine torque, N-m or Kg-m

N_e = engine RPM

T_w = drive wheel torque, N-m

N_w = drive wheel RPM

η_t = transmission efficiency, %

iii. Drawbar power of tractor

It primarily depends on drawbar pull developed by the tractor and its speed of operation. The drawbar power of tractor is given by

$$W_d = \frac{P X S}{3.6}$$ ...(11.14)

Where, W_d= drawbar power, kW

P = drawbar pull, kN

S = speed, km/hr

Or, $W_d = \frac{P \times S}{75}$ ...(11.15)

Where, W_d = drawbar power, HP

P = drawbar pull, Kg

S = speed, m/s

VI. Design Procedure for Gearbox of a Tractor

i. Design Considerations

1. To reduce the size of gearbox, the intermediate shaft should have as high speed as possible.

2. At any point of time only one set of gears should be in mesh. In other words, one set of gears must be completely disengaged before the other starts to engage.

3. The transmission ratio (TR) of a pair of gears in a gearbox should satisfy following condition.

$TR \leq 2:1$ and $\geq 1:4$ or in other words $0.25 \leq TR \leq 2$

4. The speed range ratio (Maximum shaft speed divided by minimum shaft speed) should not be more than 8.

5. In case of sliding gearbox, the centre distance between two shafts should remain constant. Or in other words the sum of number of teeth of meshing gears must be constant.

$T1 + T2 = T3 + T4 = \text{Constant}$

6. In a gearbox same module (m) of the gear set must be used.

7. The minimum difference between the numbers of teeth of adjacent gears must be 4.

8. The minimum numbers of teeth (in a set for spindle drives) should be greater than 17 to avoid interference of tooth.

VII. Differential

Differential of a tractor consists of planetary gear system which has four bevel gears (two side gears and two pinions). It also has a pair of bevel gears consisting of a pinion and crown wheel fitted at right angle to each other to transmit power received from the gearbox to the rear axles. In other words, the input power to the planet carrier attached to the crown wheel and output power to the side gears mounted on the counter shafts gives drive the rear wheels. It acts as a speed reduction and transmission of power at 90°. The differential divides the power into equal parts and finally to the rear wheels. It allows one wheel of tractor to move faster than the other wheel while taking turns. When the tractor is moving straight ahead, the bevel pinions of differential do not rotate on their carrier shafts and both the side gears rotate at same speed. A differential lock is also provided to prevent excessive spin of one wheel than the other when a resistance to wheel is different. If one wheel of tractor gets in the mud or loose soil, the other wheel on the solid ground will not move while the other wheel spins around due to differential action. To overcome this problem differential lock is provided which allow both the wheels to move with same speed and apply equal torque.

The torque transmitted by both the axles of tractor would be equal as the bevel pinions of differential are exerting equal torque on both the side gears.

Transmission efficiency of differential of tractor is given by

$$\eta_d = \frac{W_a}{W_{bp}} \qquad \text{... (11.16)}$$

Where, η_d = Transmission efficiency of differential

W_a = power output through both the axles, kW

W_{bp} = power input to differential through bevel pinion, kW

Also,

$$T_{bp} \times N_{bp} \times \eta_d = (T_{al} \times N_{al} + T_{ar} \times N_{ar}) \qquad \text{... (11.17)}$$

Where, T_{bp} = torque input to bevel pinion of differential, Nm

N_{bp} = RPM of bevel pinion

T_{al} = torque output from left axle, N.m

T_{ar} = torque output from right axle, N.m

N_{al} = RPM of left axle

N_{ar} = RPM of right axle

η_d = transmission efficiency of differential, %

While moving straight, the torque in both the axles should be equal

Therefore $Tal = Tar = Ta$ …. (11.18)

Where, T_a = rear wheel axle torque.

And average speed of the axle (N_a) would be

$$N_a = \frac{N_{al} + N_{ar}}{2}$$ ….. (11.19)

From eqns. 11.17, 11.18 and 11.19

We get,

$$T_{bp} \times N_{bp} \times \eta_d = T_a \times N_a \times 2$$

Or ... (11.20)

$$T_a = \frac{T_{bp} \times N_{bp} \times \eta_d}{2N_a}$$

$$T_a - \left[\frac{N_{bp}}{N_a}\right] \times \left[\frac{\eta_d}{2}\right] \times T_{bp}$$ ... (11.21)

ii. Speed division by the differential

While taking turns, the role of differential comes into picture and as per the principles of differential gears, the reduction in speed of inner sun gear will be added up to the speed of outer sun gear. The speed of crown wheel during turnings would be average speed of two drive wheels of the tractor as given by following equation.

$$N_c = \frac{N_i + N_o}{2}$$ ... (11.22)

Where, N_c = crown wheel speed, rpm

N_i = inner wheel speed, rpm

N_o = outer wheel speed, rpm

iii. Design of Bevel Gears of differential

The following points should be taken into account while designing a bevel gear drive for a differential:

1. The gear should have sufficient strength so that, it does not fail at starting torques under dynamic running conditions.
2. The teeth must have very good wear characteristics so that the life of gear is long.

3. The suitable material must have very good wear characteristics so that life of gear is long.

4. The drive should be compact and properly designed.

5. The proper lubrication arrangement should be made.

Design procedure

1. Pitch diameters of bevel gears: Let the number of teeth be N and module be m,.

Then, $D_1 = PCD = N \times \frac{m}{10}$

Velocity ratio =VR =1.7

Take $\sigma_2 = \frac{1}{VR} = \frac{1}{1.7}$ or $\sigma_2 = 30.4^0$ and $\sigma_1 = 90^0 - 30.4^0 = 59.6^0$

Thus, the reference angle for tooth of gear = 30.4°

Thus, the reference angle for tooth of pinion= 59.6°

Pitch line velocity: Pitch line velocity of pinion and gear is calculated by

$$V_m = 3.14 \times D1 \times \frac{N_1}{60 \times 100} \quad , m/s$$ ...(11.23)

2. Determination of Maximum Tooth Load: Assuming that the full load acts on entire length of rotor which is driven by these gears. So, the transmitted teeth load is given by

$$F_t = HP \times \frac{75}{V_m} \quad ,kgf$$ ... (11.24)

3. Materials for bevel gears and Designed Stresses: Let the material for gears be 15Ni2Cr1Mo15 (Nickel chromium molybdenum steel) having ultimate strength-

$\sigma_u = 9000\ kg/cm^2$

Taking factor of safety 2.5 for the case hardened steel

Then, design stress

$$s_d = \sigma_u/2.5 \ , kgf/cm^2$$ ...(11.25)

4. Dynamic load on Bevel Gears: Given in machine design hand books

$$F_d = C_v N_{sf} K_m F_t$$ ... (11.26)

Where, Fd = dynamic load, kgf

Cv = Velocity factor = $3.5 + V\frac{m^{0.5}}{3.5}$

V_m = mean velocity

N_{sf} = service factor =1.5

K_m = load distribution factor = 1.25

Ft = tooth load

5. Calculation of P_c and P_d : The circular pitch = $P_c = \lambda_m$

Diameter pitch = Pd = 1/m

6. Calculation of face width: Adopting a 20° in volute teeth (the gear Lewis form factor is given by

$$Y_v = 0.154 - 0.912/Z_v$$ ... (11.27)

For straight bevel gears = Z1 / cos σ1 or Z1 / cos σ2 =Zv

Z_v = virtual number of teeth

Z_1 and Z_2 = number of teeth in pinion and gear respectively

σ_1 and σ_2 = reference cone angle in degrees

$Y_v = \pi \text{ X } Y_v$

Applying Lewis eqns.

$$F_s = \frac{\sigma_u \times b \times Y_u \times (1 - \frac{b}{R})}{P_d}$$ ... (11.28)

Where, F_s = strength of tooth in kgf

σ_u = design bending stress, 3200kg/cm² for used material

R = cone distance

b = face width

P_d = diametrical pitch

If b is small, then we can take another value.

Check for dynamic load:

Dynamic load is given by Buckingham equation.

$$F_d = F_t + \left[\frac{0.164\, Vm\, (bc + F_t)}{0.164\, V_m + 1.485\sqrt{(bc + F_t)}}\right] \quad \ldots (11.29)$$

Where, V_m = pitch line velocity m/s

c = constant whose values for 20° full length steel gear is given by c = 11860 × e

E = permissible error in action corresponding to a pitch line velocity (V)

Therefore, F_d must be below the maximum permissible contact compressive stress.

Check for maximum wear:

Formula for maximum wear is given by

Fw =d X Q X K X b ... (11.30)

Where, F_w = wear load

d = Pitch circle diameter

Q = ratio factor 22/(2+1)

$$k = \text{load factor} = (\sigma)^2 \times \frac{\sin \propto \left[\frac{1}{\sigma_1} + \frac{1}{\sigma_2}\right]}{1.4} \quad \ldots (11.31)$$

α = pressure angle

b = face width

c = design compression strength

It can be checked that F_w must be greater than F_d then only gears are safe for severe services also.

Module 5. Study of tractor steering and suspension systems

Lesson 12. Introduction and selection of different components for steering systems.

1. Introduction

The most conventional steering arrangement is to turn the front wheels using a hand–operated steering wheel which is positioned in front of the driver having steering column, which may contain universal joints, to allow it to deviate somewhat from a straight line. Other arrangements are sometimes found on different types of vehicles, for example, rear–wheel steering in combine harvesters. Tracked vehicles such as bulldozers and tanks usually employ differential steering that is, the tracks are made to move at different speeds or even in opposite directions, using clutches and brakes, to bring about a change of course or direction..

The steering system works with the suspension system to provide directional control with a comfortable amount of steering effort. It must do this while allowing for the necessary movement in the vehicle's suspension system. Some parts serve both systems. The steering system consists of a steering gear, steering linkage, a steering column and a steering wheel. Two types of steering systems are widely used in tractor i.e. conventional steering and rack-and-pinion steering.

I. Basic geometry:

The basic aim of steering is to ensure that the wheels are pointing in the desired directions. This is typically achieved by a series of linkages, rods, pivots and gears. One of the fundamental concepts is that of caster angle - each wheel is steered with a pivot point ahead of the wheel; this makes the steering tend to be self-centring towards the direction of travel.

The steering linkages connecting the steering box and the wheels usually conforms to a variation of Ackermann steering geometry (Fig. 12.1), to account for the fact that in a turn, the inner wheel is actually travelling a path of smaller radius than the outer wheel, so that the degree of toe suitable for driving in a straight path is not suitable for turns. The angle the wheels make with the vertical plane also influences steering dynamics (see camber angle) as do the tires.

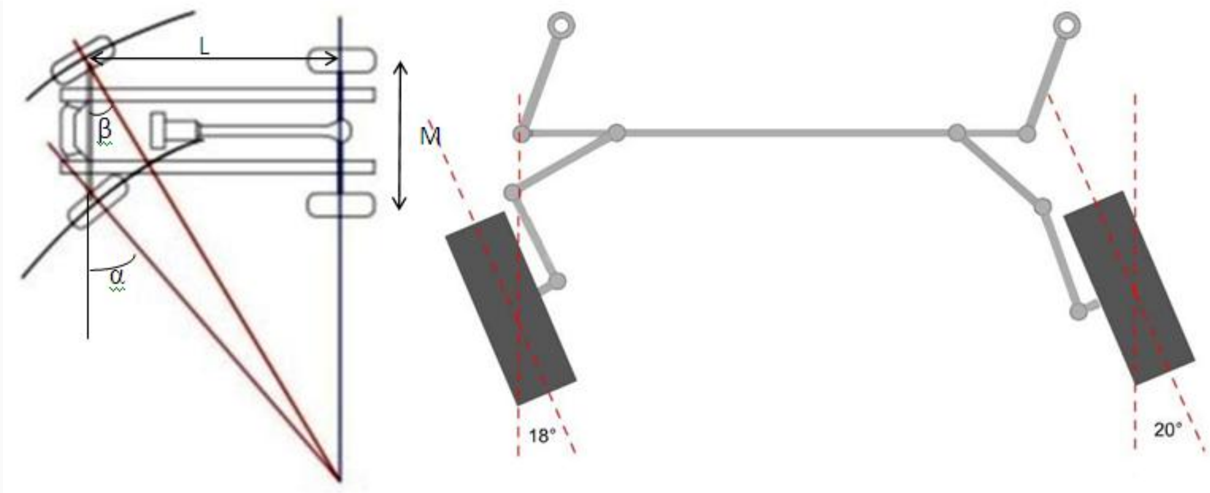


Fig. 12.1: Ackermann steering geometry and caster angle (Courtesy Melior Inc. 2004)

The steering geometry where the turning wheels advance without any lateral slip is the ideal Ackermann geometry. According to this geometry (Fig. 12.1) the steered wheels should always be rolling around a common center located on the extension of the rear axle. In other words, the inside and the outside steering angles should satisfy the following relationship:

$$\text{Cot}\,ß - \text{Cot}\,\alpha = M/L \quad \text{... (12.1)}$$

Where

ß is the angle between axis of outer wheel with tie rod

α is the angle between axis of inner wheel with tie rod

M is the distance between the two points of kingpin extension on the ground

L is the wheelbase of vehicle

If the steering systems not optimally designed, cannot comply with ideal Ackermann geometry, as a result of this inaccuracy in steering geometry, certain amount of lateral slip of wheels occurs during turns. This lateral slip increases the rolling resistance, tire wear and steering effort.

Caster angle indicates kingpin pivot line and gray area indicates vehicle's tire with the wheel moving from right to left. A positive caster angle aids in directional stability, as the wheel tends to trail, but a large angle makes steering more difficult.

Types of Steering Systems

1. Conventional Steering:

The worm and sector was an older design used for Willys and Chrysler vehicles, and the Ford Falcon. Older designs often use the re-circulating ball mechanism, which is still found on many vehicles (Fig. 12.2). This is a variation on the older worm and sector design; the steering column turns a large screw (worm gear) which meshes with a sector of a gear, causing it to rotate about its axis as the worm gear is turned; an arm attached to the axis of the sector moves the Pitman arm, which is connected to the steering linkage and thus steers the wheels. The re-circulating ball version of this type reduces the considerable friction by placing large ball bearings between the teeth of the worm and those of the screw; at either end of the apparatus the balls exit from the two pieces into a channel internal to the box which connects them with the other end of the apparatus, thus they are "re-circulated".

It is also referred to as Re-circulating Ball or Worm Gear steering (Fig. 12.3) for the type of gear it uses or on the basis of the shape formed by the linkage set like parallelogram or trapezium or simple linkage of steering.

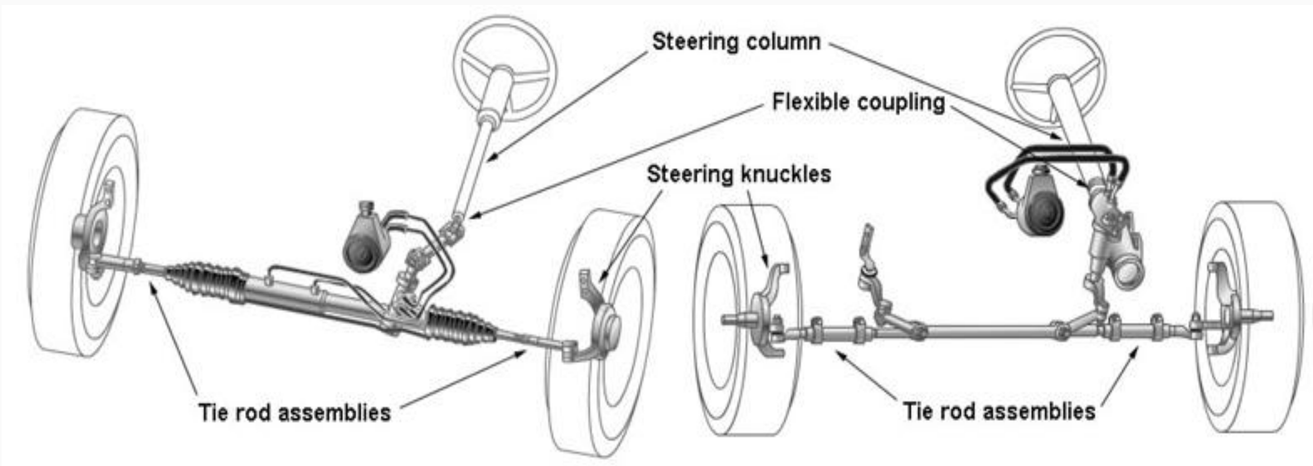


Fig. 12.2: Conventional steering System (Courtesy Melior Inc. 2004)

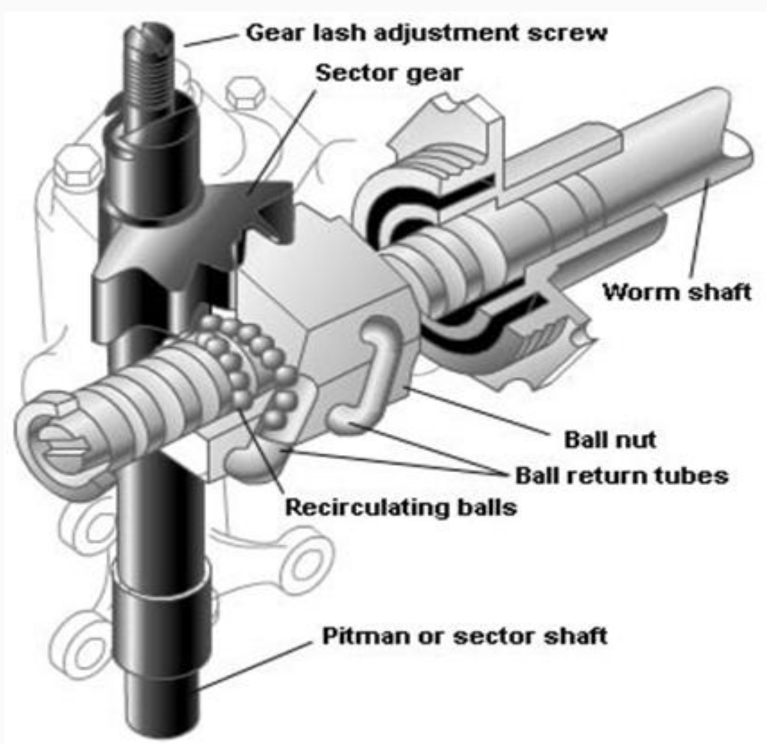


Fig. 12.3: Recirculating ball mechanism for steering (Courtesy Melior Inc. 2004)

2. Rack-and-pinion Steering:

Rack-and-pinion steering transmits circular motion from the steering wheel to a pinion that meshes with teeth on a flat rack (Fig. 12.4). The pinion moves the rack in a linear direction for steering the wheels. It is simpler and less expensive to produce than conventional steering systems. The rack and pinion design has the advantages of a large degree of feedback and direct steering "feel". A disadvantage is that it is not adjustable, so that when it does wear and develop lash, the only alternate is replacement.

The recirculating ball mechanism has the advantage of a much greater mechanical advantage, so that it was found on larger, heavier vehicles while the rack and pinion was originally limited to smaller and lighter ones; due to the almost universal adoption of power steering, however, this is no longer an important advantage, leading to the increasing use of rack and pinion on newer vehicles. The recirculating ball design also has a perceptible lash, or "dead spot" on center, where a minute turn of the steering wheel in either direction does not move the steering apparatus; this is easily adjustable via a screw on the end of the steering box to account for wear, but it cannot be entirely eliminated because it will create excessive internal forces at other positions and the mechanism will wear very rapidly. This design is still in use in trucks and other large vehicles, where rapidity of steering and direct feel are less important than robustness, maintainability, and mechanical advantage.

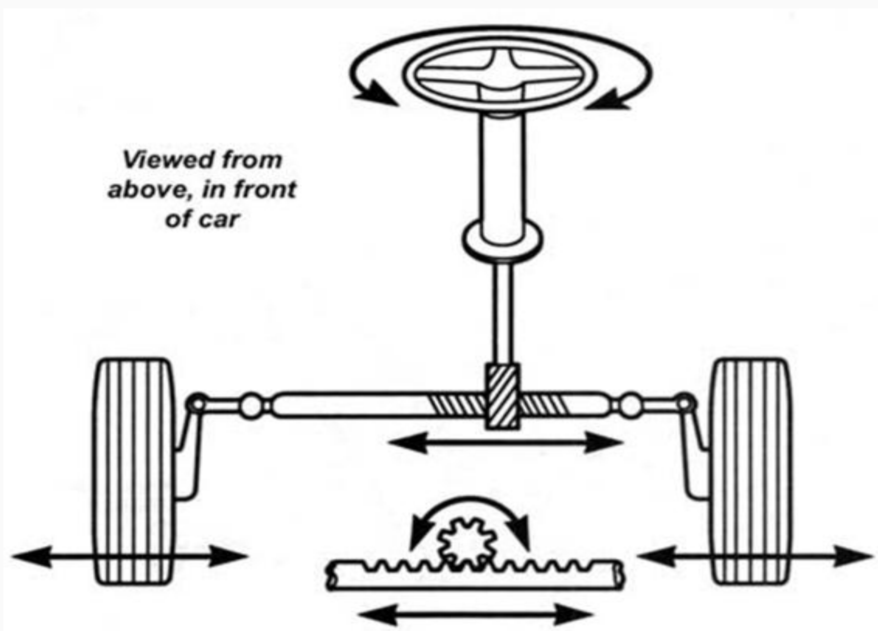


Fig. 12.4: Rack and pinion type steering system (Courtesy Melior Inc. 2004)

3. Power assisted steering:

Power assisted steering helps the driver of a vehicle to steer by directing some of its power to assist in swivelling the steered road wheels about their steering axes. As vehicles become heavier along with increase in tyre width and diameter, the effort needed to turn the wheels about their steering axis increases. To alleviate this auto makers have developed power steering systems: or more correctly power-assisted steering also for off road vehicles like tractors.

There are two types of power steering systems;

(i) Hydraulic power steering (HPS)

(ii) Electric or electronic power steering (EPS).

(i) Hydraulic Power Steering (HPS): HPS can again be classified in two type of steering

(a) Power rack-and-pinion steering

(b) Integral power steering gearbox – Conventional recirculating ball steering gear with a hydraulic control system.

(a) Power rack-and-pinion steering systems:

In this system there is a power cylinder/hydraulic cylinder inside the rack or gear housing and a double-acting, hydraulic piston in the power cylinder that acts upon the rack (Fig. 12.5). Control valve mechanism located in the steering gear senses and controls power assist. Hydraulic lines or steel tubing from the control valve to the power cylinder that carries the power steering fluid. Most power rack-and-pinion units have a small tube that runs along the housing and connects to each bellows boot. This tube allows the air pressure in the bellows boots to equalize from one side to the other during turns. The power cylinder and piston are precisely machined and sealed with rubber O-rings. In operation, fluid is directed to a chamber of the power cylinder on either side of the rack. This fluid creates pressure to move the piston and thus the rack to the left or right. To sense and control assist, two types of control valves are used: either rotary control valves, or a spool control valve. Rotary control valves use a torsion bar attached to the input shaft to make the control valve move, aligning oil passages to the proper chamber. On spool valve units, the spool valve detects the thrust action of the input shaft caused by attempting to turn the steering wheel, and directs fluid to the proper chamber of the power cylinder.

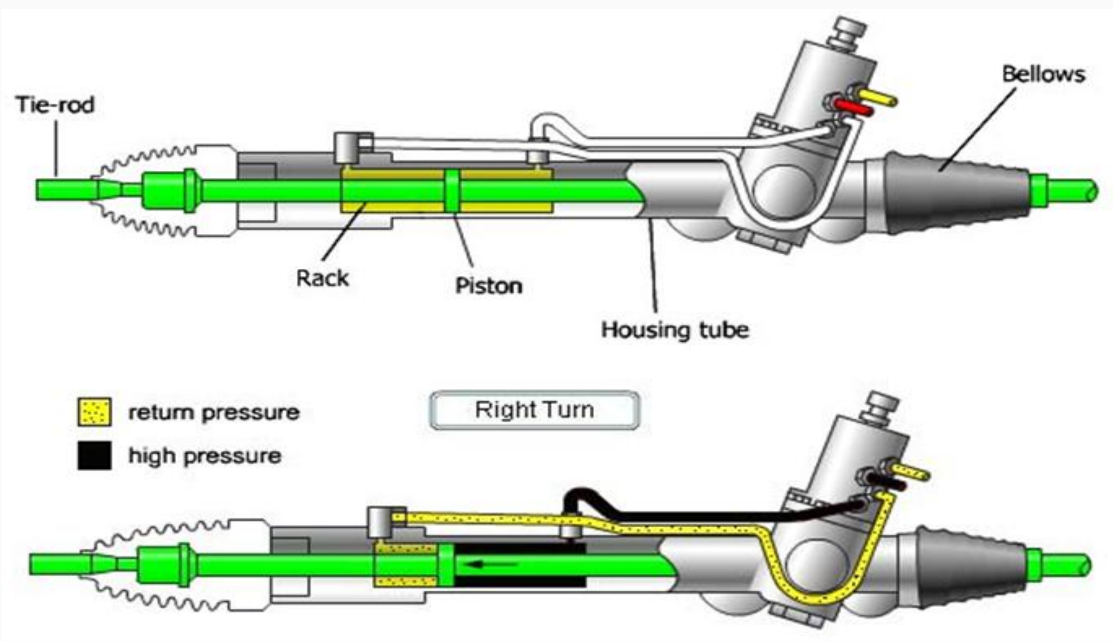


Fig. 12.5: Hydraulic power steering system (Courtesy Melior Inc. 2004)

(b) Integral power steering systems

This type of steering system is commonly used with linkage-type steering. Steering gearbox contains a conventional worm and-sector gear (Fig. 12.6). The hydraulic power piston and directional control valve are mounted inside the gearbox housing. As with power rack-and-pinion units, the valve may be a spool valve or a rotary valve with a torsion bar. When the steering wheel is in the straight-ahead position, the valve maintains equal pressure on both sides of the power piston. Oil flows back to the pump reservoir. During a turn, the control valve routes oil to one side of the power piston, which pushes it in the desired direction to provide assist. The oil on the non-pressurized side of the piston is forced back through the control valve and to the pump reservoir.

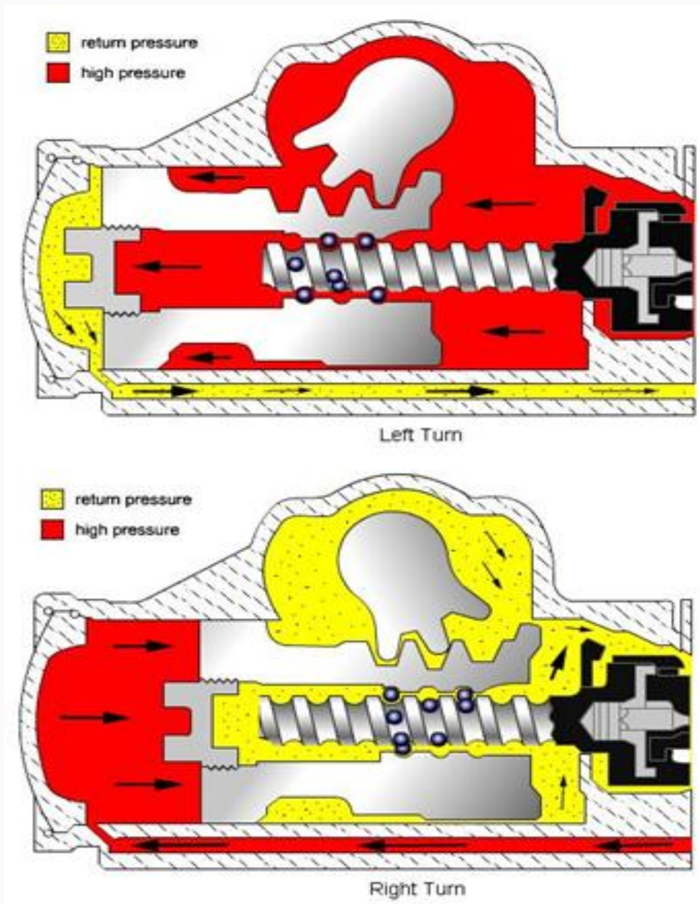


Fig. 12.6: Integral power steering system (Courtesy Melior Inc. 2004)

(ii) Electric Power Steering (EPS):

Computer-controlled electric power rack steering systems are used on some vehicles (Fig. 12.7). These systems use a small electric motor within the housing to assist in moving the rack. Some include a recirculating ball steering gear. Computer-controlled electric systems typically use inputs from the antilock brake wheel speed sensors, steering angle and steering effort sensors, and other inputs to provide the proper amount of steering assist.

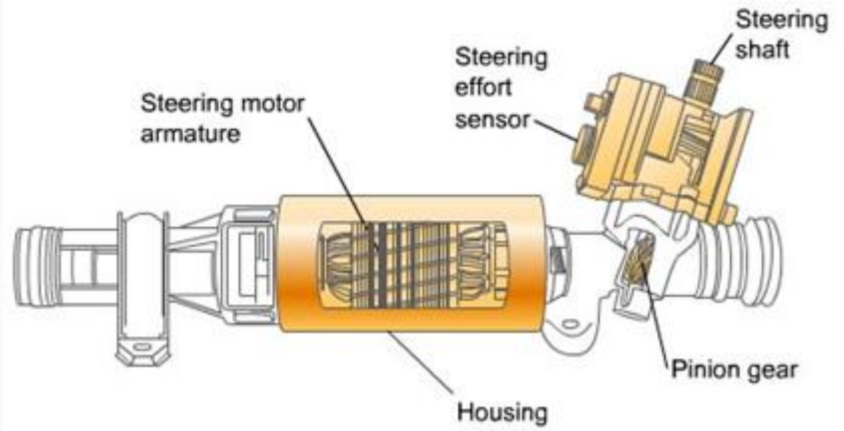


Fig. 12.7: Computer-controlled Electric Assist Rack-and-pinion type steering system (Courtesy Melior Inc. 2004)

Comparison between HPS and EPS:

A hydraulic power steering (HPS) uses hydraulic pressure supplied by an engine-driven pump to assist the motion of turning the steering wheel. Electric power steering (EPS) is more efficient than the hydraulic power steering, since the electric power steering motor only needs to provide assistance when the steering wheel is turned, whereas the hydraulic pump must run constantly. In EPS, the amount of assistance is easily tunable to the vehicle type, road speed, and even driver preference. An added benefit is the elimination of environmental hazard posed by leakage and disposal of hydraulic power steering fluid. In addition, electrical assistance is not lost when the engine fails or stalls, whereas hydraulic assistance stops working if the engine stops, making the steering doubly heavy as the driver must now turn not only the very heavy steering—without any help—but also the power-assistance system itself

4. Crab steering

Crab steering is a special type of active four-wheel steering (Fig.12.8). It operates by steering all wheels in the same direction and at the same angle. Crab steering is used when the vehicle needs to proceed in a straight line but under an angle or when the rear wheels may not follow the front wheel tracks i.e. to reduce soil compaction when using rolling farm equipment.

Fig 12.8: Agricultural slurry applicator using crab steering to minimise soil compaction

Lesson 13. Study of tractor suspension system

The suspension system supports the vehicle, allowing the wheels to move up and down over irregularities in the road. It cushions the ride for the frame, engine, transmission, and passengers, while keeping the tires in firm contact with the road under all conditions. Suspension system parts include springs, dampening devices (shocks), ball joints, steering knuckles, and spindles or axles. Two types of front suspension systems are widely used in today's vehicles: the Mac-Pherson strut suspension and the short/long arm (SLA) suspension. Early automobiles have a straight axle (I-beam) front suspension, and up until recently some vehicles were having with a variation called a twin I beam suspension. Many rear suspensions still use a straight axle.

1. Objective of Suspension System:

Ride comfort is considered as the first objective of the suspension systems of vehicles including tractors. Ride comfort is an important characteristic of vehicles that indicates how much riding is comfortable for passengers. Ride comfort is very important for agricultural tractors also, because the acceleration transmitting to the driver compared with other vehicles is very high due to more undulations in the agricultural fields as compared to the smooth road. In addition, the operators of agricultural tractors spend many hours in the field during peak working seasons. These conditions can affect the comfort, efficiency, alertness, and health of the operators.

In order to quantify the ride comfort of a vehicle, vibrations of the vehicle body should be measured in two directions of vertical and horizontal (i.e. roll, pitch and yaw). The most commonly used measurement methods is the RMS acceleration. Root Mean Square (RMS) acceleration is defined as:

$$\mathrm{RMS} = [1/T \int a2.(t).dt]1/2 \qquad \text{... (13.1)}$$

Where T = Total sample time,

a = spring mass acceleration,

t = Time.

In order to evaluate the ride comfort, the RMS accelerations of both the vertical and horizontal directions is measured.

Handling is a characteristic of a vehicle that provides stable and safe driving that can be created via a steady contact between the tires and surface. Handling is also called road holding, ride stability, and driving safety, implying the same meaning. The handling capability of a vehicle is important during maneuvers such as at turning, braking, or accelerating. In these extreme situations, weak handling reduces the control ability of the vehicle and can affect the safety of the passengers/drivers. Due to this fact, handling is considered as an important capability for vehicles, and beside the ride comfort, it is considered as the main target of using the suspensions in vehicles.

The early agricultural tractors had no suspension systems, and different types of suspension systems were employed in them gradually with time. The primary systems were seat suspensions, which were used with the aim of improving ride comfort of tractor drivers. Along with the development in tractors technology, chassis suspensions were also used for these vehicles. These systems were able to improve the handling of tractors besides the ride comfort of them. This provided more safety and stability for tractors, and their travel speed was increased This begins with characteristics of tires, and suspensions of seat and cabin. Then, the chassis suspension systems of tractors including front axle and full suspension were introduced in the tractors.

2. Suspension Characteristics of Tires

When pneumatic tires were used first time for agricultural tractors, ride comfort and handling were improved, and the travel speed of tractors was increased upto 20 km/h (Hoppe-01, 2004). Tires are the first elastic elements between a vehicle and the ground surface. For that reason, the suspension properties of the tires have an important role in the dynamic behaviour of tractors, particularly for tractors having no other suspension systems.

The suspension characteristic of a tire can be demonstrated by a simple model, which is constructed of a spring and a damper in parallel (Fig. 13.1). Based on this model, the measured stiffness and damping characteristics of a typical tire for agricultural tractors are presented. The stiffness and damping coefficients of the tire are correspondingly too high and too low than typical suspension characteristic needed for a tractor. Therefore, tires are not able to work lonely as a proper suspension system, because high stiffness of tires is equal to a very hard suspension that is unable to provide good ride comfort. On the other hand, with very low damping capacity of tires, they are not able to provide effective control on vibrations. In addition to the improper value of stiffness and damping coefficient of tires, these characteristic are not constant and depend on the inflation pressure and speed of tires. All these factors cause a poor dynamic behaviour for the conventional tractors that have no primary suspension,

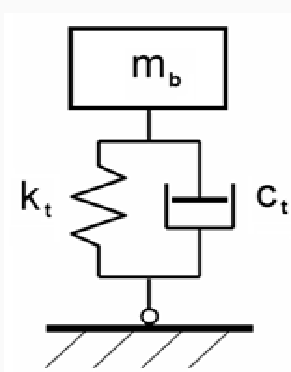


Fig. 13.1: Single point contact modeling of tires (Courtesy Shahriar Sarami, 2009)

3. Types of suspension systems

(i) Seat Suspension:

The first system used for the tractor was suspension for the seat of the operator. This system is placed directly between the driver seat and tractor body, and it affects directly driver comfort and reduces the vibration experienced by him. Seat suspensions are not so complicated, inexpensive and have a robust construction. For these reasons, they are used on all modern agricultural tractors (Fig. 13.2). A suspension seat is made of typically a foam cushion suspended on a parallel spring and damper set. Type of suspension systems may be mechanical, pneumatic, hydraulic, hydro-pneumatic, or a combination of these systems.

Fig. 13.2 Modern seat using "active seat" technology (CourtesyJonhDeere, 2013)

Air–ride seat from New Holland is another active seat system, constructed based on a pneumatic suspension. This system uses an adaptive control system that adjusts the parameters of the suspension relative to the driver's weight. Another example of the modern seats is the semi-active system produced by the tractors manufacturer of Valtra. This system is equipped with a pneumatic spring and a MR damper, which works as the actuator of the system. Besides the seat suspension, which has major role in providing ride comfort for the driver, some other characteristics influence on the ride comfort. For example, size, design, and materials of a seat have important role in sitting perception.

(ii) Cabin Suspension

In modern agricultural tractors, a cabin is used in order to isolate the driver from the outside, and it protects the driver from the annoying environmental conditions, dust, and noise. Using a suspension system for the cabin, driver place could be isolated from the tractor vibrations as well. A cabin suspension can offer more benefits than a seat suspension and provide better ride comfort for the driver. Cabin suspension decreases the structurally transmitted noise to the drivers. Since the mass of a cabin is greater than a seat, the natural frequency of cabins is lower than the one of seat suspensions. The manufactured cabin suspensions of the agricultural tractors can be categorized in two groups of semi suspended and fully suspended. In the first group, the rear side of the cabin is connected to the chassis by means of two suspension units in its corners. In spite of this, the front side is connected to the tractor chassis without suspension and only via a joint-type link. This type is often used for the tractors with front axle suspension. In this system, body vibrations appear on the cabin as pitch rotational movement, and response of this system to the roll movement of the tractor body is very limited.

(iii) Hitch Suspension

During transportation, tractors mounted with implements, change largely the mass characteristics of the tractors, and influence mainly the dynamic behaviour of the tractors. Without the primary suspension, the tires are the only elastic elements that affect the handling of the tractors, whereas the tires have no required suspension properties. Under these conditions, the dynamic behavior of the tractor becomes worse under the influence of the attached implements, particularly the bounce and pitch movement of the tractor are increased. This situation causes a reduction in the control ability of the tractor, especially during high-speed transports which leads to unsafe modes.

In order to reduce the effect of the mounted implements on the tractors and in order to control their vibration, a suspension system can be used in the connection between them and the tractors. Since the implements are normally mounted on a tractor via the three-point hitch, this suspension is applied to this mechanism and called "hitch suspension". Such a system that employs a hydro-pneumatic suspension in damping the pitch vibrations of the implement. A hydraulic actuator is used instead of the upper link in this system (Fig. 13.3). This actuator is connected to a hydraulic accumulator through a throttle valve and works as a hydro-pneumatic suspension.

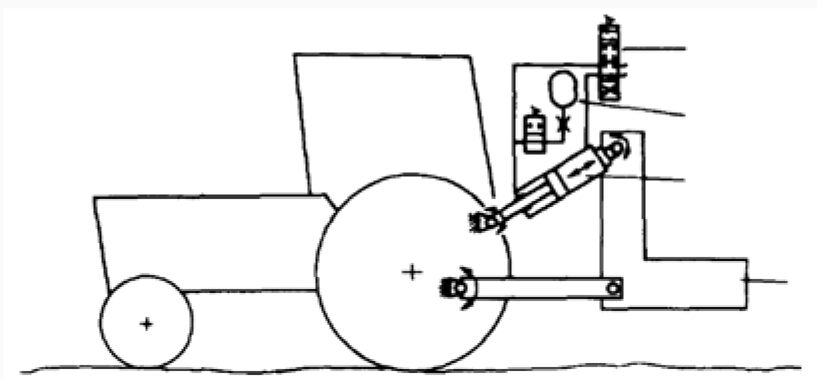


Fig. 13.3: A hydro-pneumatic shock absorber system applied to the tractor three-point hitch (CourtesyGoehlich, 1984).

(iv) Front Axle Suspension

When, four Wheel Drive (4WD) tractors became popular due to the better traction performance. The front wheels acquired a new role in the traction capability of the tractors and also in the steering ability of them. In this condition, there is a typical problem of the pitch movement of the tractors, because it creates load variation on the front tires and cause the problem of bouncing, particularly during of the pulling heavy loads by tractors. This produces a traction variation effect, called "power hop," that is not only uncomfortable for the operator, but also causes a major loss in the traction efficiency of the tractors. In order to overcome this problem, the front axle suspension was used for tractors. This suspension provides a stable contact between the front tires and ground that leads to a significant improvement in the traction and steering capability of tractors. Because of this advantage, front axle suspension has become a common option in 4WD tractors now. In addition, the front wheels are the navigating wheels. They take the major steering and brake loads of a tractor. Front suspension by keeping front tires in firm contact with the ground, allows better steering control and brake efficiency. This promotes the handling capability and increases consequently the travel speed of a tractor.

However, influence of the front suspension on ride comfort of tractors is not notable as much as the influence of this system on the handling of tractors.

(v) Full Suspension

Higher travel speed is taken into consideration for the modern tractor design (Fig. 13.4). This led to try for development of high tractor speeds, which are able to cover the transportation needs of agricultural applications (Goehlich, 1984). As mentioned above introduction of the front suspensions in tractors provided a major benefit regarding the high travel speed. However, front axle suspensions can be sufficient just to reach to a limited maximum speed. In order to achieve a higher speed, the full suspension is needed for tractors. A full suspension tractor is a tractor equipped with both rear and front axle suspensions. These tractors can provide improvement on both driving behaviour and ride comfort, promising the possibility for the rise in the driving speed.

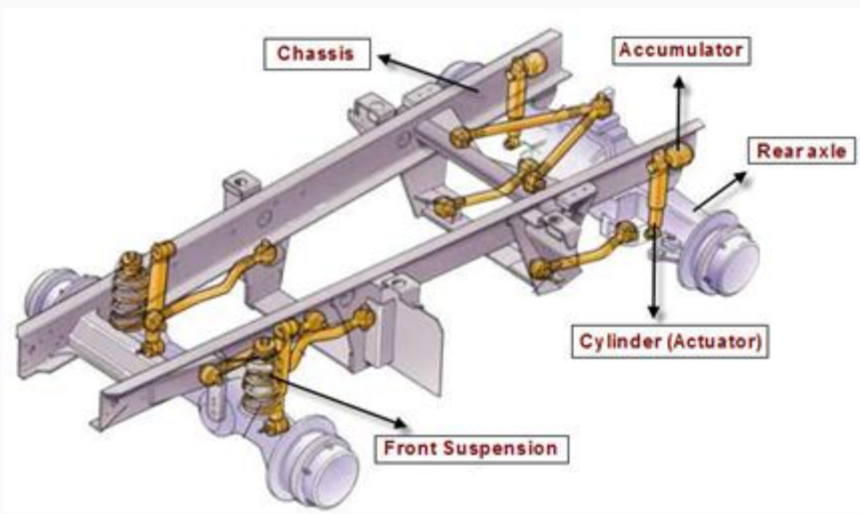


Fig. 13.4: Full frame construction of fully suspension "JCB-FASTRAC" tractor (CourtesyFASTRAC, 2013).

Tractors with only front suspensions cannot present a perfect dynamic characteristic. The front axle suspension affects negatively the vibration behaviour of the unsuspended rear axle, which keeps more than half of the load of the tractor, because by using front axle, rotation axle of the pitch body oscillation shifts to the rear axle. This increases the bounce of the rear wheels and decreases consequently the tires contact to the road surface. On the other hand, the front suspensions have significant effects only on the pitch and longitudinal vibration of the tractors, whereas the rear suspension influences the vibrations in most of the directions, particularly in the important vertical direction. After all, using the rear axle suspension besides the front suspensions can end these problems by creating an essential contribution in vibration isolation at both the rear and front axles. In this way, a full suspension system provides both safe driving and good ride comfort for the tractors. Despite of the advantages of the full suspension tractors, adding the rear suspensions to the conventional tractors is not as simple as the front suspensions. This is originated from the typical structure of the conventional or standard tractors, which are about 80 % of the whole agricultural tractors (Kaplick C., 1995). These tractors have a similar construction and called block construction. These tractors have a block construction, instead of the chassis construction. This construction is formed by connecting the three blocks of engine, transmission, and rear axle unit. Since primary types of these tractors have just rear drive wheels, in order to achieve optimal traction, at least 60% of their weight stands on the rear axle, and the rear wheels are selected bigger and heavier than the front wheels.

In the way of modifying the block-type construction of the standard tractors, finally, the tractors with full frame-type construction were presented. These tractors, similar to automobiles have a chassis that all the components of a tractor such as motor, transmission, cabin, and axles are installed on it. These tractors are four wheels drive with the usually same size of the rear and front wheels. Weight of the tractor is distributed on the wheels almost equally, causing optimal traction. Position of the driver seat and cabin is shifted from the rear part of the tractors to the mid-point of them between two axles. This leads to provide better ride comfort, even if the tractor is equipped just with front axle suspension. As an individual characteristic of the full frame tractors, the rear axle is separated from the chassis, and it is connected to the transmission via a universal shaft. With this construction, these tractors can be equipped simply with the rear axle suspensions. Therefore, along with presenting the full frame tractors, the idea of the full suspension tractors gets more practicable.

Summary of all these suspension systems used for tractor are mentioned in Table 13.1

Table 13.1: The capability of different suspension systems used for agricultural Tractors(Shahriar Sarami, 2009)

Suspension	Influence on		
	Ride comfort	Handling	Expenditure
Seat	Middle	slight	Low
Cabin	High	low	Middle
Hitch	Low-middle	Low-high	Low
Front axle	Low	high	Middle
Full Axle	High	High	High

Module 6. Design and analysis of tractor hitch system geometry

Lesson 14. Design of various components of three point hitch systems.

The tractor hitch system is that essential element of the tractor which binds the prime mover and the implement into a single working unit. The tractor or the implement will not perform alone but must work together like two wheels of a cart. The word hitch is defined as a single articulated point or combination of articulated points and links through which the tractor delivers tractive effort in the form of full or push to counteract a draft force of an implement or draft producing body. And the hitch point (virtual or real) is the point on the tractor (as integral part or otherwise) through which the "line of push" must pass.

In the beginning of traction engine development, the prime movers and implements (mostly gang plows) were one integral unit. Later as the traction engine prime movers (tractors) became more popular, tractor and implements were made separate units. This was the point of introduction of hitch system in tractors and the hitch was a single-point hitch. The depth control for the single point hitch was internal to the implement. In late 1930's Ferguson, an Englishman developed a hitch system wherein the implement could be integrally mounted to the tractor. The hitch system was called a "three point hitch". The linkage was designed with a sensing system that could sense and control implement draft. The hitch system became so popular that now every tractor models has it.

1. Design Concept

The design of a machine system (hitch system) must be carried out in five stages. First, the purpose/functions of the system must be considered. Second, necessary motions of components of the system must be studied. Third, some devices must be selected which will produce the required motions. Fourth, the forces acting on the members must be analyzed and overload factors must be considered. Finally, a choice of materials must be made and the parts properly proportioned to withstand the maximum forces determined. In hitch systems, it is very important to understand the purpose/ functions in order to relate geometrical proportions as well as loads imposed for structural requirements. Effective designing, then entails disciplined methodology in the treatment and analysis of the information.

2. Hitch System Components

Three point hitch system is the only hitch system now available for all implements except trailers and combines. Thus, information will be restricted to three point hitch system. Three types of hitching possible with three point hitch system are free float (towed), semi-mounting, and fully mounting. The components of a three point hitch system and their functions along with numbers required are given in Table 14.1.

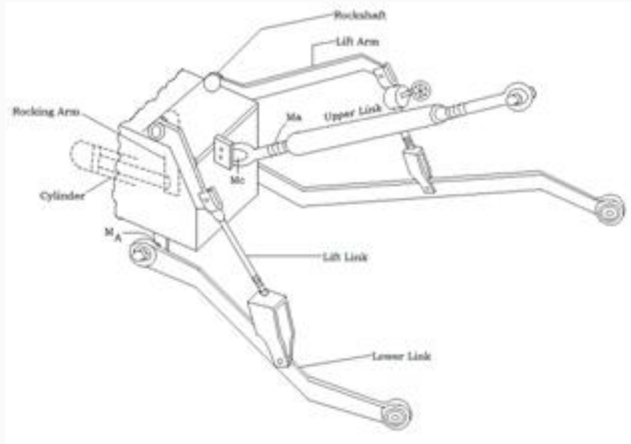


Fig. 14.1: Major components of a hitch system

Table 14.1: Major functions of various components of a hitch system

Component		No. required	Functions
1.	Upper Link	1	Basic component of hitch system. Connects implement to tractor. Transfers hitching forces of tractor to implement and of implement to tractor
2.	Lower Link	2	-do-
3.	Lateral Limiters	2	Limits the travel of implement in horizontal plane thereby inhibits the horizontal sway.
4.	Lift Link	2	Lifts the implements and supports the implement in transport position. It provides lateral stability and lateral levelling to the implement.
5.	Lift Arm	2	It provides lateral stability. It lifts implement by giving needed force and motion to lift link and supports implement in transport position.
6.	Rocking Arm	1	It connects cylinder and rockshaft. It converts linear motion of cylinder into rotation.
7.	Rockshaft	1	It transmits the rotating motion of rocking arm to lift arm.
8.	Cylinder	1	It is source of power for lifting implement. It gives linear motion to rocking arm.

3. Design Requirements

There are a number of features which are required to be provided in a good mounted hitch so that the hitch system is able to meet all functional requirements. The following requirements of hitch system are self-explanatory:

1) Depth control of implement

2) Load transfer to drive wheels of two wheel drive tractor

3) Lateral sway and center-ability

4) Inter-changeability of implement and tractor

5) Fore and aft levelling of implement

6) Lateral levelling of implement

7) Limiting sway of implement

8) Locking hitch laterally when in transport or using PTO with implement or semi-mounted implement

9) Quick and easy attachment and detachment of implement

10) Adequate lifting capacity of the hydraulic system

11) Independent vertical float of each lower link hitch point

12) Pitching the implement as it is raised

13) Simple and easy adjustment of the hitch

4. Important Features

(i) Depth Control

A good mounted hitch system should be able to provide adequate depth control of the implement. The word “adequate” is used because there are two philosophies on depth control. One; the accurate control of a preset tool depth is necessary at all times regardless of implement draft (position control) and, two: the tool depth vary in different soil-draft-load conditions to maintain constant draft load on tractor (draft control). The depth control in the later philosophy is achieved by sensing a force, which is proportional to the implement draft, by a variety of systems for upper or lower links. In either case, the basic function that must be accomplished by the sensing mechanism is to create a movement which is directly proportional to draft. The motion of sensing mechanism is then used by hydraulic system in such a way that implement is lifted if the draft is more than preset draft and implement is lowered if the draft is less than the preset draft. The sensing mechanism for depth is many a times a cam on rock-shaft. The motion of rock-shaft is then used by hydraulic system in such a way that the implement is lifted if the depth is more than the preset depth and the implement is lowered if the depth is less than the preset depth. Regulation of the sensing mechanism is another important aspect which requires attention of the designers. It is given by the following formulae:

ii. Draft Control

$$\text{Regulation (\%)} = 100\,\frac{(\text{AFSR} - \text{AFSL})}{\text{AFSR}} \quad \dots (14.1)$$

Where: AFSR=Average force to start hitch to raise

AFSL=Average force to start hitch to lower

iii. Position Control

$$\text{Regulation (\%)} = 100\,\frac{(\text{ADSR} - \text{ADSL})}{\text{ADSR}} \quad \dots (14.2)$$

Where:

ADSR=Average displacement of sensor from zero depth position to start hitch to raise

ADSL=Average displacement of sensor from zero depth position to start hitch to lower

Poor regulation occurs due to friction, tolerances and clearances which must be reduced to a bare minimum. A typical regulation curve is shown in Fig.14.2.

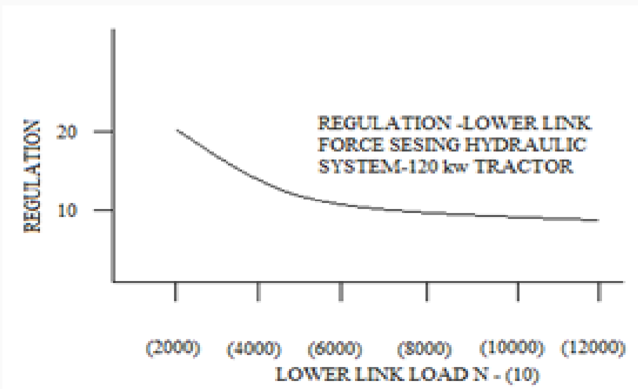


Fig. 14.2: Regulation curve for draft control by sensing force in the lower link

5. Dynamic Load Transfer

A good mounted implement should produce maximum possible amount of load transfer to tractor drive wheels. The free body diagram of tractor is shown in Fig. 14.3. The load transfer moment and dynamic load transfer is calculated as given below:

$$\text{Load Transfer Moment} = \text{PV.Cos B.Y} + \text{RRS.Z} \quad \dots (14.3)$$

Where: PV = Pull in the vertical plane (resultant of L and V)

B = Angle of pull in vertical

R_{RS} = Reaction on rear wheel under static condition and Y and Z are as shown in Fig. 14.3.

For rear wheel drive tractor, the dynamic load transfer (DLT) on to drive wheels is given below:

$$DLT = \frac{\text{Load Transfer Moment}}{\text{Wheelbase} - Z} = \frac{PV.\cos B.Y + RR_S}{\text{Wheelbase} - Z} \qquad \ldots \qquad (14.4)$$

Total load increment on drive wheels is sum of dynamic load transfer and vertical component of the pull.

$$\text{Total Load Transfer (TLT)} = PV.\sin B + \frac{PV.\cos B.Y + R_{RS}}{\text{Wheelbase} - Z} \qquad \ldots \qquad (14.5)$$

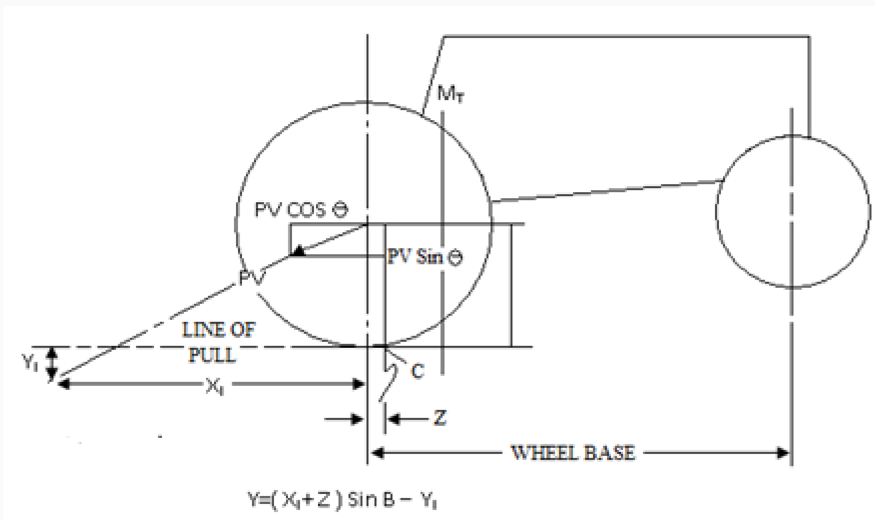


Fig. 14.3: Free body diagram for dynamic load transfer

Thus total load transfer is function of the magnitude of PV, the distance Y, angle of pull B and shift in contact point Z. Increasing Z and PV increases total dynamic load transfer. Increasing wheelbase reduces the total dynamic load transfer. The distance Y is given by the following equation:

$$Y = (X_I + Z)\sin\beta - Y_I \qquad \ldots \qquad (14.6)$$

Where:

X_I = Horizontal distance (from rear axle) of the point of intersection of the result out of useful soil forces, parasitic soil forces and weight of implement with parasitic soil forces.

Y_I = Vertical distance (below the contact point of rear wheels) of intersection of the resultant of useful soil forces, parasitic soil forces and weight of implement with parasitic soil forces.

The parasitic soil forces are zero for mounted implement and maximum for pull type implement. Hence, for mounted implements, X_I and Y_I are constant.

The value of B lies between 0 and 90 degrees. It can be easily proved that the TLT is positively increasing function w.r.t. angle B by substituting the value of Y from equation 14.6 into equation 14.5. The first derivative of TLT w.r.t. B is always positive if B lies between 0 and90 degrees. Hence hitch geometry in vertical plane affects dynamic weight transfer.

6. Center-ability (Lateral stiffness)

The term center-ability refers to the tendency of the hitch system to recenter itself when the hitch system becomes decentered (Fig.14.4). The center-ability is affected by the hitch geometry in the horizontal plane. The center-ability is provided by center-ability force of an implement. This force can be readily obtained from the measurement of a restoring force as the implement is forced sideways. The center-ability is also referred to the force tending to recenter a laterally displaced hitch. The center-ability force of a three point hitch can be increased by making several changes in the horizontal geometry of a hitch system as listed below:

1. Increase convergence of the Lower Link: This tends to shorten the effective beam length of the implement (which is the distance to the instant center T Fig. 14.4). The shorter beam length increases the lateral of the pull of lower link which provides the main component of the centering force on the tool.

2. Lengthen the Upper Link: This tends to decrease the decentering moment caused by the upper link about the instant center T. A longer link will decrease the rate at which the off set of upper link force from instant center T (i.e. V) is increasing as decentering occurs.

3. Shorten the lower links: This tends to increase the rate at which instant center T will move laterally as the hitch is decentered.

4. Shorten the lift link: As the hitch is decentered, the lift links become angled in the same direction. Hence, the lift link force in the lower link tends to recenter the hitch. Shorter are the lift links, more will be their tilt, thereby increasing the tendency to recenter the hitch.

5. Increase Leverage of Lift Links w.r.t. Lower Link Pivot Point: This means lift link should be located rearward on the lower links. This will increase the effect on the implement of the force created by the lift links force tending to pull the hitch back to center.

6. Decrease the Line of Pull of Free Floating Condition of the Hitch: This will increase the load in the lift links. The effect of the lateral component of the lift link force is increased thereby increasing center-ability.

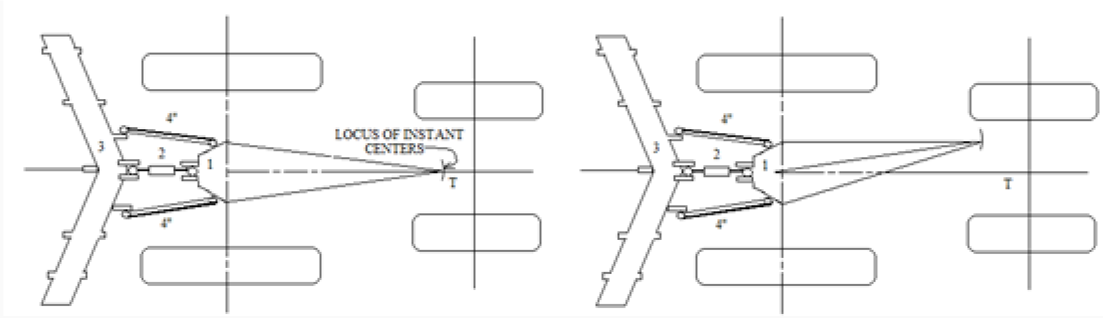


Fig. 14.4: Center-ability of the hitch system

7. Trailing Characteristics

The geometry of the hitch system in the horizontal plane influence the trailing characteristics as shown in Fig. 14.5. The trailing characteristics of a mounted implement should be such that a reasonably uniform width of cut is maintained when operating around a curve without adversely affecting the tractor steering. If the rear-mounted implement is not permitted any lateral movement w.r.t. tractor, the implement will cut to outside when operating on a curve and steering response may be poor because of the side forces introduced by the implement. These effects are particularly objectionable with a directional implement such as plow. A laterally swinging hitch gives easier steering, but the implement under-cuts on a corner A non-directional tool tends to move along the line of pull when the tractor is on a curve. The linkage adjusting itself so that BH is perpendicular to the radius drawn through H. The implement appears to be pulled from a point within small area A_1. The directional tools, however, tend to go in the direction they are pointed, rather than in the direction of pull. In this case, the implement is pulled from virtual hitch point in the zone A_2 and implement adjust itself so that A_2H is perpendicular to the radius drawn from H. Since A_2 is further forward than A_1, directional tool cuts the corner even more than an implement free to move in the direction of pull. For ideal trailing of any implement around a curve, the horizontal hitch point should be on the tractor centerline, equal distant from the center of resistance of the implement (H) and center of pull of the tractor (D).

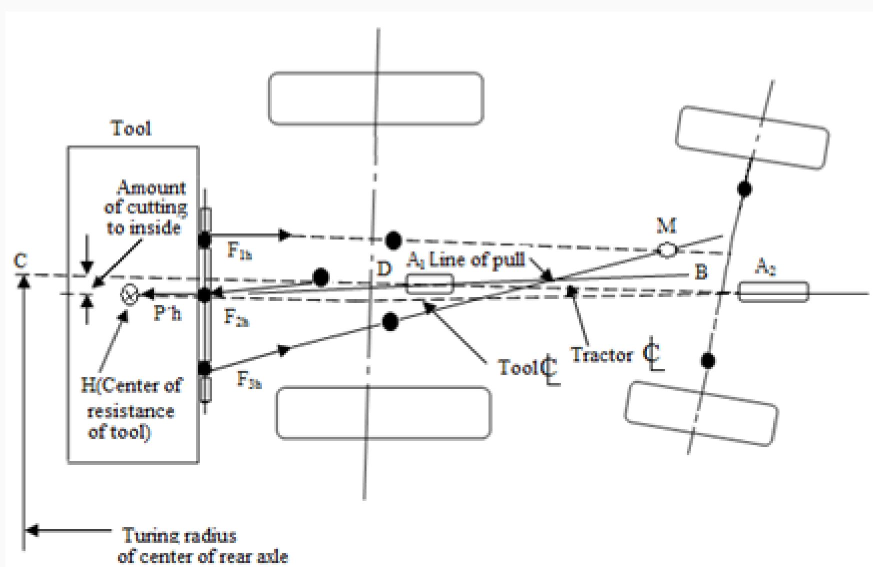


Fig. 14.5: Trailing characteristics during operation around a curve

8. Hitch Lift Capacity and Stability

A good mounted hitch should be able to lift and transport the size of implement matching with tractor power is one of the design requirements. The upper limit of the lift capacity of a given tractor is related to the tractor's front end stability moment and minimum reaction required at the front end for proper and effective steering. The lift capacity depends on design geometry of hitch system and hydraulic pressure available also. The lifting pressure requirements vary as the implement is lifted since the hitch geometry changes. It is desirable to have the lowest lifting pressure at the point the implement comes out of the ground where the greatest force is required. The instantaneous center (IC) must always be considered when evaluating lift pressure (Fig.14.6). The force in the lift link is calculated as given below:

$$LL = M_I g\, E/D \qquad \ldots \qquad (14.7)$$

Where: LL =Lift link force

M_I =mass of implement

E =perpendicular distance of implement weight from IC

D =perpendicular distance of LL force from IC

The IC will move forward as implement is lowered which changes implement moment and LL.

Transport stability is the controlling factor for the maximum implement moment that can be safely considered. The static implement and stability moments are (Fig. 14.6).

$$IMS = MI\, g\, Q'' \qquad \ldots \qquad (14.8)$$

$$SMS = R_{fs} \,.\, (\text{wheelbase}) \qquad \ldots \qquad (14.9)$$

Where:

IM_S = static implement moment

SM_S = static stability moment

R_f = static reaction on the front wheel of a tractor without implement

The dynamic implement and stability moments are:

$$IM_D = M_I\, g\, (Q'' + Z) = M_I\, g\, Q' \qquad \ldots \qquad (14.10)$$

$$IM_D = R_{fs}\,(\text{wheelbase} - Z) = R_{fs}\,(\text{wheelbase} + Q'' - Q') \qquad \ldots \qquad (14.11)$$

Tractor implement system is stable so long as SM_D IM_D and the difference (SM_D - IM_D) will appear in the form of front wheel reaction. Then, from steering ability

$$\frac{SM_D - IM_D}{\text{wheelbase} - Z} > \text{Minimum front wheel reaction} \qquad \ldots(14.12)$$

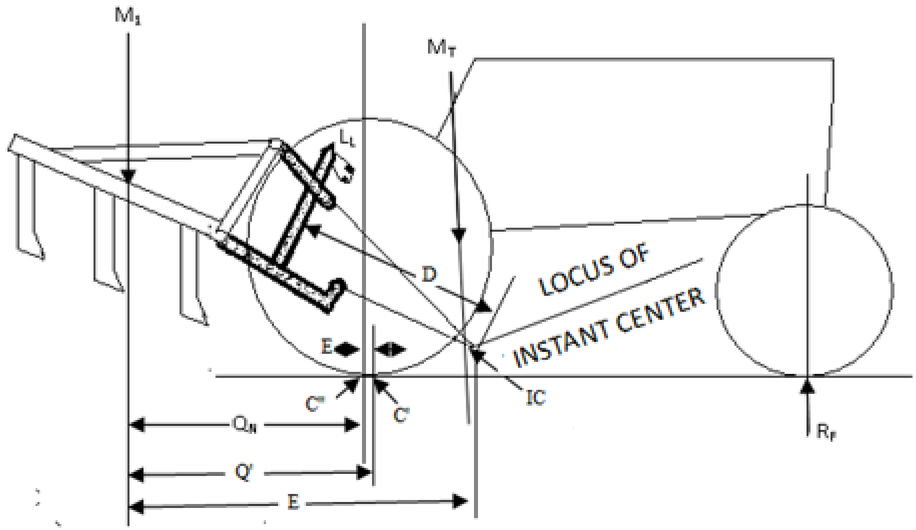


Fig. 14.6: Hitch lift capacity and implement moment

Lesson 15. Kinematic and force Analysis of hitch system geometry

1. Introduction

The hitch system geometry and types of motions needed for various components are decided based on functional requirements, necessary motions, depth control, dynamic load transfer, center-ability, trailing characteristics, lift capacity and stability. The hit and miss method is used to arrive at hitch system geometry both in horizontal plane and vertical plan.

2. Kinematic Analysis

This analysis is done to study motions of various components of the hitch system. Actual dimension of all components and their relative angles are actually measured to position them in space (to the scale). The kinematic analysis is then done in vertical-longitudinal, horizontal, and vertical lateral planes as discussed below:

(i) Vertical- Longitudinal Plane

All dual links are superimposed and hydraulic system is adequately modified to represent actual controls. The schematic of an actual hitch system with draft control (by sending it from the lower link) is shown in Fig. 15.1. In all, there are ten components, i.e. (1) tractor body, (2) upper link, (3) implement, (4) lower link, (5) loading sensing torque arm bellcrank, (6) lift link, (7) lift arm, (8) piston rod, (9) piston and (10) lever replacing hydraulic system. The total number of IC of the hitch are:

No. of links (N) =10

No. of IC =[N.(N-1)/2]/2 =45

No. of joints (G) =13

Degrees of Freedom =3(N-1) -2G =1

Thus, linkage is constrained with a definite rate relationship between all links since degree of freedom is one. This means if one link moves, all links move with it. The virtual hitch point will always be along the line of upper link (link 2). It is at the intersection of upper and lower links for free float state and at the intersection of line of PV and upper link for restrained state. The velocity and acceleration diagrams can be constructed to find inertial forces and torque acting on each link. The system can also be analyzed with regard to swap of each link as cylinder moves from minimum to maximum position.

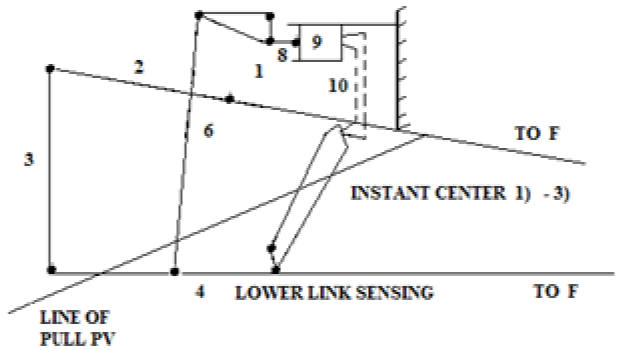


Fig. 15.1: Schematic of hitch system in vertical longitudinal plane

(ii) Horizontal Plane

In horizontal plane, the hitch system is considered to be a four bar linkage, i.e. (1) tractor body, (2) upper link, (3) lower link and (4) implement. It gives a total of six IC. The degree of freedom is the same as for vertical – longitudinal plane. The direction of motion of any point in horizontal plane is perpendicular to the line joining the IC for the link on which the point lies. Similarly, velocity and acceleration diagram of the four bar linkage can be analyzed to find inertial forces and torque acting on the links.

(iii) Vertical Lateral Plane

Most implement that are not much wider than tractor are operated with rotational restraint in this plane. Thus, hitch is rigid with no degree of freedom in the vertical lateral plane. The implements which are wide relative to tractor are not used with restraint in this plane. The lift link restraint is made free to telescope. The schematic in the above case is shown in Fig. 15.2. The instantaneous center or virtual hitch point F is above surface. The implement will rotate relative to the tractor about point F. Since the IC is above ground, the implement bottoms will have to shift laterally in the soil during rotation. The amount of lateral movement U of the implement bottom depends on the distance W, the bottom is below F for a given rotational angle. Thus, U can be made small if W is small. Hence, moving F lower is desirable but it should not be done without considering its effect in other planes.

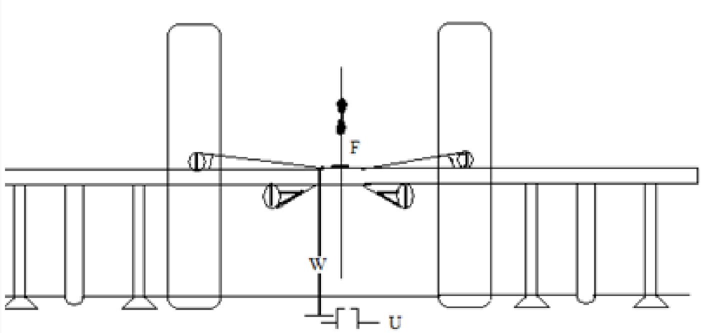


Fig. 15.2: Schematic of hitch system in vertical lateral plane

3. Force Analysis

The forces on the hitch system are a system of non-coplanar, non-concurrent and non-parallel forces. To have equilibrium, the following conditions must be considered:

$$\sum F_V = 0 \qquad \sum M_V = 0$$

$$\sum F_L = 0 \qquad \sum M_L = 0$$

$$\sum F_H = 0 \qquad \sum M_H = 0$$

This means the forces in the vertical, lateral and horizontal directions must be in balance and moments in vertical-lateral (V-H), vertical-longitudinal (L-V) and horizontal (L-H) planes must be in balance. Equations can be developed for complete force analysis in three planes for better results. However, graphical technique can also be applied to find forces at various points so as to draw free body diagram of each link. Then, each link is analyzed with regard to type of loading, i.e., tension/compression, torsion, bending and shear. The cross-section of each component is then determined by using machine design principles. Table 15.1 gives type of load acting on each link.

4. Transport Shock forces

Rear mounted implements impose a cantilever type of load through the hitch system. The combination is rigid to such a degree that implements transported over rough terrain will be exposed to high shock loads due to some looseness in the linkage. The sensing system is generally not cushioned for protection. The shock loads can be reduced by having a pressure relief value in the hydraulic cylinder. The shock factors with a proper relief valve can be still as high as six for upper link and five for lift link for 60 kW tractor for a heavy and long implement. However, in case of close coupled tool mounted on a 60 kW tractor, the shock factor can be as high as eight in upper link and four in lift link.

S. No.	Link	Types of load (s)
1.	Upper Link	Axial
2.	Lower Link	Axial, Bending and Shear
3.	Lateral Limiters	Axial
4.	Lift Link	Axial
5.	Lift Arm	Bending an Shear
6.	Rocking Arm	Bending an Shear
7.	Rockshaft	Torsion, Bending and Shear
8.	Cylinder	Axial
9.	Pins	Bending an Shear

Table 15.1: Types of loads on various links of the hitch system

Module 7. Design of a tractor hydraulic system

Lesson 16. Study of tractor hydraulic systems and controls

1. Introduction

Hydraulic System of a Tractor is provided to enable the tractor to raise or lower heavy implements as per requirements and to control implement depth during field operations with minimum efforts.

2. Fundamentals and components for fluid power transmission

Fluid power is based on the principle of Pascal's law which states that pressure applied to a fluid is transmitted equally in all direction. Hydraulic Fluid is assumed as incompressible. The fluid pressure controls the force of output. (P= F/A= force/area). The fluid flow controls the speed of output. The basic components of fluid power transmission are as follows:

1. Reservoir
2. Pump
3. Motor
4. Cylinder
5. Valves
6. Fittings and tips
7. Lines and Hoses
8. Hydraulic oil

i. Reservoir

In the modern tractors transmission case also serves as hydraulic reservoir. The reservoir is vented to atmosphere to accommodate changing oil levels. The air vent is provided with a filter to prevent dirt/dust entry into the reservoir. The hydraulic reservoir stores non-pressurized hydraulic fluid, typically hydraulic oil. This fluid is the lifeblood of the hydraulic system. The hydraulic oil also travels through a filter that collects impurities. The metal walls of the reservoir cool the fluid by allowing heat to escape. The reduced pressure in the reservoir also allows trapped or dissolved air to escape from the fluid. Generally, the size of the reservoir should be 3 times system capacity, or 1.5 times the pump GPM rating. The reservoir must also have adequate surface area to allow heat to disperse.

ii. Pump

Hydraulic pump transfer the fluid from the reservoir to the hydraulic system. This transfer raises the energy level of the fluid by increasing its pressure. One-stage, or single-stage, pump has only one maximum pressure and one flow rate. Single-stage pumps are typically attached to the crankshaft or PTO shaft on a farm tractor. Applications for a single stage pump include back hoes and manure loaders. A two-stage pump will first produce high volumes of fluid, moving the cylinder in and out quickly. When the pump receives resistance, a second set of gears will produce high pressures for lifting or splitting. However, the volume of fluid will drop considerably during this stage. This mechanism has many practical applications. For example, in log splitters equipped with a two-stage pump, in stage one, the rod travels faster up the cradle until the rod starts to split the wood. At that point, the speed slows but the force increases.

iii. Motor

The motor provides the power source for the pump. The high-pressure fluid acts upon the rod and piston within a hydraulic cylinder. Each stroke of the cylinder converts the fluid power (pressure) into work (mechanical force). The reservoir oil level falls while the rod and piston are extending, when the rod and piston retract, the fluid returns to the reservoir.

iv. Cylinder

In a single-acting cylinder, pressure is applied to one side of the piston. Therefore, work occurs in one direction only. The cylinder returns to its original position under the weight of the load (or by means of a manual lever). In a double-acting cylinder, pressure can be applied to either side of the piston. This allows work to occur in either direction. Tie-rod cylinders are held together by four rods. They cost less than welded cylinders and are easy to repair. On a welded cylinder, the fixed end is welded in place, adding strength and durability for high-pressure applications such as log splitters. If cylinders must compress air bubbles, the efficiency of the system is reduced.

v. Valves

There are two types of valves, directional control valves and pressure relief valves. Directional control valves manage the flow path of the fluid in the system. Pressure relief valves protect the system plumbing and components against pressure overloads. They also limit the output force exerted by rotary motors and cylinders. These valves open whenever the pressure goes beyond the set value, allowing oil to flow back into the reservoir. The fluid travels from one component to the next within a hydraulic system through a hydraulic hose.

Directional control or flow control valves used to control fluid flow in the system (speed of actuators). Check valve allows fluid flow in one direction, no flow in the other direction. Needle valve- acts like variable orifice to restrict flow. Pressure compensated valves-automatically adjust the fluid flow to compensate for pressure variations in the system. Ball valves and Spool valves are used for controlling the flow of fluid.

Pressure control valves are used to control pressure in the system. These are provided to protect the components within hydraulic circuit from damage from excessive pressure. These are also called as safety relief valves. Relief valve is essential for safety as it sets maximum pressure in the system. The most basic type is a poppet held against a cone seat by spring force. Pilot operated pressure regulator valve provides fast action to respond to flow changes. Other common types of valves are: Pressure reducing, sequence, unloading valves etc.

vi. Fittings and Tips

NPTF and JIC fittings both prevent leakage on the ports of hydraulic components. However, NPTF or “dry seal” taper pipe threads do this by using the resistance of the male to female thread taper. JIC or “straight” threads use an O-ring. JIC and NPTF fittings cannot be used interchangeably. However, special adapters can be used to convert from one type of fitting to another. Tractor Supply’s product catalogue for a complete listing of fittings and adaptors can be consulted.

There are three types of I.S.O. tips. All three are interchangeable with each other and universal, except as noted below. The I.S.O. tip with ball was the first standard, universal tip in the marketplace. It seals with a metal-to-metal seat. This seal tends to “weep” when disconnected, but it is still the most widely used tip in the industry. The I.S.O. tip with poppet has the same basic design. However, this tip seals with an O-ring that presses together with the poppet to form a tight, 360-degree seal. This “soft seal” reduces fluid loss. In the future, this will be the choice of OEM manufacturers. The I.S.O. tip with pressure relief poppet has a secondary poppet in the tip. When pressure builds up in the hose, this secondary poppet allows pressure to be displaced to the coupler. The tip can then connect without pressure. Certain OEM designs that predate the introduction of I.S.O. tips require the use of OEM old-style tips. These tips and couplers are unique to each manufacturer, and cannot be interchanged. Specific conversion adapters are required for these machines to accept I.S.O. tips.

Galvanized and brass fittings do not meet the psi ratings of hydraulic systems. The metal tends to flake. This flaking can contaminate the oil and damage the hydraulic pump.

Teflon tape may flake. This flaking can contaminate the oil and damage the pump. Warranties are typically voided by using Teflon tape. Use a hydraulic-rated liquid Teflon sealant instead.

vii. Lines and Hoses:

The various components of the brake hydraulic system are connected through lines and hoses. Lines are made of steel and hoses are made of braided rubber. Lines connect the stationary parts of the hydraulic system and hoses connect the parts which move in relation to each other. The size of the pipe, tubing, or hose in a hydraulic system is very important. If the hose is too small, the oil flows at a high rate of speed. This generates heat, which means that the fluid is losing power. If the hose is too large, the time and cost of installation may be too high. A 2-wire hose is recommended for applications above 126.55 kg/cm^2 (1800 psi). However, specifications vary by manufacturer, so read product packaging for specific application suggestions and psi ratings.

viii. Hydraulic Oil

Hydraulic oil is petroleum oil refined for use in hydraulic systems. This oil typically has additives to prevent rust and minimize foaming. The term “hydraulic fluid” is often used interchangeably to mean oil or any other fluid within a hydraulic system. Using the incorrect fluid can harm seals and cause the system to break down. Oil contaminants can increase operating temperatures and damage components. Change the oil and filter regularly to prolong the life of the system. Viscosity is most important property of hydraulic fluid. Generally, fluid viscosities are recommended between 12 to 48 MPa by the manufactures at operating temperature of pump. Otherwise, the performance of the pump will be affected considerably. Each tractor manufacturer specifies the hydraulic fluid that will meet requirements of both transmission and hydraulic system. The oil temperature should be kept below 60°C to reduce oxidation of oil. Additives are needed to reduce wear in gear/vane type pumps above 7 MPa operating pressures.

3. Types of Hydraulic Systems:

Two types of hydraulic system are used “open center system” and “closed center system” refer to two methods of reducing the pressure on the pump, which minimizes wear and tear. Hydraulic power is controlled by directional flow valves. Valves provide methods to control one or several flow paths from a single pump with relative ease. These valves regulate the rate of flow that is permitted to operate individual hydraulic actuators. They direct the flow path of fluid in two ways.

Open center system: Open systems were common and were used on most of the earlier tractors. When an open system is in neutral, an open center valve connects all lines directly back to the reservoir, bypassing the pump. The pump is always pumping, allowing a constant flow of oil without building pressure.The valves allow fluid to flow through the center and return to reservoir when the system is in neutral.A constant flow pump is generally used.

The open-centre system was the first type used on farm tractors, and even today it is most commonly used. In this type of system a valve ‘V’ is used to direct the fluid to a cylinder, ‘C’. The line diagram of open loop system is given in Fig. 16.1.

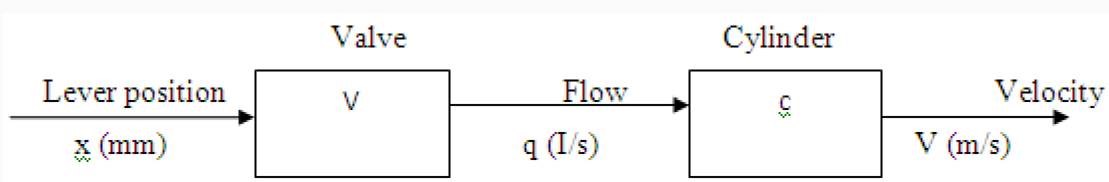


Figure 16.1: Open loop hydraulic control

The transfer function of valve V is the ratio of output ‘q’ (fluid discharge, I/s) to input ‘x’ (control lever displacement, mm) i.e. q/x and the transfer function of cylinder ‘C’ is ratio of output ‘v’ (velocity of piston/s) to output ‘q’ (pump discharge, I/s) i.e. v/q. The overall transfer function of the system can be combined simply by multiplying **V X C** as given below:

$$\text{Transfer Function (O/I)} = \frac{q}{x} \times \frac{v}{q} = \frac{v}{x} \qquad \text{... (16.1)}$$

In this type of system the hydraulic cylinder may have a stroke control device that returns the fluid to sump when cylinder reaches the end of stroke. At the end of stroke pressure builds up, causing the valve to return to neutral position. In most cases the operator is quite capable of being a part of control system by sensing (seeing) when the cylinder has reached the desired position, at which point the operator returns the valve control lever to neutral position.

Closed center system: Closed systems are common on modern farm equipment, including most of tractor models. When a closed system is in neutral, the closed center valve blocks the flow of oil from the pump. The oil travels instead to an accumulator, which stores the oil under pressure. The valves allow no fluid to flow through the center when the system is in neutral. A variable flow pump is generally used, which stops pumping when the valve is closed.

In some tractors closed- centre systems are used which employs piston type pumps. Such a system may have a feedback loop. In correctly designed system, when valve 'V' and cylinder 'C' are into closed loop system, the operator can forget about the control. F is now in the feedback loop. The velocity, 'V' of the cylinder can now be "fed back" to the valve 'V' by means of single ling device, F, through the summing junction so as to correct the position of the valve. This system provides a rapid response to the loads. The line diagram of closed loop system is given in Fig. 16.2

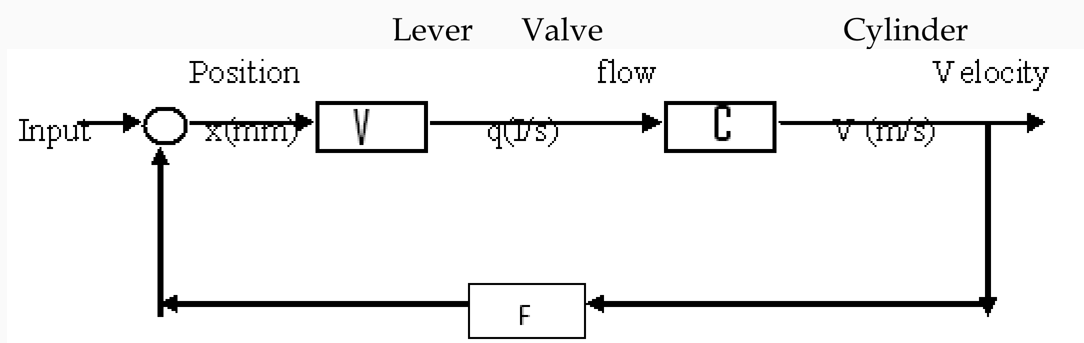


Figure 16.2. Closed loop hydraulic control

Overall Transfer Function (O/I): Overall transfer function of closed loop is given by

$$\frac{O}{I} = \frac{v \times c}{(1+VCF)} \qquad \text{... (16.2)}$$

Where, V= valve in which the input is the motion of spool (x) and output is fluid flow rate (q). The output/input ratio of valve is also known as flow gain, L/s/mm.

C = dynamic behavior i.e. Velocity of cylinder (v) of the system (Cylinder + hydraulic oil + masses attached to the cylinder).

F = feedback loop force (draft sensing force), which might be either a mechanical linkage attached to an "error bar" or pressure line to sense the load on, or position of the output of the cylinder.

4. Hydraulic control in tractor

i. Automatic hydraulic control

This is also known as an automatic control or feed back system. This compares the output signals to the input signals and uses the difference to change the output. These can be open loop control system or closed loop control system. The main difference between the two systems is that the open centre system maintains a constant flow of oil, and the closed system maintains a constant pressure when not in use.

ii. Automatic position control system

Automatic position control system is normally associated with a three point hitch system. It provides automatic control of an attached implement and allows the operator to pre select and to position the implement as controlled by the hand control lever. The relative position of hand lever and hydraulic cylinder are always identical. Within the limit of the valve controlling the maximum pressure, the hydraulic cylinder will automatically move the implement to its predetermined position and maintain it there, regardless of any leakage in the system. This system is not used with a remote cylinder.

iii. Automatic draft control system

Automatic draft control system will automatically raise or lower the implement as the draft of attached implement increases or decreases. The position of hand control lever, in effect, establishes the draft to be maintained.

The sensing device which actuates the hydraulic system to lower or raise the hitch system is located on either the lower links or upper link, depending upon the size of tractor. The load sensing system senses the load and sends a message to the pump causing it to provide just enough pressure to overcome the load. Under no-load condition, it works under less pressure. Regulation of draft sensing mechanism is given in Fig. 16.3 and it is calculated as given below:

$$\text{Regulation (\%)} = 100\,(F_r - F_l)/F_r \quad \text{...(16.3)}$$

Where,

F_r = Average force to start hitch to raise

F_1 = Average force to start hitch to lower

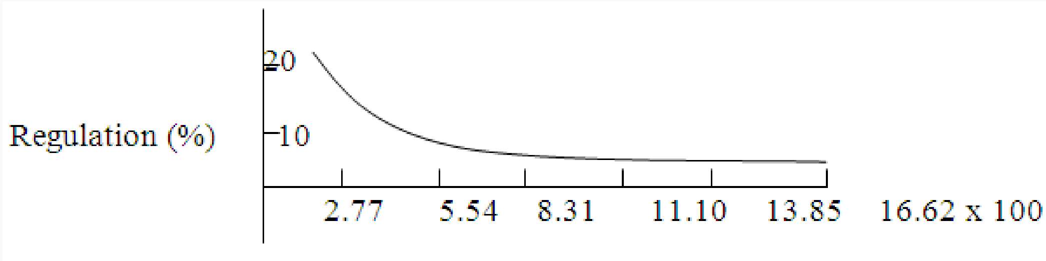


Figure 16.3. Regulation curve for draft control by sensing force in the lower link

Maintaining desired fluid pressure in the system requires power from the engine, just as power is required to maintain constant flow in open-centre system. The main advantage of load sensing system is reduction in power consumption by the pump. However, this system requires an extra line to sense the load and relay message to the pump which adds to the system cost.

Lesson 17. Hydraulic system design considerations

The most susceptible components in any hydraulic system are the pump, motors and cylinders. In addition, some systems that have proportional or servo valves may also be highly sensitive, especially to fluid contaminants.

1. Hydraulic Pumps:

The pump is a mechanical device that converts energy from the prime mover (electric motor or engine) to fluid power energy. Pumps are rated by pressure and flow. Pressure is typically measured in psi or bar. Flow is measured in liters per minute (l/m) and is a result of volumetric displacement x rpm. Currently there are three types of hydraulic pumps used; gear pumps, axial piston pumps and vane pumps. All are positive displacement pumps and each has its own limitations and advantages.

(i) Gear Pumps

When new; most gear pumps have a practical efficiency of 85% to 90% and will decrease over time. New piston and vane pumps' efficiencies are somewhere around 90 to 95% and too will lose efficiency as the pump wears. Industrial standards for pump lifetimes are between 8000 to 10000 hours of operation. All pumps work by mechanically squeezing the fluid between mating surfaces. In gear pumps it is the meshing of the gears pushing against the pump housing wall, in piston pumps it is the piston pushing in the piston silo against a valve plate, and in vane pumps it is the vanes pushing against the pump housing wall. In all cases the pumps are dependent on maintaining lubricity between mating surfaces to prevent material on material wear. All three types of pumps are sensitive to fluid contamination, some more than others. Gear pumps are the least sensitive while piston and vane pumps are the most sensitive. All pumps are also sensitive to fluid cavitations or air bubbles that form in the fluid. These bubbles when compressed will explode creating pitting and pockets in the pump material.

Pumps are designed to have a controlled rate of internal leakage to provide lubrication to the rotating parts and to provide pump cooling. As pumps wear over their lifetimes, the ability to produce pressure and flow diminishes along with ever increasing internal leakage. From a practical standpoint, when pump efficiencies start dropping below 80 to 85%, depending on the type, it is time to replace the pump or rebuild it. Petroleum based mineral oils are mostly used as hydraulic oil. Hence, hydraulic pumps have been designed around using mineral oil based fluids.

Gear pumps are the most commonly used hydraulic pumps. They are less mechanically complicated and are cheaper to manufacture. Gear pump housings come in a variety of materials from cast aluminum to 316 L stainless steel. The manufacturer decides on the best combination of materials for the target market. Even though gear pumps are less efficient than piston or vane pumps, the advantage of low cost and contamination robustness make them a good choice for the majority of applications, from mobile to portable to fixed sites. Gear pumps are used in applications that are ≤3000 psi (210 bar). Some gear pumps achieve pressures in excess of 3000 psi but this is the exception rather than the rule.

(ii) Vane pumps:

One great advantage of a vane pump provides is that it runs quieter than either gear pumps or piston pumps. Also, vane pumps exceed gear pumps in pressures up to ≤ 4000 psi. Of the three pump types vane pumps tend to be the most dirt sensitive. For some mobile applications where noise is an application consideration vane pumps are making a resurgence in use.

(iii) Axial piston:

These pumps are capable of routinely achieving continuous running pressures > 5000 psi (345 bar). Some units are now approaching 7500 psi (520 bar). A good share of piston pumps are used as hydrostatic units where the system return flow is fed back into the inlet side of the pump without the use of large hydraulic reservoirs. The higher pressures, speeds and absence of large reservoirs are a weight saving strategy. These systems run at slower speeds and pressures from 1500 to 2000 psi. Piston pumps come in two basic types; fixed displacement and variable displacement. A fixed displacement piston pump is just that. Output flow can only be varied by pump speed whereas in a variable displacement piston pump, the pump volume can be adjusted; thus varying the flow without varying the speed. Variable displacement pumps have a greater number of moving parts making lubrication critical. The ability to adjust pump volume is clearly an energy saving feature and positively affects the pump lifetime. This particular pump is to be used in open system applications.

2. Motors:

Motors are essentially pumps working in reverse. They convert the fluid energy back into mechanical energy. In the case of rotary actuators (motors) the energy is converted to rotational force (torque). Force is a function of pressure and speed is a function of flow. High pressure high torque, high flow high speed. Motors by and large are fixed displacement. Motors are classified into one of four types; Low Speed High Torque (LSHT), High Speed Low Torque (HSLT), Low Speed Low Torque (LSLT), and High Speed High Torque (HSHT). The two most common types are LSHT and HSLT. Just as in pumps there are four common materials; aluminum, cast iron, cast steel and stainless steel. Although pumps are designed as gear, vane, and axial piston; motors also have another type of design, orbital. The orbital motors are exclusively LSHT and are the most popular design of hydraulic motor in use today. Unlike pumps which can be, quite often, placed in more controlled environments, such as an equipment room, motors can and are subjected to whatever the environment offers. The robustness of the motor is critical to resisting the expected environmental conditions. Other than hoses and fittings, rotary and linear actuators are the chief sources of fluid leakage. Thus, not only must motors keep the prevailing environment out, but must keep the hydraulic fluid in. OEM equipment designers carefully select the type of motors to be used not only on the work to be done, but also on the expected operating environmental conditions.

3. Cylinders:

Cylinders are actuators that convert fluid power force into linear mechanical motion. The motion may be pushing, pulling, lifting, or lowering. Although the construction of a cylinder is fairly simple, having only one moving part, other considerations are critical to application suitability. Cylinders are made of a number of materials; plastics and composites, steel, aluminum and stainless steel. Cylinders are either double acting or single acting. Double acting means that fluid can be applied to either side of piston, rod end or tail end. Single acting cylinders are capable of applying fluid force to only one end, usually the tail end, and retract by means of some other force such as gravity or springs. To contain and direct the force sealing is critical at the piston and rod. Cylinders are applied based on force and speed of actuation. Cylinders are sensitive to force media viscosities. Where extremely high speed is required with low to medium force; pneumatic cylinders are usually applied. Since air or gases have low viscosities but high compressibility or low bulk modulus; they are limited to the high speed low force applications. High force and low to medium speeds is where hydraulic cylinders are applied. A basic rule is that the higher the speed the lower the fluid viscosity and/or the greater the flow.

Just as with motors, cylinders are exposed to a variety of environmental conditions. Cylinders are too challenged with maintaining both internal and external integrity. As a component, cylinders represent the single greatest threat to leakage. Systems with a large quantity of cylinders are a good application for fluids that are eco-friendly.

4. Reservoirs:

The reservoir can be constructed of a variety of materials including aluminum, plastics and composites, mild steel, and stainless steel. As a fluid storage tank it must assure that the fluid is protected from the environmental elements, maintain the fluid integrity and provide a ready supply to the pump. Other functions of the reservoir include providing fluid cooling through the process of thermal radiation, maintain positive pump head pressure, and suppression of fluid turbulence. The material that a reservoir is constructed from affects other system operational parameters. Reservoirs constructed of aluminum, mild steel, and stainless steel provide the benefit of fluid cooling through the process of thermal radiation to the external atmosphere. In open loop hydraulic systems and to assure that the reservoir is able to supply fluid to the pump and provide adequate cooling, it is a rule of thumb to size it a minimum of 3 times the system flow. For example: systems with flow requirements of 40 lpm would have a reservoir of 120 litres minimum. In theory the fluid would have 40 seconds dwell time in the reservoir for every 20 seconds under load. The 40 seconds will provide sufficient dwell time to cool the fluid and suppress the turbulence under normal conditions. However, when reservoirs are constructed of plastic or composites and a heat exchanger is not used, reservoir sizing may be 4 to 5 times system capacity. This allows for longer dwell times. It is almost imperative that with plastic or composite constructed reservoirs that an external heat exchanger should be employed. As far as construction materials, aluminum tanks should be closely investigated.

Tank turbulence from return hydraulic fluid must be controlled. Uncontrolled tank fluid turbulence creates conditions that can result in pump cavitation when the pump is installed in the reservoir. Reservoir breathers should be of a filter breather type. A filter breather not only helps slow water evaporation but also controls the ingression of air born contaminants. In a non-pressurized tank the breather performs an important function by allowing for the equalization of atmospheric pressures between the inside of the tank and the outside ambient pressure.

Lesson 18. Design of main components of a hydraulic System

The hydraulic system of a tractor mainly consists of pump driven by tractor engine or power train, hydraulic cylinder, control valves and implement lifting mechanism. Design of these major components is explained below

1. Pump Design

Pumps convert mechanical power to fluid power. Hydraulic pumps which are mainly used are gear type, roller vane type or axial piston variable flow type. The pressures developed by three main types of hydraulic pumps are as follows:

1. Fixed gear/vane pump : Pressure up to 10.3 MPa
2. Pressure balanced gear/vane pump : 13.8-24.1 MPa
3. Pinion type pump : 27.6-34.5 MPa

The common speed of operation of pumps ranges from 3000 to 5000 rpm.

Fluid Power of Pump (W_f)

The fluid power of pump (W_f) is given by

$$W_f = \frac{Q \times P}{60} \quad \text{... (18.1)}$$

Where,

W_f = fluid power, kW
Q = pump discharge, 1/m
P = pressure across the pump, MPa

Shaft Power of Pump

The shaft power of pump (W_s) is given by

$$W_s = T \times N \times 1.05 \times 10^{-4} \quad \text{... (18.2)}$$

Where,

W_s = shaft power of pump, kW
T = input shaft torque, N-m
N = shaft speed, rpm

Also,

$$W_s = W_f / n_m \quad \text{... (18.3)}$$

Where,

n_m= mechanical efficiency or overall efficiency of pump.

Actuator – linear: Converts fluid power to linear mechanical power. Single acting and double acting hydraulic cylinders are given in Figs. 18.1 and 18.2.

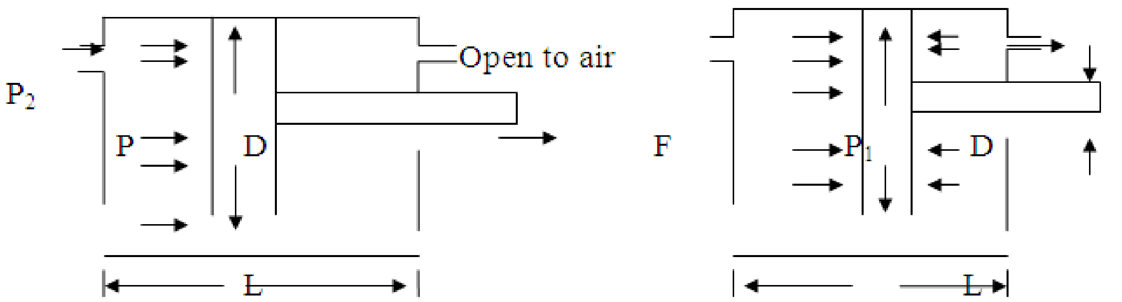


Fig.18.1. Single acting Fig.18.2. Double acting

Force in the cylinder is given by

$$F_e = P \times A_c \quad \text{... (18.4)}$$

$$F_{re} = P \times (A_c - A_r) \quad \text{... (18.5)}$$

Where, F_e= extension force in the cylinder, N;

F_{re} = retraction force in the cylinder, N

P= fluid pressure in actuator, N/mm^2

A_c = cross sectional area of ram, mm^2

A_r = cross sectional area of rod, mm^2

Where, V = speed of ram is cylinder, m/s.

Theoretical discharge of hydraulic pump is given by

$$Q_{th} = D_p \times N \quad \text{... (18.6)}$$

Where,

D_p = volume of displacement of pump in one revolution
N = pump speed, rpm

For plunger barrel type pumps, the discharge is given by

$$Q_{th} = A.L.N \times 10^{-3} \quad \text{... (18.7)}$$

Where, A= area of plunger, cm^2

L= length of stroke, cm

N= pump speed, rpm

The actual discharge of hydraulic pump is given by

$$Q_{act} = D_p \times N \times \eta_v \quad \text{...(18.8)}$$

For plunger barrel type pumps

$$Q_{act} = A.L.N \times 10^{-3} \times \eta_v \quad \text{... (18.9)}$$

Where,

η_v = volumetric efficiency of the pump, and is dependent on internal leakage and compressibility of the oil.

Pump Torque (T_p)

The pump torque (T_p) is given by

$$T_{th} = \frac{P \times D}{2\pi} \times 100 \quad \text{... (18.10)}$$

Where,

T_{th} = theoretical input torque, N-m

P = pump outlet pressure minus pump inlet pressure (bar).

The actual pump torque (T_p) is given by

$$T_{th} = \frac{P \times D}{2\pi} \times 100 \quad \text{.. (18.11)}$$

Where,

η_t = torque efficiency of pump, %.

Input or Shaft Power (W_s)

The input or shaft power (W_s) of hydraulic pump is given by

$$W_s = T \times N \times 1.05 \times 10^{-4} \quad \text{... (18.12)}$$

W_s = input or shaft power in kW

T = input shaft torque, N-m

N = shaft speed, rpm

Hydraulic/ Fluid power of pump (W_f)

The Hydraulic/ Fluid power of pump (W_f) is given by

$$W_f = \frac{Q \times P}{60} \quad \text{... (18.13)}$$

Where,

Q = actual pump discharge, 1/m

P = pressure across the pump, MP

Also $$HP_f = \frac{Q \times H}{75} \quad \text{... (18.14)}$$

Where,

Q = actual pump discharge, 1/s

H = Head, m

Overall Efficiency of Pump (η_m)

Overall Efficiency of Pump (η_m) is given by

$$\eta_f = \frac{W_f}{W_s} \quad \text{... (18.15)}$$

2. Flow Control Valves

It is used to control fluid flow in the system (speed of actuators). Check valve allows fluid flow in one direction, no flow in the other direction. Needle valve- acts like variable orifice to restrict flow. Pressure compensated valves- automatically adjust the fluid flow to compensate for pressure variations in the system. Ball valves and Spool valves are used for controlling the flow of fluid.

Following orifice equation can be used to calculate the flow rate (Q) at a given pressure drop across the orifice.

$$Q = 2.68 \times 10^{-2} \times C_d \times a \times \sqrt{\left[\frac{\delta P}{p}\right]} \qquad \text{... (18.16)}$$

Where,

Q= fluid flow rate through control valve, 1/m

C_d = coefficient of discharge, dimensionless

a = area of cross section of orifice of control valve, cm^2

σp= pressure drop across orifice, MPa

p = density of fluid, Kg/1

Velocity of fluid flow though the orifice is calculated by following equation

$$V_o = Q/6a \qquad \text{... (18.17)}$$

Where, V_o = velocity of fluid flow though orifice, m/s

3. Lines – pressure, return and intake

Hydraulic lines are used to convey the fluid to remote locations under pressure and dissipate heat developed in the system. The lines should be strong enough to with stand the fluid pressure developed during operation and their size should be such that the pressure drop is minimum. Rigid lines are made of steel while flexible are made from reinforced rubber. Wall thickness of conduit pipe used for fluid pressure lines is calculated based on maximum pressure and hoop stresses developed that would cause failure of conduit pipe along a line parallel to its centerline. It is given by

$$t_w = \frac{P_{max}\left({}^{d_c}/_2\right)}{S_d} \qquad \text{... (18.18)}$$

Where, t_w = wall thickness of conduit pipe, cm

P_{max} = maximum allowable pressure, MPa

d_c = conduit diameter, cm

S_d = Design stress for the pipe line, Mpa

4. Hydraulic Cylinder

Hydraulic cylinder converts fluid power into linear mechanical force which can be used for lifting/lowering of implements attached to the tractor and control depth of operation in the field. According to fluid flow and forces acting and specific application, the hydraulic cylinders can be classified as:

1. Single acting
2. Double acting
3. Double acting double rod
4. Telescoping and
5. Cushioned top type

Single acting hydraulic cylinders are most commonly used in hydraulic systems of tractors. Single acting type and double acting type hydraulic cylinders

Fluid force acting in cylinder (F)

Neglecting inertia force in the hydraulic cylinders, hydrostatic force transmission is given by

$$F = \frac{P_1 A_1 - P_2 A_2}{10} \quad \text{...(18.20)}$$

And $A_1 = (\pi/4) D^2_p$ and $A_2 = (\pi/4) (D^2_p - d^2_p)$ ... (18.21)

Or

$$F = \frac{\pi}{4}\left[\frac{P_1 D_p^2 - P_2 \left(D_p^2 - d_p^2\right)}{10}\right] \quad \text{... (18.22)}$$

Where,

P_1, P_2 = hydraulic pressure, MPa

D_p = piston diameter, cm

d_r = rod diameter, cm

S = stroke, cm

A_1= piston area of the cap end, cm^2

A_2= piston area at the rod end, cm^2

F = Force or load moved by hydraulic cylinder, kN

In case the return oil line from the rod end is connected back to reservoir at atmospheric pressure, then the piston is extending and

$$F_e = \frac{\pi}{4}\left[\frac{P_1 D_p^2}{10}\right] \quad \text{... (18.23)}$$

When the supply is to the rod end and the cap end is vented to atmosphere, the piston is retracting. Then,

$$F_e = \frac{\pi}{4}\left[\frac{P_2\left(D_p^2 - d_p^2\right)}{10}\right] \qquad \text{... (18.24)}$$

Speed of rod movement (V)

The speed of piston rod in cylinder is obtained by dividing the volume of fluid flow into the cylinder by the cross sectional area of cylinder bore as under:

$$Q = 6 \quad AV \qquad \text{... (18.25)}$$

Where, Q= volume of fluid flow, litres/min

A = cross sectional area, cm^2

V = velocity of piston, m/s

Power developed by the actuator (W_a)

The power developed by hydraulic cylinder in kW is given by

$$W_a = F_e . \quad V/1000 \qquad \text{... (18.26)}$$

Where, F_e = Force developed by piston during extending, kN

V = speed of ram in cylinder, m/s

Module 8. Study of electrical, electronics and guidance system of a tractor

Lesson 19. Electrical System of tractor

1. Introduction

Electrical and electronic systems have evolved over the years to become an essential element of modern off-road vehicles. A modern off-road vehicle typically incorporates an electrical system having its own power generation, storage, and distribution. Vehicle controls and diagnostics may have dozens of electronic computer-based controllers integrated into its system. Electrical system of all the tractors is almost same except one or two alterations. In some of the makes of the tractors, alternator has been introduced instead of dynamo for the recharging of a battery.

Functions of electrical system for a conventional off-road vehicle are:

- Engine starting
- Lighting (work and safety)
- Sensing, display, and control
- Air conditioning/Ventilation
- Accessory may include windscreen wiping, entertainment systems, radio, etc

2. Components of an electrical system

An electrical system of a tractor consists of the following parts/system, which are explained below

1. Battery
2. Charging System
3. Regulating systems
4. Starting system
5. Relays and fuses

i. Battery:

Since the source of electricity in a tractor is the battery, let's see how it works: A battery is an electrochemical device which converts chemical energy into electrical energy. Tractors use "lead-acid" batteries. A lead-acid battery uses a series of lead dioxide plates for its positive (+) terminal and porous, soft lead for its negative plates. All the plates are arranged alternately and submerged in a solution of sulfuric acid and water. The cross section of a battery is shown in Fig. 19.1. The positive plate's lead oxide is a compound of lead and oxygen. Sulfuric acid is a compound of hydrogen and the sulfate radical (SO4), so the acid's chemical designation is H2SO4.

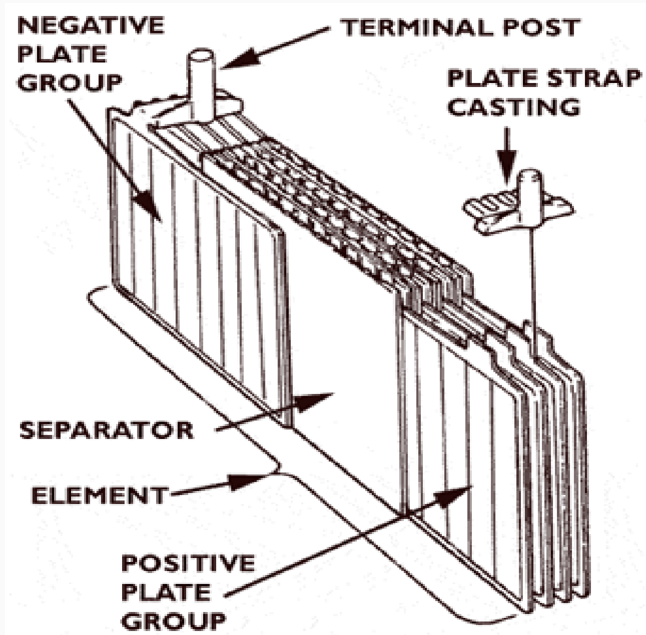


Fig. 19.1: Cross section of a battery

Chemically, when a battery is connected to an external load (a device which uses electricity) it begins to discharge. As that happens, the lead in the positive plate combines with the sulfate of the acid, forming lead sulfate (PBSO4) in the positive plate. Oxygen in the positive plate combines with hydrogen from the acid to form water (H2O), which reduces the concentration of the acid in the electrolyte. Also, the pure lead in the negative plate combines with the sulfate, forming lead sulfate and making the positive and negative plates more alike in chemical composition. Electrons are released during this reaction, creating electrical current at a specific voltage (2 volts per cell, with 6 cells in a 12-volt battery, described below). One model HMT 7511 was installed with two batteries each of 12 V connected in parallel to meet more cranking power required to start the high hp engine.

Chemical reactions:

The chemicals used in a Battery are as follows

1. Sponge Lead (Solid) in Cathode (-ve) plates

2. Lead Oxide (Paste) in Anode (+ve) plates

3. Sulphuric Acid (Liquid)

The chemical reactions take place between the three chemicals in the battery. In the presence of sulphuric acid, the electrons from one group of plates collect on the other group of plates.

The following chemical reactions take place while charging and discharging (Fig. 19.2)

While charging

At Anode (+ve Plate): $PBSO_4 + 2H_20 => PBO_2 + 2H_2SO_4$

At Cathode (-ve Plate): $PBSO_4 + H_2 => PB + H_2SO_4$

During Discharge: The acid H2SO4 attacks lead to form PBSO4 (Lead sulphate)

At Anode: $PBO_2 + H_2SO_4 => PBSO_4 + 2H_20$

At Cathode combines with it to form $PBSO_4 : PB + SO_4 => PBSO_4$

So both at anode (+ ve) and at Cathode (-ve) is formed. During this process water is also formed which dilutes sulphuric acid and thereby decreases its specific gravity. This the battery converts electrical energy into chemical energy during charging and chemical energy into electrical energy during discharging.

The capacity of a fully charged battery falls down to a much lower value in fully discharged state. To know the capacity of battery two methods are adopted.

1. Ampere Hour efficiency

2. Watt Hour efficiency

Efficient (AE) = Ah at full discharge/Ah at full charge

Efficiency(Wh) = Wh out put at full discharge/Wh input at full charge

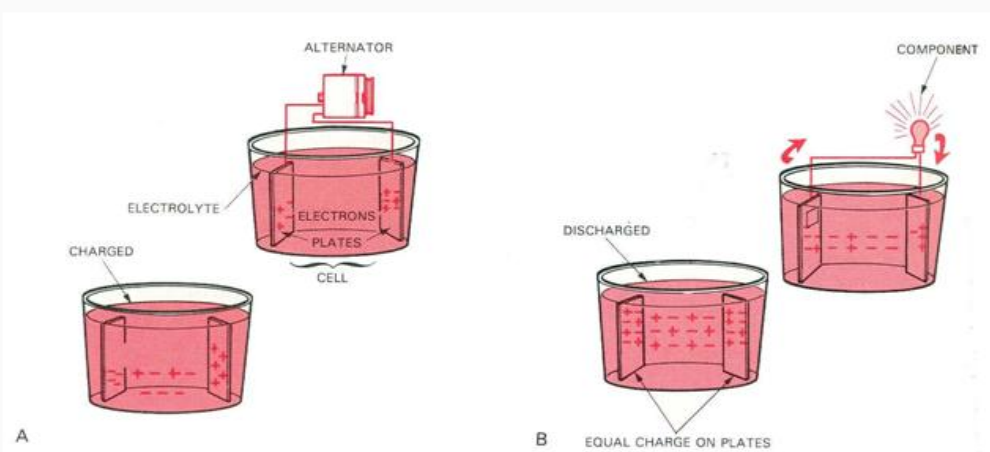


Fig. 19.2: Charging and discharging of a battery

Battery Testing:

A battery can be tested to ascertain its condition by the following tests.

- Specific gravity test
- Open Volt test
- High discharge test
- Cadmium tip test

Specific gravity test: While the chemical reaction taking place in the battery during discharge, the electrolyte becomes dilute to form water. The proportion of water goes on increasing as the discharging continues. The relative amounts of water and acid is determined by the specific gravity test. This is done by Hydrometer.

The Meter of Hydrometer ranges as follows:

1.260 to 1.280	:	Fully charged
1.230 to 1.250	:	¾ charge
1.200 to 1.220	:	½ charge
1.170 to 1.190	:	Very little charge
1.110 to 1.130	:	completely discharged

Open Volt test: The Open circuit voltage of a fully charged battery cell is about 2.1 volts. This can be measured with the help of a voltmeter. It can be observed that a charge of 0.01 Volt of open circuit voltage is equivalent to a charge of 0.010 in the specific gravity of the electrolyte.

High discharge test: High Voltage of current is required for cranking the starting motor. To satisfy this condition, high discharge test is done with the help of cell voltage tester.

Cadmium Test: The test is done to ascertain whether the battery plates are defective or not. It is done with help of cadmium rod enclosed in a perforated ebonite tube. The rod is immersed in the electrolyte and connected to the negative terminal of a Voltmeter. Its positive terminal is connected alternately to the positive and negative terminals of a battery cell. When connected with positive terminals, the voltage reading should not be less than 2.5 Volts. If it is less it indicates defective positive plates. When connected with negative plates, if it is more than 2.5 Volts, it indicates defective negative plates.

ii. Charging System (Generators or Alternators):

How the battery gets charged. In older vehicles this was done with a generator. After that time all switched to alternators.

Generator:

The basic principle at work here is that electricity produces magnetism. Conversely, magnetism produces electricity. If a current-carrying coil of wire is placed around a bar of steel, the bar will become magnetized. The more turns of wire and the stronger the current, the more powerful the magnet. By placing a soft iron core within the coil, the magnetic force lines are concentrated and strengthened. As there is less electrical resistance in the iron than in the surrounding air, the force lines will follow the core.

The various parts of a generator are shown in Fig. 19.3. The two pole shoes of a generator are constructed in this way. Rather than use magnets - which are heavy and expensive - many turns of wire are wound around the pole shoes. When a current passes through these windings the pole shoes become electromagnets, called FIELD COILS. These two field coils are connected in series (current passes through one and then through the other) and wound so that one becomes the North Pole and the other the south pole of the magnetic field.

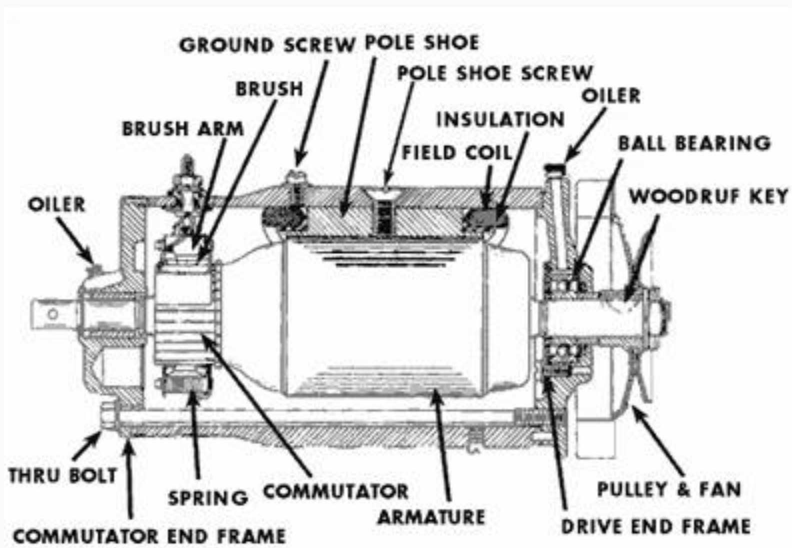


Fig. 19.3: Different parts of a generator

Inside the generator is a spinning central shaft which is supported in bearings at each end. Loops of wire (armature windings) are wound on a special laminated holder called the ARMATURE. The armature is turned by placing a pulley on one end of the shaft and driving it with a V-belt from the engine's crankshaft, as seen in the figure. Attached to the armature are electrical contact segments, called the COMMUTATOR. These segments are electrically insulated from the armature - and each other - but each is soldered to one of the armature windings. It is the commutator which distributes electricity to the armature in an on-off manner, creating a magnetic field around the armature. Riding over the spinning commutator segments are carbon "brushes". These brushes are held in spring-loaded brackets and that pressure holds them against the commutator. It is the brushes which wear out over time and require replacement.

Generator Working:

When the generator armature first begins to spin, there is a weak residual magnetic field in the iron pole shoes. As the armature spins, it begins to build voltage. Some of this voltage is impressed on the field windings through the generator regulator called voltage regulator. This impressed voltage builds up a stronger winding current, increasing the strength of the magnetic field. The increased field produces more voltage in the armature. This, in turn, builds more current in the field windings, with a resultant higher armature voltage. This voltage could, of course, continue to increase indefinitely, but it is limited (by regulation) to a pre-set peak. At this point all this sounds like perpetual motion, doesn't it? Remember, though, that the energy driving all this is the engine's crankshaft!

Alternators

Generators produce Direct Current. Alternator produces an A.C. that in turn must be rectified or converted into D.C. and then stored in a battery. Alternators are more compact than dynamo (generators) systems and can supply more current at low speeds because at idle engine speeds they run at double the engine speed. Hence life of a battery is increased with the alternators.

Alternators have the advantage of producing far more current at low speeds than generators, thus allowing more and more accessories in the vehicle. In an alternator, the "field" windings are placed around the spinning central shaft rather than on "shoes" as in the generator (Fig. 19.4). Two iron pole pieces - cast with "fingers" - are slid on the shaft, covering the field winding so that the fingers are interspaced. The fingers on one pole piece form the North poles and the fingers on the other form the South poles. This assembly is called the ROTOR. Surrounding the rotor are a series of windings around laminated iron rings, attached to the alternator's case. This assembly is called the STATOR. The engine's crankshaft spins the rotor.

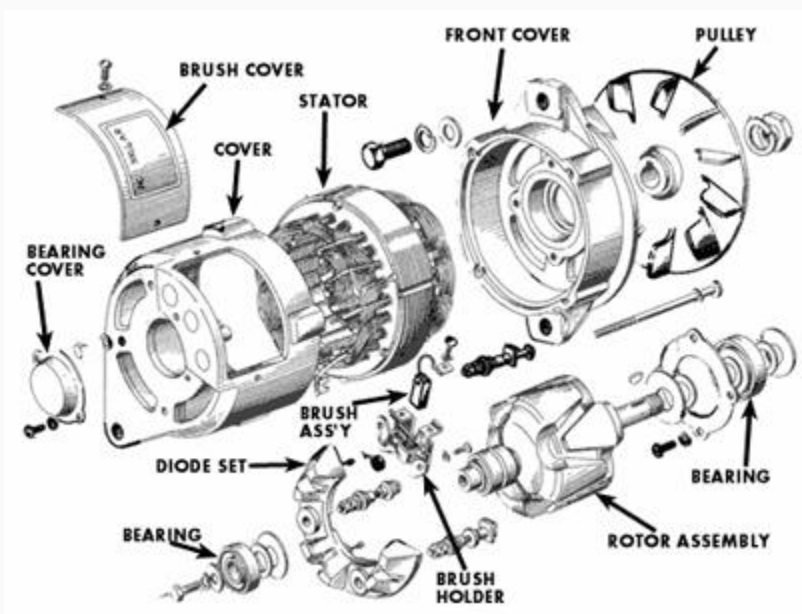


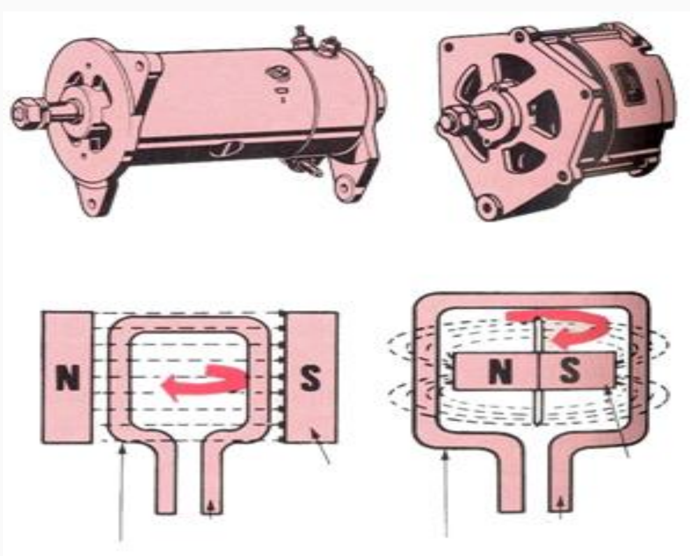
Fig. 19.4: Cut view of a typical alternators

Direct current from the battery is fed through into the rotor's field coil by using brushes rubbing against slip-rings. One end of the field coil is fastened to the insulated brush, while the other end is attached to the grounded brush. As the pole fields pass through the stator, current is electromagnetically produced (as in the generator) but since the rotor is composed of alternating North and South poles the current produced flows in opposite direction every 180-degrees of rotation. In other words, the current is "alternating". Difference in working of a generator and an alternator is shown in Fig. 19.5.

Why this is more efficient, as the stator windings are made up of three separate windings. This produces what is known as three-phase AC. When only one winding is used, single-phase current results (like in a generator). In effect, the alternator produces three times the current of a generator for the same effort on the engine's part. Also, alternators are considerably lighter and smaller than generators.

There's a small problem with alternators, though. AC electricity doesn't work in a tractor. The tractor's electrical system - and battery - need DC. Therefore, the alternator's output is "rectified" into DC. This is done by passing the AC into silicon diodes. Diodes have a peculiar ability to allow current to flow readily in one direction only, stopping the flow if the direction reverses. Multiple diodes are arranged in alternators so that current will flow from the alternator to the battery (in one direction only, creating DC) but not from the battery to the alternator.

In actual operation, the voltage regulator senses the battery voltage and overall demand on the tractor's electrical system. When charging is needed, the regulator applies battery voltage to the stator's brushes and this creates the electrical field for charging. As the system's demand for charging decreases the voltage to the brushes cuts off. All of this occurs many times per minute, with the system turning on and off repeatedly to keep everything at optimum operating efficiency.



Generator (Stationary magnetic field) | Alternator (Rotating magnetic field)

Fig. 19.5: Difference in working of generator and alternator

iii. Regulating system

As, there is no system of internally controlling the output of an alternator or in other words, the faster it spins the more voltage goes into the electrical system. If this weren't controlled the generator would damage the battery and burn out the lights. Also, if the generator weren't cut out from the tractor's circuitry when not running, the battery would discharge through its case.

That's where the REGULATOR (commonly called the Voltage Regulator, but that's only one component of the system) comes in. Regulators have seen many design improvements over the decades, but the most commonly used electro-mechanical regulator is the three-control units in one box type. These are explained below,

(a) Cutout Relay

Sometimes called the circuit breaker, this device is a magnetic "make-and-break" switch. It connects the generator to the battery (and therefore the rest of the tractor) circuit when the generator's voltage builds up to the desired value. It disconnects the generator when it slows down or stops.

The relay has an iron core that is magnetized to pull down a hinged armature. When the armature is pulled down a set of contact points closes and the circuit is completed. When the magnetic field is broken (like when the generator slows down or stops) a spring pulls the armature up, breaking the contact points.

An obvious failure mode is the contact points. As they open and close, a slight spark is generated, eventually eroding the material on the points until they either "weld" themselves together or become so high in resistance that they won't conduct current when closed. In the first case the battery would discharge through the generator overnight and in the second there would be no charging to the system.

(b) Voltage Regulator

Another iron core-operated set of contact points is utilized to regulate maximum and minimum voltage at all times. This circuit also has a shunt circuit (a shunt re-directs electrical flow) going to ground through a resistor and placed just ahead (electrically) of the points (Fig. 19.6). When the points are closed the field circuit takes the "easy" route to ground but when the points are open the field circuit must pass through the resistor to get to ground.

The field coil on the generator is connected to one of the voltage regulator contact points. The other point leads directly to ground. When the generator is operating (battery low or a number of devices running) its voltage may stay below that for which the control is set. Since the flow of current will be too weak to pull the armature down the generator field will go to ground through the points. However, if the system is fully charged the generator voltage will increase until it reaches the maximum limit and current flow through the shunt coil will be high enough to pull the armature down and separate the points.

This cycle is repeated over and over in real time. The points open and close about 50 to 200 times per second, maintaining a constant voltage in the system.

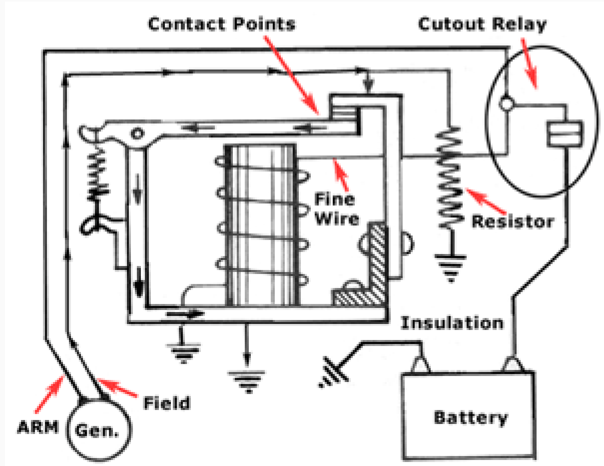


Fig. 19.6: View of a typical voltage regulator

(c) Current Regulator

Even though the generator's voltage is controlled it is possible for its current to run too high. This would overheat the generator, so a current regulator is incorporated to prevent premature failure (Fig. 19.7).

Similar in appearance to the voltage regulator's iron core, the current regulator's core is wound with a few turns of heavy wire and connected in series with the generator's armature. In operation, current flow increases to the predetermined setting of the unit. At this time, current flow through the heavy wire windings will cause the core to draw the armature down, opening the current regulator points. In order to complete the circuit the field circuit must pass through a resistor. This lowers current output, points close, output increases, points open, output down, points close, and so on. The points, therefore, vibrate open and closed much as the voltage regulator's points do, many times every second.

Because they are mechanical, voltage regulators are easy to troubleshoot. If you study the function of each of the three parts and how they interrelate, it becomes obvious which part is malfunctioning, depending upon symptoms. The point gaps and spring pressures determine the voltage/current limits and they are exceedingly hard to adjust. Sometimes it can be done on the tractor using a voltmeter, but generally it is best to replace the entire regulator assembly when a certain part of it fails. Factory assembly of regulators required relatively sophisticated measurement instruments. Adjusting them by "feel" is a matter of luck, and frequently can result in damage.

It wasn't long thereafter that the automobile companies converted to transistor voltage regulators. Utilizing Zener diodes, transistors, resistors, a capacitor and a thermistor, these regulators maintain proper voltage and current flow throughout the system. Their circuitry operates as fast as 2,000 times per second and they are tremendously reliable. On the other hand, these regulators aren't easy to repair. They are designed to be thrown away and replaced. Alternators provide three times the current and weigh much less than their old counterparts.

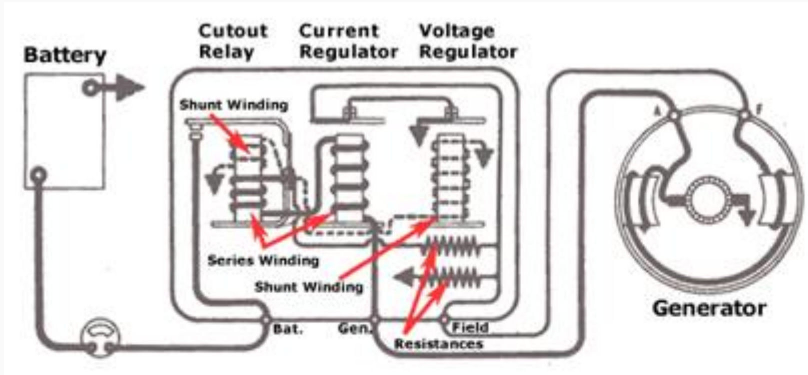


Fig. 19.7: Voltage and current regulators

d. Starting System:

Electrical system only needs 80 to 100 amps of current for general running, even when all accessories are operating. Then, why battery does have a rating of 450 to 740 amps or even more. The main reason for the battery's storage capacity is to operate the starter, and a quick look at the numbers will demonstrate why this is so important:

Let's take a 500-amp-rated battery for example. At 12 volts, this 500 amp battery is capable of putting out 6000 watts. We need all the wattage we can get to develop enough horsepower to turn the engine over for ignition and one horsepower (or the power necessary to lift 550 pounds (249.47 kg) one foot in one second) equals 746 watts. Our battery, therefore, puts out just over eight horsepower. That's just enough for a couple hundred revolutions of the engine before the charge is exhausted. Starters are incredibly strong motors that work in a hostile environment. They are the most important part of the starting system (Fig. 19.8) or circuit, consisting of the following:

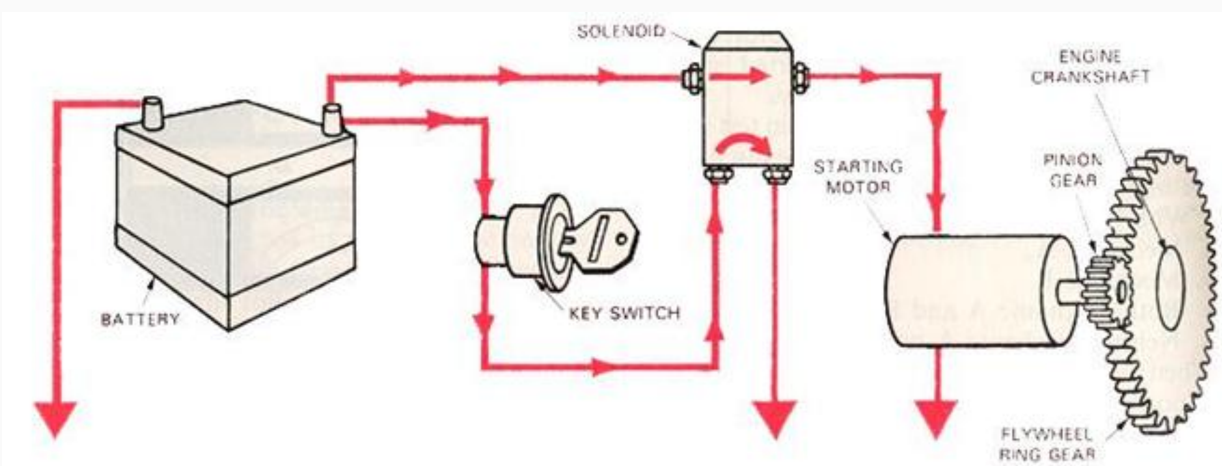


Fig. 19.7: Starting system of a tractor

Flywheel ring gear - This is a toothed ring that is fitted to the outside of the engine's flywheel. Matching teeth on the starter motor mesh with this gear in order to spin the crankshaft.

Starter solenoid (Relay) - The starter solenoid has very large contacts to carry the battery's full current. Its wire coil is actuated by a smaller current from the ignition switch, at which time the iron core slams down to make contact and turn on the starter motor. Most non-Ford starter motors employ a solenoid built into the motor itself. This type of solenoid not only provides the motor's electrical power but also mechanically engages the starter's drive gear onto the flywheel. It is commonly known as the BENDIX type of solenoid. Such solenoids operate in three stages, the disengaged, partially engaged and engaged. In the disengaged position the drive gear is released and no current is flowing. In the partially engaged stage, current from the starter switch flows through both the pull-in and the hold-in coils. Both coils draw the plunger inward, causing it to pull the shift lever and engage the pinion gear. When the plunger is pulled into the coil all the way, the pinion fully engages the ring gear. When the ring gear is fully engaged, engine cranking begins. When the engine starts the hold-in coil will cut out and the plunger will move out, retracting the pinion and opening the starter switch.

Starter motor - This is a powerful electric motor that engages the car's flywheel in order to spin the crankshaft. As in all electric motors, the starter is composed of windings of wire that form loops, ending at the commutator segments (remember these from the generator?). The armature coils are mounted on the motor's central shaft (supported with bearings) and the field coils are formed into four or more "shoes", placed inside the steel frame of the starter. Brushes are used to create electrical contact to the commutator segments and when current is fed into two of the four brushes, it flows through all the loops of the armature and shoe windings and out the other two brushes. This creates a magnetic field around each loop. As the armature turns, the loop will move to a position where the current flow reverses. This constant reversal of current flow allows the armature and field coils to repel each other and spin the motor. The greater the current flowing in the coils, the greater the magnetic forces, and the greater the power of the motor.

The copper loops and field windings are heavy enough to carry a large amount of current with minimum resistance. Since they draw heavy amounts of current, they must not be operated on a continuous basis for longer than 30 seconds. After cranking for 30 seconds it is wise to wait a couple of minutes to let the starter motor dissipate some of its heat. Starters heat quickly, so prolonged use can cause serious damage. A typical symptom of overheating starter motors is extremely slow, labored engine-cranking.

Various wiring designs are used in starter motors and one of the most popular is the four pole, three winding setup. Two of the windings are in series with themselves and the armature. One winding does not pass through the armature, but goes directly to the ground. This Shunt Winding aids with additional starting torque. However, as the starter speed increases, the shunt still draws a heavy current and tends to keep starter speed within acceptable limits.

e. Relays and fuses:

All tractors are wired so that the battery's main cable connects to the starter motor windings (the thick cable is needed for large current flow). This wire must be switched on and off, and it would be costly and inefficient to route it through the ignition switch. Hence a relay is necessary.

Relays are devices that utilize a central iron core fitted closely to the inside of a coil of wire. When the wire is energized the iron core will be drawn down the length of the coil, the direction dependent upon the direction of current flow. If the relay's iron core is fitted with large, high current-carrying contacts it can be used as a high-current switch. Relays are used for horns, electric fans, air conditioning clutches, etc. and the most important one is the starter solenoid.

Almost everything in a tractor is wired through a fuse. Fuses are designed to fail when too much current is drawn through the device. This prevents heating of the wires and subsequent melting of the insulation, followed usually by fire!

Fuses are simple in design. Inside a fuse is a soft wire with a specific cross-sectional thickness. This dimension dictates how many amps can be carried before the wire melts. Too many amps and the fuse fails, saving the rest of the circuit from damage.

Typical horn circuit having various components are put together to form a working system:

Battery voltage travels through a high current wire (red) through the relay to the horn and also through a smaller wire (blue) through the ignition switch to the relay's low-current coil. Important thing is that horn circuit is always "hot" or "live" when the ignition switch is turned on and all that's needed is a path to ground (Fig. 19.9).

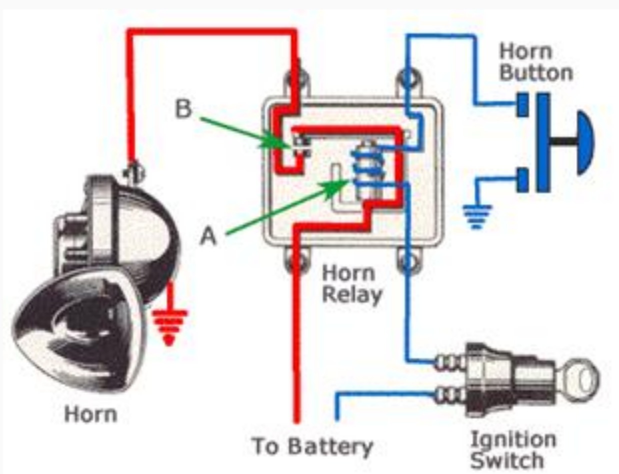


Fig. 19.8: Horn relay system

That path is completed when pushed the horn button. When the button is pushed the ground connection is made, energizing the relay's coil "A". The coil's iron core (in this particular design) pulls down arm, connecting high-current contacts "B". High current then flows from the battery to the horn (the horn is connected to ground because it's mounted to the chassis of the car).

Lesson 20. Electronics and guidance system of tractor

1. Introduction

Electronic systems have evolved over the years to become an element of modern off-road vehicles. A modern off-road vehicle typically incorporates some computer based controllers and diagnostics systems.

2. Electronics and instrumentation in tractors can be used for:

1. Continuous monitoring and tracking of tractor
2. Advanced Mechanized Farming

3. Continuous monitoring and tracking of tractor

The instrument panel of a tractor is placed so that the instruments and gauges can easily be read by the operator. They inform the operator about the vehicle speed, engine temperature, oil pressure, rate of charge or discharge of the battery, amount of fuel in the fuel tank, and distance travelled. Vehicle accessories, such as windshield wipers and horns, provide the operator with much needed safety devices. Now a days all these gauges and meters are of electronic types.

An electronic tachometer obtains a pulse signal from the ignition distributor, as it switches the coil on and off. The pulse speed at this point will change proportionally with engine speed. This is the most popular signal source for a tachometer that is used. Electronic speedometers and tachometers are self contained units that use an electric signal from the engine or transmission. They differ from the electric unit in that they use a generated signal as the driving force. The gauge is transistorized and will supply information through a magnetic, Analog or light emitting diode (LED)

Continuous monitoring of engine and location of tractor operation is very important especially when tractor is working at remote areas. Recently New Holland Fiat (I) ltd. has started a system called "Sky watch system" in India for the proper engine monitoring and tracking of its working. Alerts are sent through SMS or online detail of following parameters to the owner.

- Engine oil pressure
- Water temperature
- Engine hours
- Tractor location

- Fuel level
- Service reminders

Potential Customers of Sky Watch Tractor may be;

- Tractor Fleet Owner
- Custom hiring operators,
- Cooperative service providers
- Tractors Used at Remote Location, like forests, hills etc.
- Tractors used in commercial Applications like Loader, Dozer, Combine, Long Haulage etc.

4. Advanced mechanized farming

World over, various devices or instruments are being introduced for advanced mechanized farming. These includes communication between tractor and implement, navigators, Sensors for soil and plant parameters etc. Some of these are explained below

i. CAN-based tractor – agricultural implement communication ISO 11783 (CANBUS)

The standard forms the backbone of the autonomous agricultural machine system. A logical consequence of the observed trend toward increased use of electronics in tractors and implements is the networking of these components. The supplemental costs of networking represent just a small portion of the overall electronic development costs. Yet they have the potential of significantly enhancing performance of the total system. Only by networking is it possible to move toward the goal of achieving autonomous agricultural machines.as shown in Fig. 20.1. CANBUS have four wire system, including CAN high (yellow), CAN low (green), CAN power (red), and CAN ground (black). Also, CANBUS contains an electric power supply, also referred to as the “active terminator”, with battery power and battery ground to keep CANBUS level at the desired Voltage.

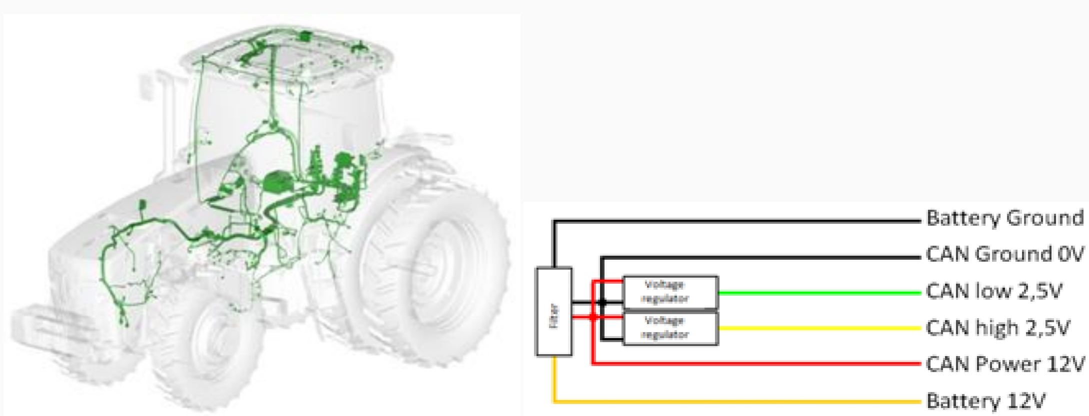


Fig. 20.1 Tractor with CANBUS and its wiring diagram (Anon, 2013)

Standardized networking permits multiple utilization of individual components in the network and this reduces development costs. Automatic interventions into the tractor controller, e.g. to modify the operating speed or rounds per minute, permits more effective use of implements. For the farmer and user of the total system standardization also opens up the possibility of combining implements produced by different manufacturers with different tractors. Hence a standard protocol has been introduced in tractors for communication and networking. The standard in the agricultural area for communications between a tractor and an implement (add-on equipment such as a thresher or a mower) is called ISO 11783 or Isobus in short. The international standard consists of the transmission medium (Physical Layer) to application of the entire spectrum of serial communications based on CAN.

Data communication

The ISO 11783 standard is based on CAN, which has been used for a long time in the agricultural industry. This is a passive two-wire bus terminated at the bus ends by a characteristic impedance. Each node must be capable of being connected or disconnected during network operation. An active termination is used to achieve these plug-and-play properties. This means that the node at the end of the bus must automatically terminate it with the characteristic impedance to prevent reflections. The data rate is 250 kbit/s with a sample point of 80 %. Furthermore the entire implement - or at least the electronics - may be supplied with voltage over the bus. Voltages of 12 V or 24 V are permitted. The maximum total length of the bus is 40 m, whereby the length of possible branch lines is limited to 0.3 m. The number of nodes on a bus segment is limited to 30. The wiring used is a 4-conductor, unshielded, and twisted cable for the CAN network and the voltage supply to the controllers and to the active termination. Various types of connectors are defined with different functions: Implement connectors (Breakaway Connector), bus extensions (Bus Extension Connector) and diagnostics (Diagnostic Connector). The entire Isobus is subdivided into at least two segments. The Tractor Bus is a segment, which permits communication within the tractor, e.g. powertrain, valves, etc. The second segment is the Implement Bus. This segment is available for communication between implement and tractor as well as between implements themselves. At least one Tractor ECU (electronic control unit) serves as the interface between the two segments. Communication on the Tractor Bus does not need to be ISO 11783-compatible.

ii. Navigation System

Automated guidance of agricultural vehicles (tractors, combines, sprayers, spreaders) has been motivated by a number of factors—most important is to relieve the operator from continuously making steering adjustments while trying to maintain field equipment or implement performance at an acceptable level. Global positioning system (GPS) guidance systems and auto-steer technology make use of the most efficient routes around a field, eliminating overlaps and skip. Precision Agriculture practices are energy savers. Site specific farming using equipment guidance (autosteer) systems, yield monitoring systems, field mapping and precision crop input application provides many economic and environmental benefits in addition to energy savings. These systems are useful particularly in applying pesticides, lime, and fertilizers and in tracking wide planters/drills or large grain-harvesting platforms. Navigation systems help operators reduce skips and overlaps, especially when using methods that rely on visual estimation of swath distance and/or counting rows. This technology reduces the chance of misapplication of agrochemicals and has the potential to safeguard water quality. Also, GPS navigation can be used to keep implements in the same traffic pattern year-to-year (controlled traffic), thus minimizing adverse effects of implement traffic (Fig. 20.2).

Relatively inexpensive navigation aids known as parallel-tracking devices assist the operators to visualize their position with respect to previous passes and to recognize the need for steering adjustments. These aids are commercially available in several configurations. One system is a lightbar, which consists of a horizontal series of Light Emitting Diodes (LEDs) in a plastic case 12 to 18 inches long. This system is linked to a GPS receiver and a microprocessor. The lightbar is usually positioned in front of the operator, so he or she can see the accuracy indicator display without taking their eyes off the field. The lightbar can be mounted inside or outside of the cab, and the operator watches the "bar of light." If the light is on the centerline, the machine is on target. If a bar of light extends to the left, the machine is off the path to the left and needs to be corrected. In like manner, if a bar of light extends to the right, the machine is off to the right.

Guidance systems are rapidly growing in popularity as savings permit a very short pay-back time.

Manual guidance – here a display tells the operator where to drive but the operator does the steering. This type of guidance will generally eliminate half the overlap, reducing it from an average of 5-10%.

Fig. 20.2: Tractor with satellite navigator (ARAG, Italy)

Automatic guidance – these systems steer the tractor for you and are available in various accuracies. As steering is done for you it is possible to reduce overlap from 10% down to about 1%. All guidance systems use commercially available satellites. for basic vehicle positioning but require a correction signal – there are alternatives with differing degrees of accuracy but the RTK offering 2cm accuracy is

Module 9. Ergonomics, controls and safety features of an agricultural tractors158

Lesson 21. Importance of ergonomics in tractor and agricultural machinery design.

1. Introduction

Human engineering or ergonomics deals with the aspect of man-machine system which means engineering the product or machine to fit the operator. Ergonomics (ergo=work; nomos =laws in Greek) virtually became a field of specialization recently, because now the objective is to have maximum operational efficiency, which lead to multi-disciplinary approach. There is a slight variation between two approaches, first approach deals mainly with integration of man- machine system, whereas the second approach deals with welfare of the individual concerned. Hence, ergonomics deals with the relationship between man and his occupation and environment, particularly the application of anatomical, physiological and psychological knowledge to the problem arising thereof. Objective of ergonomics is also to achieve a rational use of human capabilities and to an optimum adaptation of the work situation to these capabilities. Ergonomics, known as Man-Machine-Environment System, deals with the machine, its operator and working environment as a complete system affecting the intended work performance. It is sometimes known as human factors engineering or human engineering. Ergonomics is the study of designing equipment and devices that fit the human body, its movements, and its cognitive abilities. It deals with the physical work environment, tools and technology design, workstation design, job demands and physiological and biomechanical loading on the body.

2. Ergonomics in Tractor and agricultural machinery design

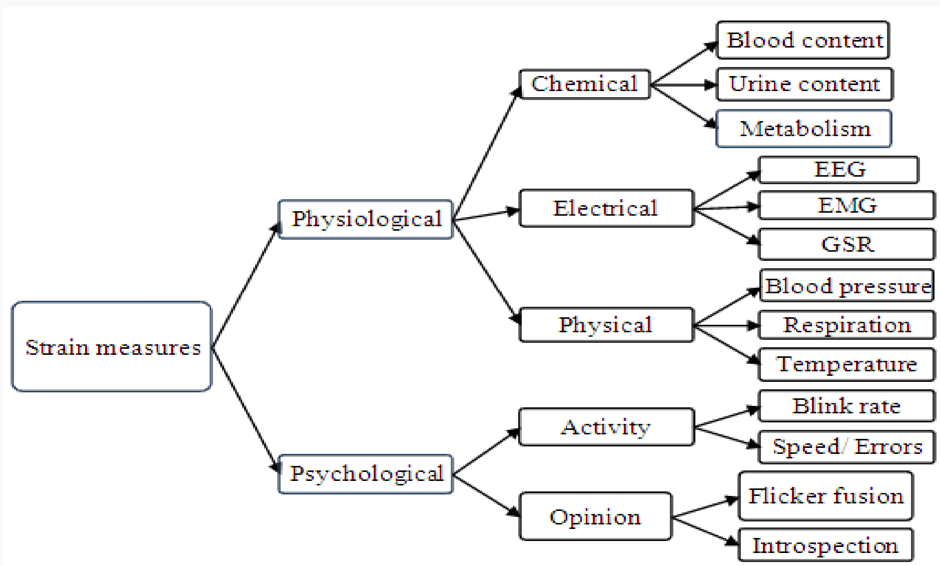
The ergonomic aspects during application in agricultural machinery are of great importance as the operator has to operate the machine in field. The physiological as well as psychological fatigue affects performance of the operator. Objective of ergonomics is not only to improve work performance but also to improve human comfort as well as safety. If ergonomic aspects are not given due consideration, the performance of the system will be poor and the effective working time will be reduced. The goal of ergonomics is to design workplace to conform to the physiological, psychological, and behavioural capabilities of workers. There are many factors acting as stress on the operator during the work. These stresses may be due to workload, immobilization for longer duration work, ambient temperature, relative humidity, vibrations, noise, dust, smoke and other gases. A feeling of chance of accident during work, space confinement, overload of information to be handled, etc. results in psychological fatigue. During the ergonomic studies, these stresses can be measured in terms of strain on the operator. The most important among physiological strains are related to heart activity, respiration, discomfort, muscular fatigue, etc. For the psychological /mental strain measurements stress on eyes, hearing loss, errors, speed of work, work performance are mostly used in studies (Fig.21.1).

3. Subjects

Whenever we have to plan for ergonomic study, subjects (operators or workers) are an integral part of the study. The objective is to eliminate the affect of individual characteristics from the rest of independent parameters and also to have an estimate of human workload during the actual work. The subjects must be medically fit and represent real user population in operation of the selected machinery. Their selection is made on the basis of gender, age and weight. Generally male subjects are selected for conducting ergonomic studies on agricultural machinery in India.

4. Physiological factors for measurements

Physical activities stimulate certain physiological responses in human beings. These responses provide basis for human energy expenditure and fatigue. The physiological measurements are made generally in terms of heart and respiration activities.



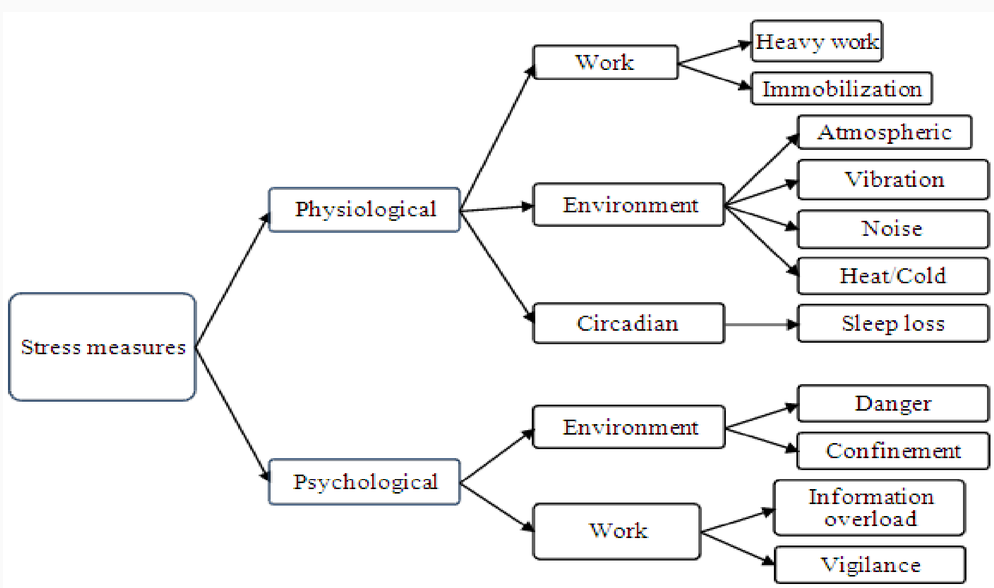


Fig.21.1. Stresses and strains in ergonomic studies

5. Heart rate

Heart rate (HR) is the most reliable dependent parameter in ergonomic studies. This is because the heart rate has a direct and linear relationship with the human workload and stress. A starting period of 2-3 minutes is sufficient for heart/pulse rate to stabilize depending upon nature of exercise. Also, care has to be taken so that the operator is not subjected to workload leading to heart rate more than HR_{max} i.e. the upper limit of heart rate allowed during an activity.

Here,

$HR_{max} = 220 - age$ ...(21.1)

6. Respiration rate

The respiration is another basic variable in work physiology as it is linearly related to the workload. It is measured in terms of rate of volume of air inhaled or air exhaled or oxygen intake (VO_2) or respiration rate. The greater the demands made on the muscle by the physical activities, the more air or oxygen is inhaled. The human energy expenditure is computed by multiplying the oxygen consumption with the calorific value of oxygen. The human workload has been categorized between light work and extremely heavy work depending upon heart rate or oxygen consumption (Table.21.1).

Table 21.1. Limits of physiological responses and work category.

S. No.	Work category	Physiological response	
		Oxygen consumption (l/min)	Heart rate (beats/min)
1	Light work	< 0.5	Up to 90
2	Moderate work	0.5 - 1.0	90-110
3	Heavy work	1.0-1.5	110-130
4	Very Heavy work	1.5-2.0	130-150
5	Extremely heavy work	> 2.0	150-170

7. Discomfort rating

Body posture is one of the major factor which causes muscular fatigue and discomfort in the body. Uncomfortable body posture in different activities reduces work efficiency, capacity and safety of operator. It is widely agreed that awkward working postures are the principle risk factor associated with muscular-skeletal injuries and disorders during occupational activities. The effect due to working posture can be measured in terms of overall discomfort rate and body part discomfort rate techniques. Table 21.2 gives the pain intensity score as measure of overall discomfort rate. The same score can be used for measurement of body parts discomfort rating.

Table 21.2. Pain intensity score as a measure of overall discomfort rating (ODR).

Subjective feeling	ODR Score	Subjective feeling	ODR Score
Comfortable	0	Moderately painful	4
Uncomfortable	1	Highly painful	5-6
Pain starts	2	Very highly painful	7-9
Slightly painful	3	Extremely painful	10

Psychological factors for measurements

Certain working operations need overload of information, vigilance, danger or work performance accuracy. In such conditions, there is a higher load on sensory/neuro organs of the human body. Such situations cause higher stress on eyes, hearing system, brain activity, etc. resulting in poor work performance, more errors, more missings, lesser endurance, etc. These situations sometimes may lead to headache, drowsiness and even accident. These stresses can be measured in terms of blink rate, flicker fusion, critical hearing threshold level, speed & errors in work performance, etc.

1. Anthropometry

Anthropometry is the technology of measuring various human physical traits, such as body dimensions of workers and their strength. Engineering Anthropometry is an effort to apply such data to equipment and workplace design to enhance the efficiency, safety and comfort of the operator. Anthropometric measures vary considerably due to effect of various factors viz. gender, race, age, etc. The anticipated user population, therefore, controls the application of anthropometric data. An anthropometric database, involving 79 body dimensions and 16 strength parameters, of agricultural workers is being prepared at the country level. It is critical for the designer to consider the anthropometry at the time of conception of the design rather than as a follow–up or add-on part of the design. The other application of such database is workspace and controls layout for the machinery. Table 21.3 lists a few important body dimensions and their usefulness. However, the database is to be given statistical application in terms of range, mean, standard deviation, 5^{th} and 95^{th} percentile values.

Table 21.3. Some important anthropometric dimensions and their usefulness.

S.N.	Dimension	Definition	Usefulness
1.	Weight	It is measured on a calibrated weighing scale.	General body description.
2.	Stature	The vertical distance from standing surface to the	General body description, work

		top of the head. The subject stands erect and looks straight-forward.	place designs.
3.	Vertical reach	The vertical distance from standing surface to the height of middle finger when arm hand and fingers are extended vertically.	Workplace layout, design of controls
4.	Eye height	The vertical distance from standing surface to the inner corner of the eye. The subject stands erect and looks straight forward.	Design of controls and displays
5.	Knee height	The vertical distance from standing surface to the midpoint of knee cap. The subject stands erect and looks straight forward.	Body linkages, work place design.
6.	Arm reach from wall	The distance from the wall to the tip of middle finger measured with subject shoulder against the wall, his hand and arm extended forward.	Design of controls and display panel, work place layout.
7.	Sitting height	The height, from the sitting surface, to the top of the head. The subject stands erect and looks straight forward.	General body description, control panel layout, work place layout.
8.	Sitting eye height	The height from the sitting surface to the external canthus. The subject sits erect and looks straight forward.	Display and control panel design, seat design, visual field determination.
9.	Knee height sitting	The height from the footrest surface of the musculature just above the knee. The subject sits erect and looks straight forward.	Work place layout, seat design, general body description.
10.	Hand length	The distance from the base of the hand to the top of the middle finger measured along the long axis of the hand.	Handle design, control panel design, hand tool design.
11.	Span	The distance between the tips of right and left middle fingers when the subject's arms are maximally extended laterally.	Work place design, design of controls.

Lesson 22. Human engineering in tractor design

1. Introduction

Human factors when properly incorporated in design, allow the operator to perform task with better efficiency, comfort and safety. Different factors which need to be considered in tractor/farm machinery design from human factor point of view are:

1. Operator-Machine interface
2. Design of instrument panel of a tractor
3. Operator exposure to environmental factors
4. Location, arrangement and easy operation of controls
5. Operator seat

This chapter provides detailed information and principles of human factors that are essential in the design of a tractor operator's workplace and are discussed below.

2. Operator- machine interface

In any activity, the tractor operator receives and processes information and then acts upon it. There are many interfaces between the tractor operator and the tractor; they include various actions such as:

- Riding in and out daily many times
- Maintenance such as cleaning, servicing and refuelling
- Riding on and operating the controls for performing desired tasks

Therefore, when a tractor operator operates the tractor, the sensing and decision making and muscular powers of the operator are attached to an engineering system (tractor). The tractor operator uses sensory system; hearing, sight, sense of smell, touch, heat/cold or feels through nervous system to the brain. The brain feels senses and interprets the inputs from the machine; the operator will then take action as a result of the decision and to interface the control instruments through manipulation to achieve the desired output of the tractor as shown in Fig. 22.1.

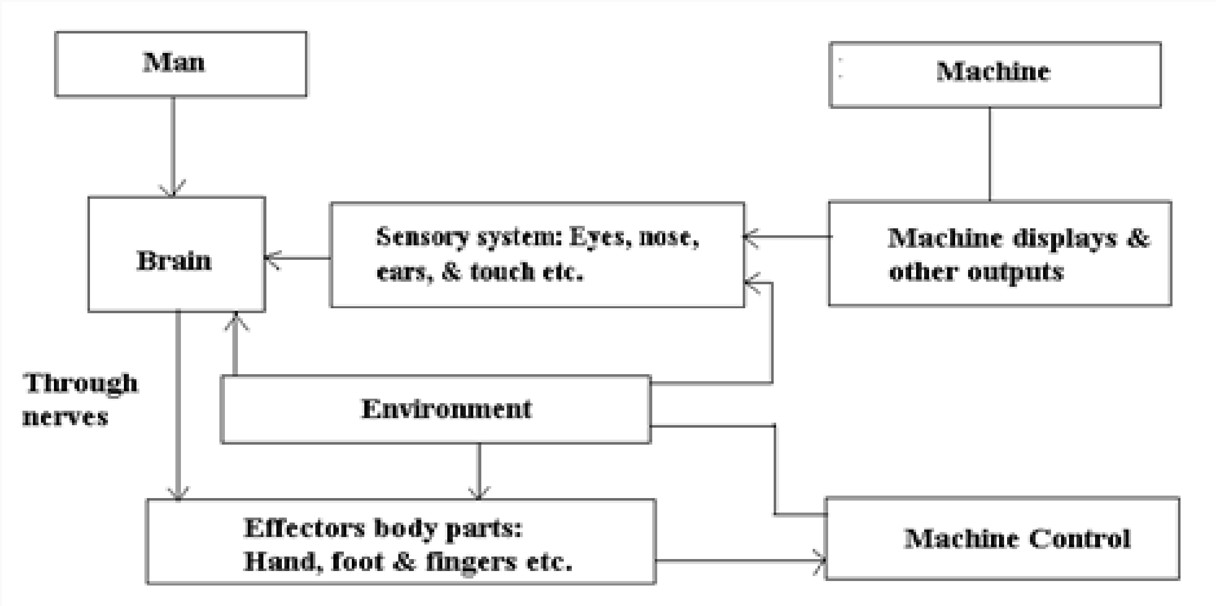


Fig. 22.1: Man –machine interface and decisions

For design of workplace for a tractor operator, following important factors/parameters should be kept in view:

1. Safety, comfort and convenience of the operator.

2. Location and construction of the operator's work place.

3. The work place should be located on the machine so that visibility in the driving position is good without requiring the operator to work in an awkward, tiring position.

4. The operator should be able to change his working position easily.

5. Levers, pedals and instruments should be conveniently and logically located.

6. The work place should fit both tall and short operators.

7. The work area should be free of sharp edges and obstruction such as transmission cases.

3. Design of instrument panel of tractor

Good visibility for the tractor operator is more important than abundant displayed information about the tractor. In order to have proper visibility over the various displays, the instrument panel of tractor should be close to the operator's line of vision with minimum eye movement away from the tasks. This would require prime instrument panel that would enhance operator's performance and minimize errors. The instruments and panel controls should be logically positioned on the tractor so that all operators become familiar with the system and be able to drive the tractor with confidence. For instrument panel design main guidelines to be followed are:

1. The instrument panel designed should be symmetrical as far as possible.
2. A central zone of high priority instruments panel should be in 30° cone for easy eye movements which is 380 mm wide at 700 mm from the operator's eye movements which is 380 mm wide at 700 mm from the operator's eye.
3. Similar functions instruments or controls should be grouped on the panel.
4. The size of related group of instruments should be same.
5. The gauges should be grouped in the priority zone horizontally and according to their functions e.g. engine gauges to the left, steering column, or tachometer or group of indicator lights at the panel center and other functional gauges to the right side.
6. All other remaining instruments can be placed on either side of the priority group and keep their relative position same.
7. The placement of controls on the instrument panel of tractor should also follow standards. The priority controls should be on the right hand side and located such that they may not interfere with the steering wheel.
8. The horn button should always be placed to the left of key ignition switch so that it can be found out easily in an emergency by the operator.

4. Operator exposure to environmental factors

Agricultural tractors are generally used under varying agro-climatic conditions. The tractor operators are exposed directly to thermal stresses due to excessive environmental temperatures, humidity, wind, dust and even chemicals during spraying and dusting operations. These environmental parameters especially temperature, humidity, air flow and dust concentrations have considerable bearings on performance and safety of tractor operator. Most of the parameters are interrelated and the tractor operator needs to be provided with a comfortable environment in order to enhance his work efficiency and safety. These parameters must be considered for design of operators enclosure of tractor to minimize their effect and provide thermal comfort and quality air in enclosures. The comfort and bearable zones of temperature, humidity and air ventilation rates are reported in Table 22.1. However, the effect of ultraviolet radiations on humans is not known so far.

TABLE: 22.1. Comfort and bearable zones of different environmental parameters

Sr. No.	Environmental Zone	Environmental Parameters		
		Temperature (°C)	Humidity (%)	Ventilation rate (m^3/min)
I	Comfort Zone Lower Limit Upper Limit	 18 24	 30 70	 0.37 0.57

II	Bearable Zone Lower Limit Upper Limit	 -1 38	 10 90	 0.14 1.4

i. Dust exposure: During performance of field operations with tractor a lot of dust is generated near the tractor operator's breathing zone especially during land levelling, tillage, harvesting (combining operation) and crop threshing. However, no specific information about the dust concentration levels near operator's breathing area is available but, some of the dust concentrations reported in field operations are:

1. In tillage operations peak dust concentrations of 577 mg/m^3 with mean value of 144 mg/m^3 have been reported
2. Permissible guideline limit for dust concentration on combines in Netherlands is 15 mg/m^3.
3. In tractor's pressurized cab at 50 Pa fitted with air filters of fine quality, dust concentration of 24.7 mg/m^3 in operator's breathing zone has been found.

ii. Exposure to chemicals: Greater use of pesticides in the field crops exposes the tractor operator to hazardous chemicals during plant protection operations. Therefore, in pesticide application operations the tractor operator should either use personal protective equipments or tractor cab/enclosure as a protective device.

iii. Thermal comfort: It is defined as state of mind that expresses satisfaction with the thermal environment. Thermo-dynamic heat exchange process between tractor operator and his environment was given by Gagge et. al(1941) as given below:

$$S = M - E \pm R \pm C - W \quad \ldots (22.1)$$

Where, S= amount of heat gained or lost, if body is in thermal balance, S=0

If S has positive value, it will cause the mean body temperature to rise and negative value will cause it to fall.

M= metabolism, 70-140 watts/m^2

E= Evapo-transpiration

R= Radiation

C= Convection

W= work accomplished

The above heat exchange is related with the operator's body surface area. The metabolic rate for a tractor operator will be in the range of 70-140 watts/m^2. Average body surface area of a man will be 2m^2 resulting in 140-348 watts. In order to maintain thermal equilibrium tractor enclosure environment must be maintained to balance the metabolism of tractor operator.

a. Metabolic heat of operator

Amount of heat produced in the body by metabolism depending on activity being performed by the operator is expressed by the following metabolic energy equation:

$$I = W + M + S \quad \ldots(22.2)$$

Where, I= energy input via nutrition

W= external work done by the operator

M= metabolic heat generated in the body of operator

S= energy stored in the body

or $I - W = \text{Constant} = M + S$ ...(22.3)

The system is in balance if all the metabolic energy M is dissipated to environment without change in quality S. The metabolic energy required to perform different physical activities is given in Table 22.2

Table 22.2: Metabolic energy required to perform different physical activities

Activity	Heat produced	
	(Kcal/min)	(KJ/min)
Basal condition	1	4.3
Light physical work	<3.50	<13.0
Moderately heavy physical work	3.50-5.25	13.0-22.0
Heavy physical work	>5.25	22.0

b. Heat exchange between operator body and environment

Heat from the tractor operator body is exchanged with the environment through Radiation (R), Convection (C) and Evaporation (E) as given below:

$$M \pm R - E = \pm S \quad (22.4)$$

Where, M= heat metabolism (according to level of physical activity)

R= radiation heat gain or loss

E= evaporation heat loss

S= amount of heat gain or loss by tissues of body (In case of thermal equilibrium S=0)

c. Heat exchange through Radiation

Radiant heat gain or loss by the tractor operator is given by

$$R= 5.7\ (t_s-t_r) \qquad \dots (22.5)$$

Where, R= radiant loss or gain, kcal/m²/hr

t_s= skin temperature, °C

t_r= radiant temperature of surface, °C

Heat exchange through Convection

The heat gain or loss by the operator through convection is given by

$$C = 0.5\sqrt{V}\,(t_s - t_a) \qquad \dots (22.6)$$

Where,

C = amount of heat loss/gain in kcal/m²/hr

V = air speed, m/min

= skin temperature, °C

= air temperature, °C

d. Thermal comfort in operator enclosures

Tractor enclosure design: The tractor operator's enclosure must provide clean air and proper air velocity, temperature and humidity for his thermal comfort to enhance his work efficiency and safety. Therefore, the enclosure design must include cab pressurization, filtration, air filtration, air movement, heating, cooling and window defrosting etc.

Comfort Equation: To predict comfortable environment in terms of combination of air temperature, man radiant temperature, air humidity and relative velocity, Fanger (1972) developed following comfort equation:

$$F\left(\frac{H}{A_{Du}}.I_{cl}.t_a.t_{mrt}.P_a.V\right) = 0 \qquad \dots (22.7)$$

Where,

H/A_{Du} = internal heat production per unit body surface area (A_{DU}= DuBois area)
A tractor operator will expend 150 kcal/h.m²

Secondary person will average 50 kcal/h.m²

I_{cl} = thermal resistance of clothing

Heavy clothing values of 0.5, 1.0, 1.5 respectively.

t_a = air temperature. °C

t_{mrt} = mean radiant temperature,°C

On bright sunny day t_{mrt} can be 5°C to 10°C above cab air temperature

P_a = pressure of water vapour in ambient air

V = relative air velocity, m/s. Cab air velocity should be in the range of 1 to 3 m/s

Above comfort equation developed by Fanger can be effectively used to predict the effects of any combination of environmental factors on the comfortable environment for a clothed tractor operator performing field operations especially during summer season.

e. Effective Temperature Scale (ET): Effective temperature is based on simple model of human physiological response and is defined as an empirical index for human thermal comfort. Most individual will be comfortable if ET (Effective Temperature) is between 24°C and 27°C. The operator can make appropriate adjustments to meet his comfort by changing following environmental factors:

1. Air speed and its direction
2. Air temperature
3. Clothing worn

5. Spatial, visual and control requirement of the operator

i. Work place layout: The layout of workplace should be compatible with not only system performance requirement but also with the user. It should also ensure safety and comfort of operator and controls must be within the reach to minimize errors. Proper workplace layout requires consideration of workplace dimensions, controls and operations being controlled with due regard to:

- The operator's size
- His position and the directions in which he can most easily work.
- The optimum spaces in which he can manipulate the controls
- Arrangement of controls and displays
- Visual requirement for maximum operator efficiency
- Working posture of the operator viz. Sitting, standing or squatting
- Special influence such as protective clothing.

To decide about proper workplace layout following important factors must be considered:

- Anthropometric parameters of operators
- Placement of operator on tractor for optimum work task vision or vision of displays
- Placements of controls in optimum areas for the operators.

ii. Anthropometric Data: Human being must not only fit spatially in a man task system, but must also be able to move in the work space. With the aid of anthropometric data we can provide an optimum work space layout, including good posture, contributing to considerable decrease in work load and an improvement in the performance. In design of work space and other facilities various considerations need to be taken. In particular, the type of people and their body dimensions are given in Table 22.3. Normally, during collection of human engineering data skip the first and last five percentile. Thus while designing a seat, it should be designed to accommodate a reasonable range of individuals, usually from 5^{th} to 95^{th} percentiles. The seat must be adjustable in a fast, easy and safe way-in horizontal and vertical direction to realize an adoption to the measurements of various population groups. Seat should be designed to take maximum weight expected. In order to realize a good performance, it is necessary that the movements of the body members are in synchrony, simple and logical motions are made, which can be performed almost automatically by the central nervous system. Lower percentile values of seat height and seat depth should be taken. Layout studies can be carried out to find maximum and optimum work space area.

Table 22.3: Body dimensions of tractor operators

S. N.	Dimensions	Percentile		
		5^{th}	50^{th}	95^{th}
1	Height, cm	162	173	185
2	Seating height erect, cm	84	91	97
3	Seating height normal, cm	80	87	93
4	Knee height, cm	49	54	59
5	Popliteal height, cm	39	44	49
6	Elbow rest height, cm	19	24	30
7	Thigh clearance height, cm	11	15	18
8	Buttock knee height, cm	54	59	64
9	Buttock Popliteal length, cm	44	50	55
10	Elbow to elbow breadth, cm	35	42	51

11	Seat breadth, cm	31	36	40
12	Weight, Kg	58	75	98

iii. Placement of operator for optimum vision

The seat of tractor must give the operator an optimum field of vision and be in a position on the tractor which helps give him comfortable and safe operating conditions. Tractor operator may require vision to front and rear, or front and sides. A wide field of vision is required for both short and long ranges. Moreover close range vision is required during handling of mounted implements. These visibility requirements are satisfied by upright seating posture in order to permit easy movements of head and upper body from the front, to side, or rear as required for gathering necessary visual information. Good visibility for the operator is more important than excessive number of displays, especially when the machine is operating satisfactorily. The display area has to be close to the operator's line of vision which requires only minimum eye movements away from his task. Table 22.4 would be quite helpful in designing the location of displays of tractor in relation to the operator.

Table 22.4: Optimum vision of operators

Type of movement	Direction	Lateral		Direction	Vertical	
		Opt.	Max.		Opt.	Max.
Head rotation only	Left and right	0	60	Up and down	0	50
Eye rotation only	-do-	15	35	-do-	0 30	25 35
Head and eye rotation	-do-	15	95	-do-	0 30	75 85

iv. Control requirements of operator

A control is a device or hardware that can be considered as a link between the tractor and operator which converts the output of operator into input and change of state of tractor. Concept of optimum dimensions and limiting dimensions is used in placement of controls in space and dimensions usually chosen to define boundaries of the space is estimated to cater for 5^{th} to 95^{th} percentiles of operators. The optimum dimensions defines that most desirable space or ideal area for the location of most important and frequently used controls both in neutral position as well as in working position in any direction. The limiting dimensions define the acceptable but not the most desirable space for location of controls as the controls are neither too close nor too far from the operator. Generally two types of controls are used in tractors i.e. hand controls and foot controls.

a. Hand Controls:

Variety of hand controls is commensurate with the versatility of the hands. Hand controls can be operated either in sitting position or standing position, but seated position is preferred to the standing position especially when the controls are used for any length of time. Use of controls in standing position is less efficient and results in fatigue. Moreover, the accuracy of movement will be lesser in standing position. Hand controls are precise and have high speed. Certain hand controls can be used effectively without vision or without looking at the control e.g. gear levers. Hand controls are much more accurate and are preferred to foot control where, accuracy of control positioning is important and continuous or prolonged application of moderate or large forces (89N or more) is necessary.

b. Location of Hand controls:

The comfort zones are easy to reach and the controls which do not require movement of upper body should be located based on anthropometric dimensions of tractor operators. The comfort angles of hands should be maintained for easy reach of controls. The forearm should not be raised much above the horizontal to avoid fatigue. The controls must look efficient, attractive and easy to use. When all controls in a tractor are put together, it is desirable that these are logically arranged in orderly manner and well balanced and well placed that enables the operator to perceive the interrelationship. Preferred hand should be used where speed, accuracy or strength of controls movement is important. The optimum area of hand controls for adult operators in seated position is given in Fig.22.2.

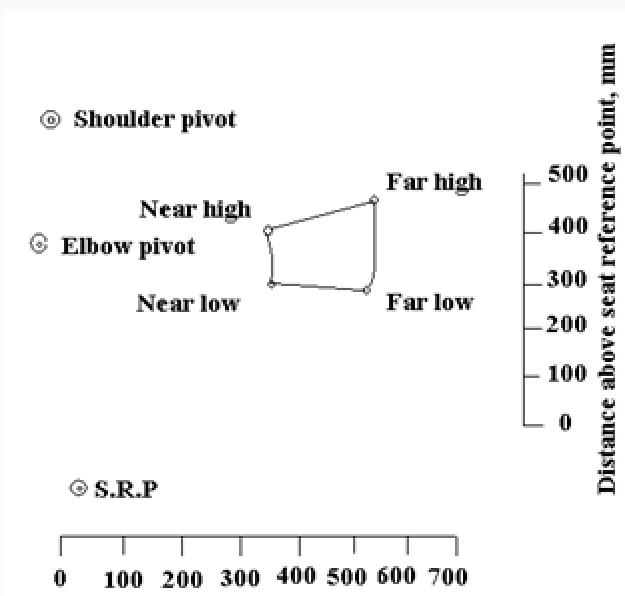


Fig. 22.2: Optimum area of hand controls for an adult operators in seated position

For proper location of hand control following points must be keep in mind.

- Normally the dimensions of control placement are with respect to seat reference point.

- The reference point should be adjustable at least 75 mm horizontally and 125 mm vertically.
- Recommended dimensions for optimum manual control area is about 600 mm wide and 300mm to either side of midline.
- When all controls cannot be placed with in the optimum area, locations immediately adjacent to optimum control areas are more desirable than those farther away.
- The upper arm should make 50° angles with the upper body line and the fore arm should be 165° to the upper arm.
- The controls must be kept approximately in a line ahead of shoulder joint so that the elbow is not required to move sideways from the body at angle more than 20°.
- Grouping of the controls is important. Primary controls which are used continuously for a longer period of time should be placed as near to or within the horizontal planes 0-300 mm.
- The controls such as engine and transmission (throttle, gear shift), hydraulic function controls which require accurate manipulation should be grouped and placed on the right hand side of operator.
- The controls which generally do not require accurate adjustment i.e. P.T.O clutch, differential lock, parking brake can be provided towards left hand side of operator. However, these must be visible and reached easily by the operator. Steering wheel can be operated by left hand during use of other controls.
- A difference in shape in knobs of different controls will help avoid errors in their use separately. Moreover clearance between the adjacent knobs should be 25-50 mm. if these controls are used blindly their spacing should be 125-175 mm with shape coded knobs

v. Foot Controls: Foot controls should be designed to be operated in seated position and backrest should be provided. Most people prefer the right leg especially for critical tasks. A maximum of 4 foot controls can be operated by an operator who does not require skill or practice. These are best for provision of powerful or continuous force. Foot controls are to be used in preference to hand controls where,

a) There is continuous control task and precision control positioning is not important.

b) Application of moderate to large forces (89-130N) is needed intermittently or continuously.

c) Hands are in danger of being overburdened with control tasks.

Pedals are provided in relation to floor and seat, based on anthropometric data of operators. The pedals should be provided with non-slip surface. The force required to operate each control is dependent on mechanical equipment and comfort of riding the tractor. The restoring force of pedal should be large enough to support the weight of foot. The pedals are divided into two groups:

- Group-I: When the force used by the leg is above 44-89N, e.g. brake pedals.
- Group-II: Where small force (about 44N) is largely obtained from the ankle for continuous operation e.g. accelerator pedal.

Location of foot controls: After determination of optimum seat position on the tractor, location of most frequently used controls in relation to seat should be provided for comfort and safety of operator. The size, shape and location of foot controls and the space in which the operator has to work must be decided based on anthropometric dimensions of operators from 5th percentile to 95th percentile. Both small and large operators sit with their heels on the same heel point. The optimum foot pedal area may be selected by locating the comforts zones which are easy to reach. The optimum foot pedal area for location of foot controls both in neutral position and when displaced in any direction. The angle of comfort of leg 20° either side of centre may be taken for location of foot controls and accordingly brake pedal and clutch pedals may be positioned.

(a) For light pedal pressures (44-89N), the foot should be applied to the pedal so that long axis of the tibia (lower leg) is immediately over and in line with the axis of pivot of pedal.

(b) The long axis of foot and lower leg should form 90^{o} angle, thus requiring least muscular effort to hold the foot in position.

For location of foot controls in seated position in optimum areas, following are three main considerations:

(i)The fore and aft location : The distance from seat reference point (S.R.P) to pedal is an important determinant of amount of pressure exertible on the foot control, as smaller the distance more the exertaible force.

(ii)Vertical location: Where comfort matters more than the exertible force, the foot pedals can be placed below S.R.P. by vertical distances varying from type of task performed.

(iii) Lateral fore and aft location : As pedals are moved laterally from midline of leg, the exertible force decreases and discomfort of operator increases. The reduction in exertible force is related with the lateral distance and is given in Table 22.5.

TABLE 22.5: Relation between lateral distance of leg and exertible force

S.N.	Lateral distance on either Side of leg, mm	Reduction in exertible force (%)
1.	75	10.0
2.	175	27.0
3.	250	37.0

Therefore, when placement of pedal at leg mid line is not possible, it should be displaced only 75-125 mm from mid line.

6. Operator seat

Tractor seat is most closely linked with the operator's comfort and it must be able to provide with comfortable and controlled seated posture to the operator. It must provide the operator adequate vision to perform all the tasks safely and efficiently. All the hand and foot controls should be positioned in relation to seat in such a way that these can be operated with ease and with minimum possible efforts by the operator in seated position. Above all it should be able to reduce/absorb the mechanical shocks and vibrations transmitted to the operator. It should be strong, stable and reliable and extremely durable with minimum cost. Seat should be designed to accommodate, equally well, the total population of tractor operators, regardless of age and gender with a reasonable range of individuals, usually from 5 to 95 percentiles. The top view of tractor operator seat and the terminology related with tractor seat is given in Figs. 22.3 and 22.4 respectively. Therefore, for ergonomic design of tractor seat following important points must be considered:

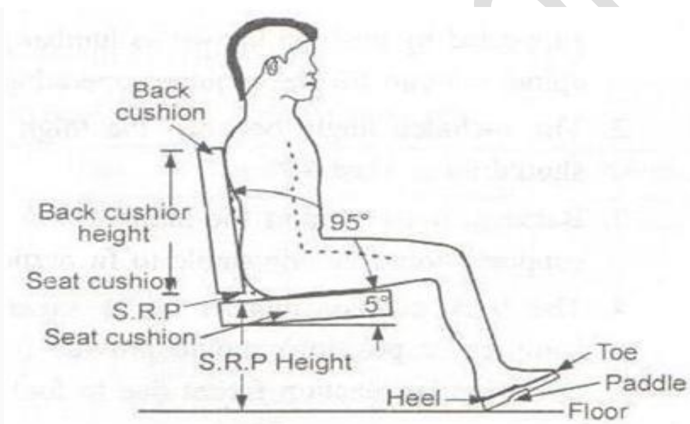


Fig. 22.3: top view of tractor operator seat

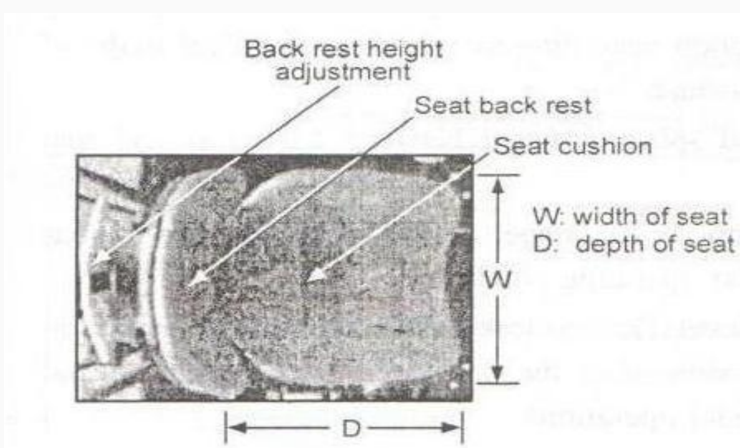


Fig. 22.4: terminology related with tractor seat

i. Seat height range:

The seat height should accommodate 5 to 95% population. So, based on anthropometric data, the seat height for small people with a 10 cm seat adjustable to accommodate larger people should be selected.

1. Seat adjustments should provide at least 150mm of fore and aft movement for accommodating larger size operators.

2. Seat adjustments should provide at least 100 mm of vertical movement to accommodate larger size operators.

ii. Seat width: The seat width should be selected for 95% population.

iii. Seat depth: Again, it should accommodate 95% population.

iv. Seat cushion:

1. Weight of buttocks and thighs should be properly supported by a seat cushion. Human buttocks have bony structure known as ischial tuberosities are capable of transmitting body weight directly and uniformly from spinal column to the seat cushion. If seat cushion is not properly designed according to physiology of buttock region, after a prolonged time (2 to 4 hours) it may result in high degree of discomfort or pain to the operators.

2. Most of body weight of operator should be supported by ischial tuberosities. Peak pressure under the ischial tuberosities should be limited to 90 g/cm^2 by providing flat and firm cushion in the central region of seat.

3. The pressure in the thighs of operator should be limited to 30 g/cm^2 to avoid pinching of nerves of thighs which can be accomplished by cushion contour, cushion tilt, cushion firmness at the front and seat height above the foot support.

4. The seat cushion should be elevated by 5 degree seat angle from horizontal from the front side of seat.

v. Back cushion:

1. In order to minimize backache and fatigue the upper body of operator should be properly supported by cushion known as lumbar support according to natural geometrical shape of spinal column for the required operating posture.

2. The included angle between the thigh and spine or angle between back rest and seat should be at least 95°.

3. Backrest must support the lumbar back properly for longer period of sitting. The lumbar support should be adjustable to fit particular operating conditions.

4. The back cushion/support up to sacral level (75 to 150 mm above seat cushion in compressed position) should provide firm support to the operator's back during normal operation i.e. reaction forces due to foot pedal operations.

5. For free swing of shoulders and arms the back cushion width of tractor seat should be limited to 330 mm.

6. For free swing of shoulders and arms the back cushion height of tractor seat should be limited to 330 mm.

vi. Arm rests:

(a) Armrests should be provided for support and comfort to shoulders

(b) Armrests should be adjustable vertically for varying sizes of persons.

vii. Location of controls in relation to seat:

- All the hand and foot controls should be positioned in relation to seat in such a way that these can be operated with ease and with minimum possible efforts by the operator in seated position.

- Leg to thigh angle should be 110-120° for pedal operation with a minimum foot-to-leg angle of 90°.

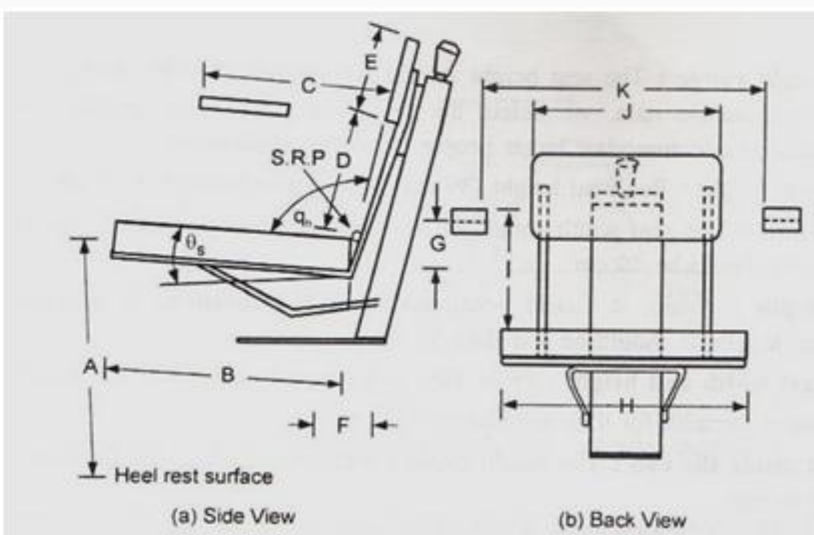


Fig. 22.5 Optimum design of tractor seat

Based on anthropometric data of tractor operators the optimum design of seat incorporating all the desirable features are reported in Table 22.6 and Fig. 22.5 given below:

Table 22.6: Optimum tractor seat design dimensions, mm

Sr. No.	Description	Item	Maximum	Minimum	Nominal
1	S.R.P height	A	-	375	400
2	Seat depth	B	400	375	-
3	Distance of arm length from seat back	C	150	125	-
4	Distance of S.R.P from lower end back	D	200	175	-
5	Back cushion length	E	150	125	-
6	Fore and aft. Adjustment	F	150	100	-
7	Vertical adjustment	G			
8	Seat cushion width	H	-	-	475
9	Back cushion width	I	325	-	-
10	Arm rest height	J	250	200	-
11	Arm rest lateral spacing	K	-	-	475
12	Seat cushion angle	Θ_s	7°	5°	-
13	Back cushion angle	Θ_b	115°	110°	-

Lesson 23. Tractor noise, vibration and other environmental factors

1. Introduction

There are different sources of pollutions, when tractor is used to perform different operations in agriculture. Operator is the main subject to be affected by tractor noise and vibration including other environmental factor like dust etc. Different types of pollution sources during tractor operations are explained in the following sections

2. Noise

The noise produced by engines may cause discomfort, nervousness, tension, irritability and fatigue. Levels from 86 to 115 dB(A) can cause specific effects to the ear such as the damage of the corticells and can involve psychosomatic diseases. Noise also results in increase in the pulse rate & blood pressure and irregularities in heart rhythm. Occupational Safety & Health Administration, USA has given a standard OSHA-1910.95 for occupational noise exposure. It mentions that the permissible daily (8-h) exposure to the operator is to be upto 90 dB (Table 23.1). The other remedial measures against noise as health hazard may be noise reduction at source or at emission or use of personal protection such as ear plugs.

Table 23.1. Permissible daily noise exposure as per OSHA -1910.95.

Duration per day, hours	Sound level, dB(A)	Duration per day, hours	Sound level, dB(A)
8	90	1.5	102
6	92	1.0	105
4	95	0.5	110
3	97	0.25	115
2	100	--	> 115

i. Operator exposure to noise

Zander (1972) stated that the application of human biological sciences to achieve the optimum mutual adjustment of man and work, the benefits being measured in terms of human efficiency and well being. Human factors when properly incorporated in design, allow the operator to perform task with better efficiency, comfort and safety. In tractor design, noise is one of the important factors which need to be considered, as the design of tractor operator work place has direct impact on noise levels at operators' ear level. Noise is unwanted sound and its effect depends on frequency, sound pressure level and duration of exposure. Noise in tractor is generated due to rotating and reciprocating parts, vibration in engine components, exhaust gases and flow of hydraulic fluids. It is transmitted by the moving (rotating, reciprocating and vibrating) structural components of tractor or air borne or combination of the two. The tractors generate sound in the range of 125-500 Hz depending upon age and ear sensitivity. Hence, continued exposure of tractor noise to its operator will have harmful effects on their comforts and efficiency. Noise has annoying and damaging effect. Therefore, the design of mechanical components of tractor and its engine to limit the sound energy levels for operator's comfort and efficiency is a challenge for the design engineers.

Noise: It is defined as acoustic sound or unwanted sound and is wasted energy damaging to human ear which is physically speaking, mechanical vibrations in gaseous, fluid or solid medium. It is characterized by frequency, amplitude and phase. The simplest vibration is a pure tone that consists of sinusoid with frequency

The frequency is given by

$$f = \frac{1}{T} \quad \text{... (23.1)}$$

Where,

T = period in seconds.

The magnitude of noise is usually expressed in terms of RMS (root mean square) value, which is given by

$$A_{RMS} = \frac{1}{\sqrt{2}} \times A_{PEAK} \quad \text{... (23.2)}$$

It is measured with the help of noise level or decibel meter has got three frequency weighing scales A, B and C. It is expressed in terms of dB(A). The sound level meter incorporates electrical circuits known as weighing networks. A, B, C scale operating conditions can be selected on the sound level meter. Least sensitivity is provided in A-scale and highest in C-scale. A-scale is used for measuring frequencies that human ear can detect.

Sound Pressure Level (SPL): It is expressed as sound level (SPL) relative to reference sound pressure.

$$SPL = 20 \log \frac{P}{P_0} \, dB \quad \text{... (23.3)}$$

And $$SPL = 20 \log \frac{P}{0.00002} \quad \text{... (23.4)}$$

Where,

P = measured RMS sound pressure, N/m^2

P_0 = reference sound pressure, N/m^2

log = logarithm to the base 10

Sources and effect of noise on tractor operator: According to Nebraska's Organization for Economic Cooperation and Development (OECD). Tractor tests the tractor noise level at the operator's site will be in the range of 89-98 dB (A). Almost all the models of tractors manufactured n India also produce noise level in the range of 88-100 dB (A). Noise levels of farm machinery ranged from 90 to 97 dB (A) for the operations normally carried out by the operators.

Noise sources in tractor: One of the major problems associated with the tractor is the high level of noise emission. Main sources of noise in tractors given under different categories are as:

Tractor engine: High noise generating components in tractor engine are:

(a)Engine exhausts (b) Intake
(c) Combustion (d) Piston slap
(e) Fuel injection pump (f) Valve train
(g) Gears (h) Bearings

(i) Crank shaft

- Hydraulic system
- Differential (power transmission system)
- Brakes etc.

Out of the above noise sources in a tractor, the noises produced by combustion and piston slap are the biggest sources of noise. It is mainly caused due to pressure pulsation and turbulent flow created by sudden opening and closing of inlet and exhaust valves. The tractor operators in India are exposed to noise levels above the safe permissible limit drawn by Occupational Safety and Health Agency (OSHA), ILO and BIS in 90% of models of all category of tractors.

Levels of noise of different sources: The generation and transmission of noise by various sources depend on the frequency and level of noise. It has been reported that highest sound levels on tractors were in the frequency range of 75 to 300 Hz (Weston 1963). Noise levels of different sources are given in Table 23.2.

Reference air borne sound pressure level (SPL) = 0.00002 N/m^2 = 0 dB

The noise conservation measures are mandatory at 65 dB (A) and noise controls are required when noise levels reach 90 dB (A) for 8 hours a day.

Principal effects of noise: Communication between man and his tasks (or men) takes place through hearing. Human ear converts the sound wave into neural signals which can be transmitted to brain. Exposure to noise may adversely affect overall efficiency, Safety and hearing ability of the workers. The entire spectrum of audible noise range from 20 Hz to 20 kHz and deterioration in threshold of hearing (DITH) was observed in all the audible frequencies if close of noise is continuous for longer period of time. The noise generated is beyond tolerable limits. OSHA in USA has set permissible noise exposure level of 90 dB (A) to 8 hours per day. The average working hours per day of farm machinery operators vary from 12-14 in sowing and harvesting season and 5-6 h in lean season. The exposure to noise in sowing/ harvesting season is sufficient to cause noise induced hearing loss (NIHL).

Table 23.2: Different sources and levels of noise

Sr. No.	Source	Levels
1.	Modern Tractor with cab	80 dB (at operator's ear)
2	Tractors without cab	89-98 dB (at operator's ear)
3.	Threshers and Combine harvesters	90-98 dB
4	Power operated spray pumps	90-98 dB
5	Power Tiller operator zone	105-110 dB
6	Milling machine (1.2 m)	86 dB
7	Cotton ginning Machines	96 dB
8	Power lawn mover	98 dB
9	Pneumatic chipper (2m)	113 dB

The noise environment and its severity associated with the tractors may have following main effects on the operators:

- Undesired physiological reactions as noise is annoying (objectionable to unbearable).
- Lowering of concentration, fatigue due to longer exposure and interference which decreases the speed, quality and precision of work. Longer exposure to noise may affect the performance in terms of rhythm disturbance and interference with worker to worker communication in a team.
- Hearing loss due to continuous and prolonged exposure to high noise levels.
- Damage to hearing caused by noise (temporary and permanent) due to hearing thresh hold shift. Excessive noise would cause more strain on operator and may result in permanent hearing loss. They experience stress related disorders and suffer temporary or permanent shifts to hearing ability. This is due to deterioration in threshold of hearing (DITH).
- Heart rate of tractor operator increase with increased exposure of noise.

- Greater incidence of physical illness and increased strain among those exposed to high intensity noise. Evidence of pathological effect of continuous exposure of 95 dB (A) or more was reported by some researchers.

3. Vibration in tractor

The vibration is defined as oscillatory motion about a fixed point. It is defined usually by its frequency, amplitude, velocity, acceleration and direction. However, the human vibrations are measured in terms of acceleration only. Mechanical vibrations have instantaneous and long term effects upon the human body. Kinds of effect depend upon the duration of exposure and the frequency of vibrations. In walk behind type machine, vibrations are transmitted to the operator through his hands. In case of a riding type, vibrations are transmitted to the operator through seat as whole body vibration (WBV) and through his hands as hand transmitted vibrations (HTV). Workers exposed to hand arm vibrations often experience aches and pains in upper limbs. Daily exposure to hand arm vibrations over a period can cause permanent physical damage known as "White Finger Syndrome" or Reynaud's phenomenon of occupational origin. Exposure to whole body vibrations can cause back injury. Hence measurement and evaluation of human vibrations are necessary for assessing operator's comfort and to suggest remedial measures for continuous operation of machine. The vibration studies are to be conducted as per standard guidelines. The ISO 5349-1 & 2: 2001; ISO 2631-1: 1997; ISO 9996: 1996; ISO 5805: 1997; ISO 13090-1: 1998; ISO 10816-6; BS 6841: 1987; IS 13548: 1992 are used in vibration studies.

I. Human exposure to vibrations: Any engineering system possessing mass and elasticity are capable of relative motion. When this motion repeats after a given interval of time, then this motion is known as vibration. In many cases it is undesirable and is a form of wasted energy. This is particularly true in tractors and farm machinery as they generate noise, break down parts and transmit unwanted forces and movements to different components. Vibrations and noise in tractor are generated due to rotating and reciprocating parts, vibrations in engine components, exhaust gases and flow of hydraulic fluids. These are transmitted by the moving (rotating, reciprocating and vibrating) structural components of tractor of air borne or combination of the two. The physical objects have their individual resonant frequencies which are a function of their mass. Tractors with pneumatic tyres have resonant frequencies primarily in the range of 1 to 4 Hz and for track type tractors more than 4Hz. It is important to note that in the frequency range of 4 to 8-Hz, human tolerance to vibration is minimum. Exposure of human body to vibrations can result in

- Biological effects
- Mechanical effects
- Psychological effects

II.Vibration: It can be defined as an oscillatory motion of mechanical system and can generate sound in a gas, fluid, or solid medium. Vibration is characterized by frequency, amplitude and phase. In the simplest case mechanical vibration can be derived from simple harmonic wave form. In vibration analysis, the frequency of periodic motion is number of cycles per unit time and it is a function of time period as given below.

$$f = \frac{1}{T}$$

Where,

T= period in time required for a periodic motion to repeat itself in seconds

The frequency of vibration can be sinusoidal, complex or random. It is important to note that in the frequency range of 4 to 8Hz, human tolerance to vibration is a minimum.

III. Types of Vibrations

The vibration in a system can be of following two types:

Forced vibration: It is defined as the periodic motion observed, as the system is displaced from its static equilibrium position. The forces acting are spring force, the friction force, the weight of the vibrating mass and external forces acting on the system during its vibratory motion. The system will tend to vibrate at its natural frequency at forced vibration. This will follow the frequency of the excitation force. In the presence of friction, the portion of motion not sustained by sinusoidal excitation force will gradually die out. As a result of this the system will vibrate at the frequency of excitation force regardless of initial conditions or natural frequency of the system. The part of sustained vibration is called as steady state vibration or response of the system.

Free vibration: It is defined as the periodic motion observed as the system is displaced from its static equilibrium position. The forces acting are spring force, the friction force and the weight of the vibrating mass. This may occur when after an initial disturbance, no external force is present i.e. F (t) =0. The vibration will diminish with time due to pressure of friction. This is sometimes called as transient vibration. The differential equation for free vibration would be as under:

iv. Vibration in tractor chassis: The tractor driving may have considerable ill-effects on the health of operator. This is largely due to effect of vibrations and shock continuously acting on human body and setting up harmful stamina and partly to the need to keep the body in cramped condition and unhealthy posture for long period. Tractor ride vibration intensities are normally related with the ground speed. The vibrations become intolerable as the speed is increased. Tractors with pneumatic tyres have resonant frequencies primarily in the range of 1 to 4 Hz and for track type tractors more than 4Hz. It is important to note that human tolerance to vibration is minimum in the frequency range of 4 to 8 Hz, According to survey majority of large tractor are found to be operating at less than two-third of maximum power because of following reasons.

- Operator’s inability or unwillingness to withstand the ride at full speed.
- Ride induced vibrations do have ill-effects on the operators.

Therefore, proper care must be taken in designing tractors particularly their seat.

- To reduce vibrations and shocks to a minimum by appropriate suspension and shock absorption.

- To arrange the tractor controls in a manner to a comfortable posture and minimum effort.

Vibration input to tractor seat due to vertical motion of tractor body as tractor ride vibration intensities are positively related with ground surface and ground speed during field operations is given by following equation:

$$Zi = Zt + \theta g \quad \text{... (23.5)}$$

Where, Zi = Vertical motion input to tractor seat, m

Zt = Vertical motion of tractor e.g., m

θ = Rotation or pitch about tractor e.g, radians

g = Longitudinal distance from tractor seat to c.g, m

4. Tractor Seat Design

From vibration point of view: Tractor seat suspension for vertical vibrations transmitted by the tractor chassis to the seat and experienced by the tractor operator. During the process of whole body vibration of tractor operator, the vibration transmitted to the body can be amplified or attenuated due to body posture, type of seat and frequency of vibration. The dynamic performance of seat suspension can be analyzed based on output vibration in response to a given input vibration, which can be expressed as a function of

- frequency of input vibration
- seat spring rate and
- mass damping properties

From eqn. 23.6, it is clear that ω (undamped natural frequency) of the seat is a vital Parameter for matching with vibration input from the tractor. The value of ω (undamped natural frequency) of the seat should be less than the frequency input from the tractor chassis.

Therefore,

$$\omega_t > 1.414\omega_n$$

to avoid vibration attenuation in the seat suspension. A soft spring should be used to keep the natural frequency value to a minimum. This will also affect ease of adjustment and convenience of the operator.

Also $$C_c = 2 \times M \times \omega_n \quad \text{... (23.6)}$$

Where, M = mass of tractor seat and tractor operator, kg

ω_n= undamped natural frequency of tractor seat, rad/s

It has been observed that the seat suspensions used on tractors and agricultural machines would normally require a damping rate © of about 30-50% of critical damping rate (C_c). Damping can be controlled by appropriate seat design, spring design and cushion of seat. Thus, the physical effects of vibration on whole body of operator are greatly influenced by body posture, and materials provided between the body and source of vibration i.e. seat, cushion and springs etc.

A properly designed seat can effectively reduce the vibration intensity which would otherwise be transmitted to operator, especially in low frequency range (2 to 5 H_z) and may have considerable ill-effects on the health of operator. The tractor seat suspensions are comprised of cushions mounted to resilient spring/damper to reduce the level of input tractor chassis vibrations.

5. Effect of whole body vibrations on operations

Exposure of human body to vibration can result in Biological, Mechanical, Physiological and Psychological effects as given below:

1. There may be direct mechanical interference with the activity due to whole body vibrations.

2. The whole body vibrations may result in increased working stress level, tension and deformation as a source of localized pain and fatigue.

3. General discomfort and anxiety with certain subjective sensations which may be annoying to the operators.

4. Abdominal, chest and testicular pains which may be contributing to operator's long term health.

5. There may be indirect physiological induced alterations/effects on metabolism.

6. The combined mechanical, physiological and physiological responses to sinusoidal vibrations can affect the operator's ability to perform control functions in different types of tasks as under:

(i) Visual tasks: dial reading, visual scanning

(ii) Simple motor task that require precision and coordination

(iii) Psychomotor tasks including tracking tasks

7. Fatigue in the body.

6. Dust

Dust consists of tiny solid particles carried by air currents. Agricultural activities like field preparation, harvesting and threshing produce a lot of dust. Larger particles settle down while lighter ones remain suspended in the air.Respirable dust (size 0.1 to 5 microns) penetrates the respiratory system and settles deep into the lungs; thus acting as serious health hazard. Personal dust protecting masks, having plastic net, tissue paper, cloth, foam, etc. as filtering material, gives sufficient protection against respirable dust.

Lesson 24. Safety features including ROPS in tractor

1. Introduction

Farm mechanization along with increased application of other agricultural inputs enhanced the productivity and production in agriculture. But on the other hand, it has also increased casualties through agricultural accidents. Loss of human life brings sorrow to the victim's family and to the society; in addition to causing considerable loss to the country as a whole. There is a wide ignorance or misconception about the meaning of accident. The definition of accident states that a) accident is an unexpected, unplanned and unwanted event or a sequence of events; b) occurs through a combination of causes; and c) results in physical harm (death or injury) to an individual, damage to machine or properties, economical loss or a near miss. Tractors are frequently involved in accidents leading to major physical injuries and even death. The tractor and trailers related accidents can be reduced by installing safety gadgets and by following safety guidelines during use.

2. Slow Moving Vehicle Emblems (SMVE):

It is a fluorescent orange equilateral triangle with a red reflective border. It is to be fitted on rear side of tractor seat and on left and right rear side of trailer. The orange colour is visible in sunlight; whereas, red border reflects light when headlight of vehicle coming from rear side falls on it. The length of each sides of SMVE should be 44.5 cm but not less than 20.0 cm, if need be. Due to Government regulation all of new tractors being sold in India are fitted with SMVE (Fig. 24.1).

3. Roll Over Protective Structure (ROPS):

A tractor with Roll Over Protection Structure (ROPS) provides the safety to operator (Fig. 24.1) against being crushed under the tractor in case of accidental overturning. The ROPS have sufficient strength to bear safely the load of tractor in case of overturning. However, the driver must wear seatbelt to get benefit of ROPS.

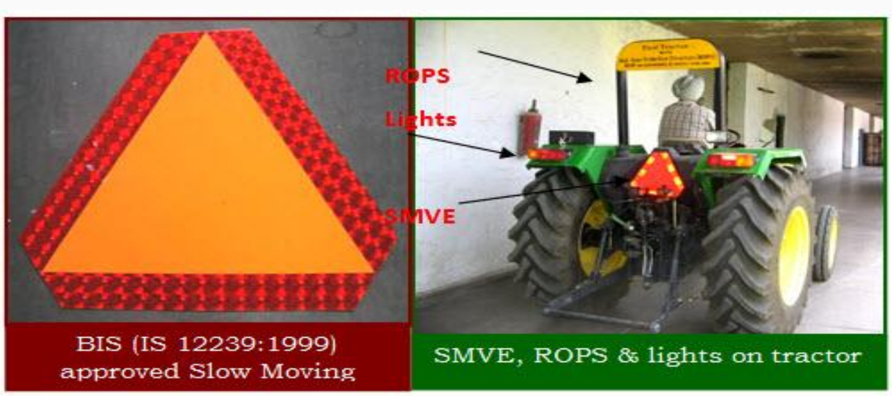


Fig. 24.1: Standardized SMVE (IS12239:1999) and ROPS for tractor and trailers

4. Hydraulic brakes for trailers:

The tractor brakes should be in a good condition to stop it within desired distance. If the tractor is to be frequently operated with a loaded trailer, hydraulic brakes can be fitted on trailer too. The hydraulic brakes of trailer are coupled with tractor near the PTO link. The brake pedal of tractor, when pressed, activates the brakes of tractor as well as trailer (Fig. 24.2).

Fig. 24.2: Tractor trailer with hydraulic brakes

5. Lights:

The tractor should have all lights in full operational conditions. These lights include headlights, tail-lights, brake lights, reversing lights and turning indicators. The trailer should also have lights fitted on the rear side. These lights can be coupled with tractor in such a way that control switches provided on the tractor operates the tractor as well the trailer lights.

6. Other Safety guidelines during tractor trolley use:

- Don't use intoxicants like liquor, opium, etc. while operating.
- Don't make adjustments when tractor is in operation.
- Don't put or take off belt while pulley is running.
- Don't sit or stand at unsafe places such as drawbar, mudguard, load, etc. when tractor is moving.
- No person should mount or dismount from a tractor while it is in motion, except in an emergency.
- Don't wear loose clothes, shoes, etc.
- Put the gear, PTO to neutral and lower the attached implements to ground before leaving the stopped tractor.
- Lock the brake pedals together when traveling on public roads.
- Stop at all unguarded railway crossings and make sure that no train is coming.

- Operator should use a seat belt when operating tractor fitted with ROPS or cabin. It is strongly recommended that no seat belt be used if ROPS or cabin is not provided.
- To avoid sideway overturning of tractor, special care should be taken during driving at sharp slope, uneven, soft or slippery ground, alongside ditches or banks, during turning or reversing.
- To avoid tipping backward, special care should be taken while driving heavy loads on a slope, soft ground, ditches or uneven ground. If necessary, front of tractor should be fitted with dead weights.
- When traveling on public roads, keep on the correct side of the road. Use light signals with intention to turn, stop or slow down.
- While transporting farm produce, trailer should not be overfilled or over loaded.
- Use rear view mirror in properly adjusted angle.

Module 10. Tractor testing

Lesson 25. Standardization and importance of testing for tractors

1. Introduction

Agricultural machines are mostly being manufactured by the small scale manufacturer except established manufacturers of tractors. Testing of Agricultural machinery including tractors is the only solution to make the manufacturers clear about performance and durability of the equipment for proper/efficient utilization along with the technical information available to the farmers for proper selection of the required equipments.

Testing is defined as analysis of behaviour of machine when compared with standard codes/norms under ideal and repeatable conditions. On the other hand evaluation involves measurement of performance under actual field/working conditions. Testing deals with measurement, variation and computation of various indices as per norms prescribed by an authorized institution. Testing of farm machines with a standardized set out procedure has a major role in the judicious selection. Testing provide an important means not only for making an appraisal of an equipment but also for in-building the requisite level of quality by exercising proper checks during production.

2. Importance of testing:

Testing of a machine means systematic determination of functional performance, structural strength, durability, power requirements and capacity by running the test under a wide range of conditions in the laboratory and field. Testing is useful for all the stakeholders like manufacturers, consumers/farmers, exporters, export inspection agencies as well. How testing is important for

Manufacturers:

- Streamlining of production processes and introduction of quality control system.

- Independent audit of quality control system by BIS

- Reaping of production economies accruing from standardization

- Better image of products in the market both internal and overseas

- Winning for wholesaler’s retailers and stockiest consumer confidence and goodwill

- Preference for standard marked products by organized purchasers agencies of Central and State government, local bodies, public and private sector undertaking etc. Some organized purchases offer even higher price of standard marked good.

- Financial incentives offered by the Industrial Development Bank of India (IDBI) and nationalized banks.

- To know where his machine stands in comparison with similar types of machines in the market, and he can improve his product.

- It enables him to add more information to the technical literature relating to the machine.

Consumer

- Conformity with Indian standards by an independent technical national level organization.

- Helps in choosing a standard product

- Free replacement of standard marked products in case of their being found to be of substandard quality

- Protection from exploitation and deception

- Assurance of safety against hazards to life and properly

- The knowledge of the comparative performance of similar type of machinery will help the user to choose an appropriate machine to his requirement at the lowest cost

Organized purchasers

- Convenient basis for concluding contracts

- Elimination of the need for inspection and testing of goods purchased saving time, labour and money

- Free replacement of products with Standard Mark found to be substandard

Exporters

- Exemption from pre-shipment inspection wherever admissible.

- Convenient basis for concluding export contracts

Export Inspection Authorities

- Elimination of the need for exhaustive inspection of consignments exported from the country, saving expenditure time and labor.

3. Authority for testing:

Testing of tractors is being conducted since 1919, when the Nebraska Tractor Test Law took effect in USA. The idea for official tractor testing at the University of Nebraska, Lincoln (UN-L) was started when Polk County farmer purchased a lemon back in 1916. Tractors were something new on the farm then, just beginning to replace real, live, oats-powered horsepower. Farmer bought a "Ford B" tractor to replace his mule team, from the

Minneapolis, Minnesota Ford Tractor Company. New purchased tractor gave him so much trouble that he demanded a replacement from the company, but the replacement tractor was no better than earlier one. A representative of every model of tractor rated at 40 horsepower or more sold in USA, must be tested at the Nebraska Tractor Test Laboratory (NTTL) on East Campus. Today, NTTL is the only officially designated agriculture tractor testing lab in the Western Hemisphere, elevated to worldwide status as a sanctioned testing station for the Paris-based Organization for Economic Cooperation and Development (OECD). There are other active testing facilities in Germany, France, Italy, Spain, Japan and China for instance, but for U.S. farmers and tractor owners, it all comes down to the track of concrete at UN-L. Central Farm Machinery Training and Testing Institute, Budni (MP) is responsible for testing of the locally manufactured tractors in India.

OECD Tractor Codes allow participating countries to perform tractor tests according to harmonized procedures, and to obtain OECD official approvals which facilitate international trade. The codes cover the testing of:

- Tractor performance - All tested tractors must complete compulsory tests of: engine power output and fuel consumption; drawbar power output and fuel consumption; hydraulic power output; hydraulic lift capacity. In addition, the manufacturer can complete optional test procedures including: braking performance, turning area and turning circle; low temperature starting; centre of gravity location; external noise level; axle power; engine (bench) test); waterproofing test; performance in a hot atmosphere.
- Noise levels at the operator's driving position
- Operator safety - Roll-over Protective Structures (ROPS) and Falling Object Protective Structures (FOPS)

4. Major testing and evaluation centers in India for Agricultural Machinery

Following organizations are involved in testing of agricultural machinery. But CFMTTI, Budni is involved in tractor testing as a main authority in India.

1. Central Farm Machinery Training and Testing Institute, Budni, Madhya Pradesh-
2. Northern Region Farm Machinery Training and Testing Institute, Hisar, Harayana
3. Southern Region Farm Machinery Training and Testing Institute, Anantpur, Andhra Pradesh
4. Eastern Region Farm Machinery Training and Testing Institute, Biswanath Chariali, Distt. Sonitpur (Assam),
5. BIS Testing Laboratory, Sahibabad, Uttar Pradesh
6. BIS Centers of Tractor, Power Tiller, Diesel Engine, Electric Motor, Irrigation Pumps
7. ICAR Institutes

8. Agricultural Universities
9. Central Food Technology Research Laboratory, Mysore, Karnataka

Lesson 26. Procedure of testing and standard code for testing of tractor performance

1. Introduction

The International Organization for Standardization (ISO) is the apex body in the area of standardization at international level and has its membership on National Standards Bodies of various countries. In the context of farm machinery, it has been observed that acceptance of farm machinery by the farmers largely depends on their quality. Hence, in order to reap the benefits of standardization including manufacture of high quality products, a need was felt for preparation of India Standards for agricultural machinery. Organized efforts in this direction were made by the Bureau of Indian Standards (BIS) in late 50's by way of setting up a Technical Committee for formulation of standards for this group of industry. The committee is generally consisted of representatives of Government department, research, education and testing institutions and the manufacturing industries.

2. Procedure of testing

BIS. has published standards on machine/components for the machines used in the country. Mostly testing of the particular machine is undertaken as per relevant clauses of the code. In case, the standard has not been published for the machine, code and procedure is developed by the testing center and same used for testing purpose. These test procedures help in formulation of test codes by BIS. The complete testing of a machine involves:

i. Checking of specifications

ii. Development of test facilities and instrumentation

iii. Conduct actual tests

iv. Analysis of the data

v. Presentation of data and report writing

vi. Product certification marks scheme

i. Checking of specifications: Generally the test codes include few important specifications of the machine/equipment those are mandatory to meet a specific requirement. Few specifications have to be specified by the manufacturer and the testing center has to verify such dimensions within the tolerance limits.

ii. Development of facilities and instrumentation: The test codes give a guide line for development of test set up required for carrying out a specific test in the machine/equipment/component. The testing center has to develop a setup which should meet the requirements specified in the test procedure of the test center. As far as possible the high quality instrumentation should be included in the test set ups.

iii. Conduct actual tests: The actual tests should be carried out on the machine as per the test procedure specified and data recorded in the given blank tables.

iv. Analysis of data: The data obtained during testing is analyzed for presentation in the required format. Use of computer should be encouraged.

v. Presentation of data and report writing: The report should include the sections for the clauses those comply with the standard and those do not conform to the standards.

vi. Product Certification Marks Scheme: The Bureau operates a certification marks scheme under the Bureau of Indian standards Act, 1986 and the Rules and regulations framed there under. The Bureau's standard Mark (ISI) on an article certifies that the article complies with the requirements specified in the relevant Indian standards and also guarantees that the manufacturer operates a quality control system in his production which is monitored in terms of regular inspections and checks in such a form as to give assurance that the article will comply with the requirements of the relevant Indian standards. The Certifications Marks schemes also provide an inbuilt mechanism for ensuring the quality of the product right from the raw material stage to the finished product. The BIS Certification Marks Scheme is operated on voluntary basis.

3. Tractor Tests Eligible for OECD Approval :

Compulsory Tests: Approval shall require checking as follows:

- Main power take-off and five extra points for calculating fuel consumption characteristics
- Hydraulic power and lifting force
- Drawbar power and fuel consumption (un ballasted tractors)

Tractors without a main power take-off or with one that cannot transmit the full engine power can be tested at the engine flywheel or by drawbar tests. The testing station in agreement with the manufacturer shall make the choice between the two methods. Tractors without a lifting system and/or without a hydraulic service coupling remain eligible under the Code. However, the design of these tractors shall be specified in the test report. Optional tests may be performed and reported in any combination provided they are requested simultaneously with the compulsory tests

Optional Tests: Approval of any optional tests shall require checking as follows:

- Engine test
- Additional Power take-off ratio (economy)
- Reagent consumption during Power take-off and Drawbar Power testing

- Hydraulic power: optional tests
- Performance at the belt or the belt pulley shaft
- Performance in a hot atmosphere
- Low temperature starting test
- Additional drawbar tests
- Ten-hour test (ballasted tractors)
- Axle power determination
- Turning area and turning circle
- Centre of gravity
- Braking (wheeled tractors only)
- External noise level (wheeled tractors only)
- Waterproofing test

Repeats of Any of the Compulsory or Optional Tests at Different Settings: Approval shall require checking as follows:

- Eligibility for the same category
- Compliance with test conditions under the Code
- Clear specification of differences from original tests and caveat
- Compliance with Specimen Test Report
- Results.

Other Tests: Tests performed according to other internationally recognized methods, to be reported and clearly marked as not being subject to the OECD approval procedure. Such test methods would have to be mentioned in the report and made available to the OECD in a published form, in either of the official languages of the Organisation.

4. Bureau of Indian Standards (BIS) for Tractors:

Tractor Test:

The brief outline of various types of tests performed by Center of Farm Machinery Testing and Training Institute (CFMTTI), Budni (MP) are as under. Tractor test is carried out in accordance with Indian Standard (IS):5994-1998 as amended from time to time. A tractor is subjected to the following tests & evaluation

Laboratory Tests

- Checking of specifications
- PTO performance test
- Belt pulley test(optional)
- Drawbar performance test
- Power lift & hydraulic performance test
- Brake test
- Air cleaner oil pull over test
- Noise measurement
- Mechanical vibration measurement
- Location of centre of gravity
- Turning ability
- Visibility

Field tests: - For Initial commercial tests (ICT) for 35 h and for batch test of 35 h. (if there is any major breakdown during the ICT) of field tests with the following implements

Plough/ Rotavator(20 hrs. for I.C.T & 20 hrs for Batch Test)

Puddling test of 10 Hrs. duration under actual field conditions followed by Water Proof Test of 5 h for ICT and batch test if applicable.

Haulage test: This is done with 2/4 wheel trailers and the gross load recommended by the manufacturer. Components & assembly inspection is done to assess the wear, breakdowns, etc.

Power Tiller Test

Performance evaluation of power tiller is conducted in accordance with Indian Standard (IS):9935-2002 as amended from time to time. A power tiller is put into the following tests and evaluation:

Laboratory Tests

- Specification checking.
- Engine performance test.
- Rotary shaft performance test.

- Drawbar performance test.
- Parking brake test.
- Noise measurement.
- Air cleaner oil pull over test.
- Mechanical vibration measurement.
- Turning ability test.
- Chemical composition test and wear characteristics test of rotavator blades.

Field tests: For Initial commercial tests & batch test 35 h, of field tests with the following implements

- Mould board ploughing (20 hrs. for I.C.T. only) dryland
- Dry rotavation (35 hrs. for I.C.T. & 35 hrs. for Batch tests)
- Puddling under actual field condition (15 h for I.C.T. & Batch test both)

Haulage test: Components and assembly inspection is done to assess the wear, breakdowns, etc.

5. Quality system

The organizational structure, responsibilities, procedures, processes and resources used to implement quality policy and objectives are collectively referred to as quality systems. To cope with the growing change of competitiveness, ISO 9000 series of standards has been formulated by ISO to provide for quality management systems. Indian has adopted ISO 9000 series of standards as IS/ISO 9000 series of standards. These standards provide not only guidance and criteria for formal control of products and services by the company but also give an assurance to the purchaser and the set of stated requirements

ISO 9000 series of standards are generic in nature and applicable to the wide arena of business activity covering all the four main heads: Hardware, Software, Processed materials and Services

ISO 9001 is applicable to those manufacturers who have design, development and production facilities.

ISO 9002 is applicable to those manufacturers who have only production in facilities.

ISO 9003 is suitable only for trade houses.

In common usage the concept of quality is linked to excellence which is subjective in nature. Thus the perception of quality varied from person to person, what may be of good quality to one, may be of poor quality to the other or vice versa, depending upon the individual needs, wants and desires. Quality should not be defined in comparative terms as poor, fair, good or excellent. Quality is an absolute entity and viewed from the point of customers. Quality is the goal of each and every business. So, the objective definitions of quality are:

- Fitness for use
- Fitness for purpose
- Conformance to requirements
- Conformance to specifications
- Customer satisfaction
- Product satisfaction
- Product designed and made to work properly
- Worth for money

Module 11. General revision

Lesson 27. Indian Tractor Industry

1. Introduction

Tractors came to India through imports and later on indigenously manufactured with the help of foreign collaborations. Indian tractor industry is relatively young, as manufacturing process of tractors started in 1961-62. But now has become the largest market worldwide. Higher productivity and greater output are the two major contributions in farm mechanization. Tractors form an integral part of farm mechanization and have a crucial role to play in increasing agricultural productivity. Tractor is a highly versatile piece of machinery having a multitude of uses mainly used in agriculture. Besides that, Tractors are also used as a mode of transport, in electricity generation, in construction industry and for haulage operation. It has now become an integral part of farm structure .The application of tractor for agricultural activities which swept India during the last twenty years have erased the problem of farmers.

Farm mechanization program in India aims to integrate the use of available human and animal farm power with mechanical sources of power for increasing the productivity. Indian tractor industry, have expanded at a spectacular pace during last four decades. Consequently it now occupies a place of pride in India's automobile industry. U.S.A., U.S.S.R. and only a few Western European countries exceed the current production of tractors in India, but in terms of growth India's growth is unmatched even with countries of long history of tractor manufacturing.

2. Comparison with Tractor Industry World over

The tractor industry in India has made a significant progress in terms of production and capacity as well as indigenization of technology. It is a typical sector where both imported technology and indigenous developed technology have developed towards meeting the overall national requirements. The global spotlight on tractor manufacturers certainly in terms of volume seems to be swinging away from the USA, UK and Western and Eastern Europe towards India where growth in the number of producers and the total volume in recent years have been impressive. In India tractor industry has played a vital role in the development. India's gross cropped area is next only to United States of America and Russia and long with fragmented land holdings has helped India to become the largest tractor market in the world. But it drops to eighth position in terms of total tractor use in the country when compared to international figures, only 3% of total tractors used all over the world . It is to be noted that while the overall automobile industry is facing recession the tractor industry is growing at 9-10%. About 20% of world tractor production is carried out in our country only. The arable land in India is high as 12% of the total arable land in the world.

Tractor market in India is about Rs 60000 million. On an average around 400000 tractors are produced and their sale is 260000.Uttar Pradesh is the largest tractor market in our country. One out of every four tractor is being purchased in India.

3. Growth of Tractor Industry in India

The tractor penetration level in India is very low as compared to the world standards. Also the penetration levels are also not uniform throughout the country. While the northern region is now almost saturated in terms of new tractor sales, the southern region is still under penetrated. The medium horse power category tractors, 31-40 HP are the most popular in the country and fastest growing segment. There are currently 14 players in the industry including two major international players i.e. John Deere and New Holland.

Mahindra & Mahindra is the leading player in the industry. Monsoon season is a key driver for sales of tractors. A series of good or bad monsoon can affect the sales. In recent years the industry has registered a good growth in sales, both domestic as well as exports. This is also partly because of the initiative of the government to boost up agriculture and agricultural machinery industry. The tractor industry reported a strong 28.3% growth in sales volumes during 2009-10, there by ending the phase of cyclical correction that had pulled down tractor sales during the preceding two years (2007-09). Significantly, the revival of 2009-10 happened despite the drought-like conditions in many states during the kharif season dampening sentiments.

4. Tractor demand drivers in the country

The key factor enabling the demand growth of 2009-10 was strong rural liquidity, which in turn was sustained by several factors, including:

- Higher minimum support price (MSP) for crops
- More ability of farmers to make cash purchases (including the usage of Kisan Credit Card which are increasingly being used to part-finance tractor purchases)
- Enhanced employment opportunities (with rural employment schemes being implemented by the Government of India)
- An improved credit environment
- Continuance of replacement demand

Apart from these factors, non-agricultural use of tractors especially for haulage in construction and infrastructure projects continued to increase, benefiting tractor demand. Availability of labour for agricultural activities continued to decline, with infrastructure projects and rural employment schemes increasing employment opportunities. Hence, even farmers with medium-sized land holdings to either rent their land or purchase tractors. On a regional basis, the performance of the eastern, northern and western parts of the country was robust during 2009-10 in terms of tractor demand, while that of the southern region was moderate. A strong growth in tractor volumes, albeit on a low base, was witnessed in the eastern States, including Bihar, Orissa and Jharkhand, which had a good paddy crop.

Indian agriculture is characterised by low farm mechanization, fragmented land holdings, and high dependence on monsoon rains (in the absence of adequate irrigation facilities). Tractor penetration in India is low at around 13 tractors per 1,000 hectares as against the global average of 19 and the US average of 29. While this does indicate the relative backwardness of Indian agriculture, it also points to the significant scope that exists for raising tractor penetration, which is well for tractor demand over the long term.

5. Government support for tractor industry

Although agriculture contributes just around 20% to India's GDP, it provides employment to a large rural population, which is why the sector remains a strong focus area for the Government. The tractor industry benefits significantly from the Governmental focus on agriculture, with measures such as nil excise duty on tractors (even the excise duty on tractor parts has been lowered from 16% to 8%) and inclusion of tractor financing under priority sector lending (by PSBs) serving as long-term demand drivers. Financing of tractor purchase is of great significance for the industry, it being a key demand facilitator.

6. Tractor Exports :

Indian tractor manufacturers have been increasingly targeting the international markets over the last few years. The industry exported a total of around 37,900 tractors during 2009-10, with the USA, Africa, South America, and some Asian countries being the top destinations. The industry leader, Mahindra and Mahindra (M&M), has acquired Yan cheng Tractors, the fourth largest tractor manufacturer in China (in terms of FY2008 volumes), to improve its presence in the country. In the developed markets, Indian tractors have a relatively marginal presence, with sales being largely restricted to the hobby farming segment. Tractor exports from India grew at a CAGR of 36 % from 2005-06 to 2009-10. Around 60 % (in 2005-06) of these exports were to the US mainly driven by an increase in hobby farming in the country. Exports to other countries such as South Asian countries, Malaysia, Turkey and Africa are estimated to have been growing fast as well. In year 2006-07, over 50 % of exports were to non US destinations.

7. Market Share of different players

The market shares of the top four players in the Indian tractor industry did not change much during 2009-10 in comparison with 2008-09. M&M remained the market leader with around 41.1% market share, followed by TAFE with a market share of around 22%, Escorts with around 12.1%, and International Tractors (ITL) with around 8.9%. M&M remains particularly strong in the southern region (50.4% market share during 2009-10). However, John Deere was able to increase its market share in the region by around 250 bps in 2009-10, mainly at the expense of M&M (market share down by 140 bps) and Escorts (down by 140 bps). In the western region too, John Deere performed well in 2009-10, increasing its market share by 190 bps, even as TAFE lost market share by around 90 bps there. In the northern region, where M&M has been traditionally weak, the company increased its market share by 140 bps during 2009-10, even as ITL and Escorts lost market shares by around 90 bps and 60 bps respectively, there. In the eastern region, M&M was able to raise its market share by around 140 bps in 2009-10 at the expense of Escorts and TAFE.

8. Recent trend in volume and growth of tractor industry

Volume and growth of tractors in last five year plan is shown in Table 27.1. The Indian tractor industry has experienced strong volume growth during last two years (2010-2012) on the back of favourable cyclical and structural demand drivers. The demand-side economics in the tractor industry continue to find favour from factors such as support from the Government of India (GOI) towards rural development and agri-mechanisation; scarcity of farm labour especially during the sowing season; increase in credit flow to agriculture; increase in non-agri application of tractors as in infrastructure projects; growth in niche power segments [<20HP (14.91 kW) and >50HP (37.28 kW)] and untapped territories; besides healthy export sales. However, there are some concerns emerging over the earnings of farmers from the crops; growing non-performing assets (NPAs) of tractor loans with public sector banks; and demand fatigue after strong sales growth during the last 2.5 years. On a regional basis, the western and southern parts of the country have performed above par while the eastern and central parts have reported muted growth figures in the year 2012. Further, the northern region, which is the largest tractor market of the country, grew at a healthy pace during the period, benefiting from sustained replacement demand.

Table 27.1: Volume and growth of tractor industry in India

	FY08	FY09	FY10	FY11	FY12
Volume (Domestic + Export)	346,508	345,827	441,174	545,128	605,092
Growth (%)	-2%	0%	28%	24%	11%

The demand outlook from southern India continues to be robust over the medium term and many OEMs are shifting focus from saturated markets to relatively under penetrated geographies in southern states. In fact, roughly 50% of the incremental capacity expansion for the industry is expected to come up in southern India. The domestic tractor industry is currently in a capacity augmentation phase and supply-demand dynamics of the industry are expected to change with the commissioning of large manufacturing capacity. Sharp increase in production capacity may have a bearing on the pricing power of tractor OEMs, ultimately putting pressure on their profitability metrices. Even during 2012, Indian tractor manufactures witnessed margin contraction in light of continued hardening of rubber and steel prices, notwithstanding price increases to offset hike in input cost as well as change in emission norms (only for greater than 50 HP (37.28 kW) category).

Volume growth in the Indian tractor industry has remained good in the year 2012 but lesser than half as for the previous two years. But in comparison, automotive industry has experienced slackening demand on account of rising inflation, hardening interest rates and increasing fuel prices. After a period of downturn during 2008-09, the up-cycle in the tractor market has extended over the last three years (2010-12). Some of the cyclical factors that have contributed to healthy demand side economics are good south-west monsoons supporting farm output, strong rural liquidity sustained by higher minimum support price (MSP) for crops and double digit food inflation, besides adequate credit availability driven by NBFCs and private banks. Structural drivers like scarcity of farm labour in light of alternate employment opportunities, steady replacement demand and growing non-agricultural use of tractors have also supported tractor volumes. In addition, long-term drivers of the industry such as low tractor penetration, increasing budgetary allocation towards the rural sector and government support for farm mechanisation remain favourable.

Lesson 28. Cost estimation and selection of tractor

Machinery and equipment especially tractors are major cost items in farm businesses. Larger machines, new technology, higher prices for parts and new machinery, and higher energy prices have all caused machinery and power costs to rise in recent years.

1. Cost estimation

Farm machinery/Tractor costs can be divided into two categories: annual **ownership** costs, which occur regardless of machine use, and **operating** costs, which vary directly with the amount of machine use.

The true value of these costs is not known until the machine is sold or worn out. But the costs can be **estimated** by making a few assumptions about machine life, annual use, fuel and labor prices.

Ownership costs (also called **fixed** costs) includes depreciation, interest (opportunity cost), taxes, insurance, and housing and maintenance facilities.

Operating costs (also called **variable** costs) include repairs and maintenance, fuel, lubrication and operator/labor cost.

a. Fixed Costs :

Depreciation

Depreciation is a cost resulting from wear, obsolescence, and age of a machine. The degree of mechanical wear may cause the value of a particular machine to be somewhat above or below the average value for similar machines when it is traded or sold. The introduction of new technology or a major design change may make an older machine suddenly obsolete, causing a sharp decline in its remaining value. But age and accumulated hours of use are usually the most important factors in determining the remaining value of a machine.

Before an estimate of annual depreciation is calculated, an **economic life** for the machine and a **salvage value** at the end of the economic life need to be specified. The economic life of a machine is the number of years for which costs are to be estimated. It is often less than the machine's service life because most farmers trade a machine for a different one before it is completely worn out. A good rule of thumb is to use an economic life of 10 to 12 years for most farm machines and a 15-year life for tractors, unless it's known that machine will be traded sooner.

Salvage value is an estimate of the sale value of the machine at the end of its economic life. It is the amount expected to receive as a trade-in allowance, an estimate of the used market value if expected to sell the machine outright, or zero if plan is to keep the machine until it is worn out.

Note that for tractors, combines and forage harvesters the number of hours of annual use is also considered when estimating the remaining value. The factors were developed from published reports of used equipment auction values, and are estimates of the average "as-is" value of a class of machines in average mechanical condition at the farm. Actual market value will vary from these values depending on the condition of the machine, the current market for new machines, and local preferences or dislikes for certain models. There are many four methods for calculating the depreciation of any machinery

Straight Line Method: The annual depreciation charge is given by following relationship, Alternative method. Depreciated value after n-years may be expressed as:

$$D = \frac{P-S}{L} \text{, Rs/year} \qquad (28.1)$$

Where,

P= Purchase price, Rs

S= salvage Value, Rs

L= Economic machine life, years

This method is the simplest, as it change on easily calculated, constant amount each year.

Declining-Balance Method: An uniform rate is applied each year to the remaining value (includes salvage value) of the machine at the beginning of the year. The depreciation amount is different for each year of the machines life. It is given by following relationship,

D= $V_n - V_{n-+1}$

$$V_{n=}P\left(1-\frac{X}{L}\right)^{n} \text{ and } V_{n+1=}P\left(1-\frac{X}{L}\right)^{n+1} \qquad \text{------ } (28.2)$$

Where,

D= The amount of depreciation charged for year (n+1)

N= The number representing the age of the machine in years at the beginning of the year in question

V= The remaining value at any time

x= The ratio of the depreciation rate used to that of the straight line methods. The value of x may be any number between 1 and 2.

Alternate Method: Depreciated value after n-years may be expressed as

$$Vn = (1-r)n * P$$

And solvage value may be expressed as

$S = (1\text{-}r)^{L} *P$

Sinking Fund Method: This method is generally used by engineering economist. This method considers the problem of the depreciation as one of establishing a fund which will draw compound interest uniformly annual payments to this fund are such a size that by the end of life of machine the funds their interest have accumulated to an amount which will purchase another equivalent machine.

Sinking fund annual payment (SFP) and the value at the end of year n are,

$$SFD = (P-S)\frac{i}{(1+i)^2} - 1$$

$$V_n = (P-S)\frac{((1+i)^2-(1+i)^n)}{(1+i)^2-1}) + S \qquad \text{-------}(28.3)$$

If x= 2, the method is called a double declining balance method permitted by IRS. For used machines the maximum rate is x= 1.5

Sum of the years-Digits Methods. It is given by following relationship,

$$D = \frac{(L-n)}{YD}(P-S) \qquad (28.4)$$

Where, YD = The sum of years digits, (1+2+3+….+L)

N= The age of the machine is years at the beginning of the year.

An example problem will be used throughout this chapter to illustrate the calculations. The example is a 50-PTO horsepower diesel tractor with a list price of Rs. 600000. An economic life of 15 years and an interest rate of 8 % is assumed. The tractor is expected to be used 400 hours per year.

For the 50-hp (37.3 kW) tractor with 400 hours of annual use in the example, the salvage value after 15 years is estimated as 23 % of the new list price:

Salvage value = current list price x remaining value factor =600000 x 23%

= 138000

Total depreciation = purchase price - salvage value =600000 – 138000

=462000

Annual Depreciation (considering 15 years life of the tractor = Rs. 30800

Interest:

If money is borrowed to buy a machine, the lender will determine the interest rate to charge. But if you use your own capital, the rate to charge will depend on the opportunity cost for that capital elsewhere in your farm business. If only part of the money is borrowed, an average of the two rates should be used. For the example we will assume an average interest rate of 8%.

Interest is calculated on the average investment of the machine taking into consideration the value of the machine in first and last year. It is given by following relationship,

$$I = \frac{P+S}{2} \times \frac{i}{H}, \text{Rs/h} \qquad \text{--- (28.4)}$$

Where, i= % rate of the interest

H = working hours per year, h

Annual Interest paid = 738000/2 x 8% = Rs. 295200

Taxes, insurance, and housing (TIH):

These three costs are usually much smaller than depreciation and interest, but they need to be considered. There is no taxes on ownership of farm machinery but recently taxes are put on tractor. Insurance should be carried on farm machinery to allow for replacement in case of a disaster such as a fire or accident. If insurance is not carried, the risk is assumed by the rest of the farm business. There is a tremendous variation in housing provided for farm machinery. Providing shelter, tools, and maintenance equipment for machinery will result in fewer repairs in the field and less deterioration of mechanical parts and appearance from weathering. That should produce greater reliability in the field and a higher trade-in value. An estimated charge of 1.0 % of the purchase price is suggested for taxes, insurance and housing costs.

Annual TIH = 0.01 x purchase price

For our tractor example, these three costs would be: TIH = 600000x 1% =*6000*

Total ownership cost

The estimated costs of depreciation, interest, taxes, insurance and housing are added together to find the total ownership cost. This is almost 10 %t of the original cost of the tractor.

Total ownership cost = 30800 + 29520 + 6000

=Rs. 66320 per year

If the tractor is used 400 hours per year, the total ownership per hour is:

Ownership cost per hour = 66320 / 400 hours

= Rs. 166 per hour

b. Operating Cost

Fuel

Fuel costs can be estimated in two ways. One method is that how many drums of diesel are consumed in a year. The total numbers of litres can be divided by 400 hours and per hour diesel consumption of tractor can be calculated. If fuel meter is attached with the tractor fuel line then exactly for each operation, fuel consumed per hour can be measured.

Average fuel consumption (in gallons per hour) for farm tractors on a year-round basis without reference to any specific implement can also be estimated with these equations:

0.14 x maximum PTO horsepower for **diesel** engines

For our 50-horsepower diesel tractor example: Average diesel fuel consumption = 0.14 x50 horsepower = 7 litres/hour

Average fuel cost per hour = 7 l/hour x Rs. 50/litre =Rs. 350/hour

Lubrication

Surveys indicate that total lubrication costs on most farms average about 15 % of fuel costs. Therefore, once the fuel cost per hour has been estimated, you can multiply it by 0.15 to estimate total lubrication costs.

For our tractor example, average fuel cost was Rs. 350 per hour, so average lubrication cost would be:

Lubrication cost = 0.15 x 350 = Rs.52.5/hour

Repairs and maintenance

Repair costs occur because of routine maintenance, wear and tear, and accidents. Repair costs for a particular type of machine vary widely from one geographic region to another because of soil type, rocks, terrain, climate and other conditions. Within a local area, repair costs vary from farm to farm because of different management policies and operator skill.

The best data for estimating repair costs are records of your own past repair expenses. Good records indicate whether a machine has had above or below average repair costs and when major overhauls may be needed. They will also provide information about your maintenance program and your mechanical ability. Without such data, though, repair costs must be estimated from average experience.

Because the tractor in the example will be used about 400 hours per year, it will have accumulated about 6,000 hours of operation by the end of its 15-year economic life. As an estimate that after 6,000 hours of use, total accumulated repair costs will be equal to about 25 percent of its new list price. So, total accumulated repairs can be estimated to be:

Accumulated repairs = 0.25 x 600000 = Rs. 150000

The average repair cost per hour can be calculated by dividing the total accumulated repair cost by the total accumulated hours: Repair cost/hour= 150000 / 6,000 hours = Rs. 25/hour

Labor

Because different size machines require different quantities of labor to accomplish such tasks as planting or harvesting, it is important to consider labor costs in machinery analysis. Labor cost is also an important consideration in comparing ownership to custom hiring.

Actual hours of labor usually exceed field machine time by 10 to 20 percent, because of travel to and from field and the time required to lubricate and service machines. Consequently, labor costs can be estimated by multiplying the labor wage rate times 1.1 or 1.2. Using a labor value of Rs. 25 per hour for our tractor example:

Labor cost = 25 x 1.1= Rs.27.5/r

Different wage rates can be used for operations requiring different levels of operator skill.

Total operating cost

Repair, fuel, lubrication and labor costs are added to calculate total operating cost. For the tractor example, total operating cost is:

Total operating cost = 350 +52.5 +25+27.5 = 455 per hour

Total cost

After all costs have been estimated, the total ownership cost per year can be added to the operating cost per hour to calculate total cost per hour to own and operate the machine. Total cost per hour for our example tractor was:

Total cost = 166 + 455=Rs.621 / per hour

Implement costs

Costs for implements or attachments that depend on tractor power are estimated in the same way as the example tractor, except that there are no fuel, lubrication or labor costs involved.

Used Machinery

Costs for used machinery can be estimated by using the same procedure shown for new machinery. However, the fixed costs will usually be lower because the original cost of the machine will be lower. And repair costs will usually be higher because of the greater hours of accumulated use. Therefore, the secret to successful used machinery economics is to balance higher hourly repair costs against lower hourly fixed costs. If you misjudge the condition of the machine such that your repair costs are higher than you anticipated, or if you pay too high a price for the machine so that your fixed costs are not as low as you anticipated, the total hourly costs of a used machine may be as high or higher than those of a new machine.

Total Costs per Operation

Tractor costs must be added to the implement costs to determine the combined total cost per hour of operating the machine. Total costs in the example are:

Total cost = Rs. 621 per hour

Finally, total cost per hour can be divided by the **hourly work rate** in acres per hour or tons per hour to calculate the total cost per acre or per ton.

The hourly work rate or field capacity of an implement or self-propelled machine can be estimated from the effective width of the machine (in meter), its speed across the field (in kms per hour), and its field efficiency. The field efficiency is a factor that adjusts for time lost due to turning at the end of the field, overlapping, making adjustments to the machine, and filling or emptying tanks and hoppers.

2. Tractor Selection

It is vital to select the right options and optimise the way the tractor is operated to reduce costs. There are many choices when purchasing a tractor, especially in the area of transmissions, tyres and ballast. In some hp sectors there is even a choice of tractor size and weight as well. The starting point is knowing what the tractor is used for. Crucial questions include which tasks the tractor will perform, the hours taken on each task, the speed required and the implements to be used with it. Technology is becoming available to assist this task in the form of telematic systems which will be able to monitor how the tractor is used including engine load levels, hours by application, idle time and detailed fuel usage but these are not yet widespread and the purchaser must make judgements.

a. Power:

A suggested procedure for determining the minimum horsepower needed is:

Step 1: Determine the most critical field operation requiring implements with a high draft Ex. Mixing of rice straw in field using rotavator

Step 2: From past experiences, estimate how many days are available to complete this critical field operation Ex. Sowing of wheat after rice harvesting in narrow window period of about 15 days. If you plan to run a double shift be realistic about maintenance of the machine and the operator's personal time.

Step 3: Calculate the capacity needed in acres per hour in order to get the job done within the time allotted.

Step 4: Determine the size of implement needed.

Step 5: Select a tractor of proper size to pull the implement. To do this:

1. Determine draft of implement

2. Determine drawbar horsepower needed to pull implement,

3. Determine PTO horsepower needed.

Obviously the most important decision is to determine the size of the largest tractor. Normally the size of the largest tractor should be based on getting the critical, high-power jobs done within a specified time period. It follows, then, that as much use as possible should be made of the same tractor for other operations. Keeping in mind, also, that large tractors should be matched with large, heavy duty equipment to withstand the heavy loads created by the tillage implements. By the same, overloading a tractor can lead to serious mechanical failure. This can lead to down time and when a tractor is down, all work associated with that tractor stops.

Several terms are used by manufacturers to describe the capacity of their tractors. The basic definitions are:

Brake Horsepower - - The maximum power the engine can deliver without alterations. This power is particularly useful in sizing stationary engines.

Power-Take-Off-Horsepower (PTO) - - The power as determined at the power-take-off shaft of the tractor.

Draft (Drawbar) Horsepower - - The power transmitted by the tractor to the implement. The Nebraska Tractor Tests indicate that maximum drawbar horsepower will average approximately 85 percent of the maximum PTO horsepower for most of the tractors.

b. Two wheel drive, Front wheel assisted or Four wheel drive tractors

Tractors can be divided into 3 categories:

(i) Two-wheel drive (2-WD)

(ii) Front-wheel assisted (FWA) or unequal 4-wheel drive

(iii) Equal 4-wheel drive tractors (4-WD).

Each one of these tractors has different tire configurations and different ballast requirements. Two-Wheel Drive Tractors (2WD) are most commonly used in dry or upland farming situations and for transportation. They need 80% of the weight distributed over the rear axle to maximize traction. The biggest advantages of this type of tractor over other 4-wheel tractors are smaller turning circle, simplicity of design, fewer mechanical parts and lower purchase price. However, a 2WD tractor does not work at all well in wet, hilly and muddy conditions.

Front Wheel Assist (FWA) is commonly known as 4-WD or unequal 4-wheel drive. It is the most popular 4-wheel tractor in many parts of the countries worldwide. These tractors range in size from 5 HP - 240 HP (3.73- 178.96 kW) and are capable of delivering between 50-55% of the rated power at the drawbar. Typically, between 75 and 85% of the rated engine HP is delivered to a rear PTO (Power Take-Off) on any diesel tractor.

On a FWA tractor the front drive tires are smaller than the rear tires. These tractors require 40% of the weight distributed over the front axle and 60% over the rear axle. The major advantage in using this type of tractor is that it can deliver 10% more power to the ground at all 4 tires for the same fuel consumption, and thus has much better traction and flotation capabilities than 2-wheel tractors of the same size. FWA tractors normally cost about 15-35% more than the same horsepower two wheel drive tractor.

Equal Four-Wheel Drive (4WD) tractors have all four tires of equal size and range in size from 35 HP - 600 HP (26.1 -447.42 kW). This tractor type has the greatest power to weight ratio and can deliver between 55-60% of power at the drawbar. It is challenging to maneuver and often the size and expense makes these tractors impractical.

c. Fuel consumption

This parameter plays very important role in selection of a tractor. Specific fuel consumption g/kWh. is the measure of the number of grams of fuel used to produce 1 kW for 1 hour and appears in official tests as it allows you to compare tractors of different horsepower. This is measured at the engine flywheel, the PTO or at the drawbar depending on the type of test. The main tests are according to OECD standards and notably carried out by Nebraska Test Laboratory and CFMTTI, Budni.

Fuel Efficiency litres/unit of production. This measurement tells you how much work you achieve from a litre of fuel. It could be litres/hectare or litres/tonne and is by far the most meaningful figure to use as it takes into account the work done for an amount of fuel. The detail regarding saving of fuel by optimising tractor field efficiency is discussed in next chapter.

d. Hydraulic System

There are two different hydraulic systems available today – open and closed systems, however hybrid systems between the systems are also available.

Open Centre: Oil flows continuously round the tractor through all the valves. So oil is pumped all day whether you are using hydraulic functions or not. As a result there is a fuel cost in pumping all this oil.

Closed Centre - Pressure compensated: This system is a hybrid. Although oil is pumped all the time, it does not have to travel round the whole hydraulic system. When no oil is required, this system goes into a short circuit saving energy. Oil only flows to the valves that operate functions when required.

Closed Centre - Pressure and flow compensated: These are the most efficient of the systems. When there is no requirement for oil, the pump shuts down and produces no flow. This saves energy and so saves fuel. Oil is only pumped when required at the flow rate and pressure demanded by the service that is in operation becoming widespread.

e. Transmissions

For many power ranges there may be a choice of transmissions and there is a need to evaluate the type and duration of tasks as well as the speed of operation. Generally the cost increases with the degree of sophistication but so does the task and fuel efficiency, and certainly the comfort, if correctly matched. Synchronised transmission is often fitted to smaller lower specification tractors and is ideal for loader work especially if fitted with a power reverser allowing clutch-less direction changes. It is good for applications at fixed speeds e.g. fertiliser spreading and spraying will carry out tillage work but work rate will be lower compared to tractors that can shift on the move. Partial and full Power shift transmissions are good for field work as the transmission can perform multiple shifts under load and can better optimise work rate. Eco Shift transmissions are available to allow the tractor to run at maximum speed on the road at reduced rpm with fuel savings. Infinitely Variable Transmissions are the most versatile of all the transmissions with the ability to continuously vary the ratio to the engine power available and as a result deliver the highest work rate. These transmissions have the ability to reduce engine rpm, so saving fuel if the load reduces and operations where full power is not required will automatically be carried out at reduced rpm.

f. Power Take Off (PTO)

PTOs are available on a number of speeds and shaft configurations. These are:

- 6 spline shaft, 34.9 mm (1 3/8 in) nominal speed 540 rpm
- 21 spline shaft, 34.9 mm (1 3/8 in) nominal speed 1000 rpm
- 20 spline shaft, 44.5 mm (1 ¾ in) nominal speed 1000 rpm

Typical speeds are 540, 540E, 1000 and 1000E. The economy speeds are provided for lighter applications that allow nominal pto speed to be reached at reduced engine rpm, saving fuel. The use of an economy pto vs full speed pto typically will result in an 18% fuel saving. So if you have pto applications for significant hours, economy speed pto’s should be specified and used if possible.

g. For custom hiring or self

Tractor is purchased for operation on custom hiring operation or purchased by the cooperative societies of the village, then tractor fitted with telemetry and GPRS will be more suitable. Signal of its operation and some engine parameters will be sent through SMS during the operation of tractor in remote areas. This data may be useful for better management of tractor fleet.

h. Clutch type

There are two types of clutch available – dry and oil cooled. Dry clutches suffer some wear every time they are disengaged and engaged. This means that a dry clutch will wear out eventually and require replacement but may be more economical for low hour usage. An oil cooled clutch virtually eliminates this wear so is better suited to applications that have frequent clutch use e.g. loader work.

i. Suspension and comfort options

As well as improving comfort and allowing greater productivity front axle suspensions can improve traction in the field effectively increasing usable power.

j. Selection of Tyres

The selection of tyres is one of the most important considerations. Even if you optimise the specification of your chosen tractor in all areas but get tyre selection wrong, you will not be able to apply power to the ground effectively. When selecting tyres, you must ensure they have adequate carrying capacity for the applications you carry out and the implements used. The only real way to determine this is to weigh the tractor with the implement and from that, you can determine the additional weight the implement adds to the tractor axles. The markings of load index and speed symbol are also shown on the side wall of the tyre and tell you how much weight the tyre will carry at what speed. The figures must be looked up in a tyre book.

Tyre choice should be made in the following order:-

1. Choose the tallest tyres that will fit the tractor. Taller tyres give a longer footprint and reduce rolling resistance in the field. The wall of soil that the tyre has to climb up stays the same width but the larger footprint reduces sinkage, so reduces rolling resistance. This improves efficiency.

2. Choose the widest tyres that are compatible with your applications. A wider tyre will have a larger footprint and reduce ground pressure. It does not necessarily reduce rolling resistance as taller tyres do. Although the height of the soil wall is reduced, it is also wider.

3. Choose tyres of adequate carrying capacity for your most demanding application. If cropping dictates you have to use a small narrow tyre, be aware that the tyre may not be capable of transmitting the full power available or carrying the full weight of the tractor plus any imposed load. So if you have a tyre that say fits your potato operation, it may not be adequate for general cultivation work, transport with heavy trailers and large mounted implements.

4. Choose a tyre that is adequate for the tractor hp and operate at proper pneumatic pressure according to the operation.

Lesson 29. Optimization of Tractor Field Efficiency to Save Energy/Fuel

Tractors and related field equipment can use a lot of energy in the form of fuel on the farm, so it makes sense to take practical steps to optimize their efficiency. Field efficiency means completing a particular field operation while wasting the least amount of time, fuel, and farm resources. The term refers to the time the operation should take vs. turning and other non-productive time. For example, spending an amount of time turning around at the ends of short, wide fields or overlapping tillage operations within a field can result in higher fuel consumption per acre. Machine maintenance and repair also affect field efficiency – equipment that is well-maintained and in good condition operates most efficiently. Timely replacement of air and fuel filters and lubricants can reduce fuel use while increasing horsepower. Repair of leaking valves and piston rings will improve engine performance and therefore, energy efficiency. Some practical steps to optimize the tractor field efficiency are suggested here

1. Turning time

To reduce turning time, farmers should make fields large, long, and narrow by eliminating fence rows, ditches, or other barriers. Larger implements, if matched to tractor size, can be more field efficient because bigger implements cover larger areas and require a smaller number of turns. Long narrow fields can enhance the efficiency of field operations. The concept of "tilling off the corners" of the field when tilling diagonally can also save fuel by having the turning result in a tillage operation.

2. Wheel traffic pattern

Controlled wheel traffic patterns can save fuel and reduce total soil compaction in a field. The tractor and other machinery operate in the same tracks for all operations, improving tractive efficiency with compaction occurring only in a narrow area. Crop growth in the uncompacted areas of the field is considerably better than if some compaction occurred all over; however, poor drainage or other problems may occur near the compacted zone.

3. Conservation Tillage

Conservation tillage generally uses lesser fuel than full tillage systems because the soil is tilled less intensely and less often. These tillage practices may also allow seedbed preparation, fertilizer application and seeding in fewer passes. Such practices are also eligible for carbon credits.

Deeper tillage results in greater fuel use. With every inch of increase in mould board plowing depth, approximately 0.57 more liters of diesel fuel per acre is used. There is a proportionate increase for other tillage operations at increased depths. Secondary tillage should not be deeper than one-half the depth of primary tillage.

For example, if a field is plowed 8 inches deep, disking should be no deeper than 4 inches. Shallower secondary tillage has the added benefits of not only saving fuel, but reducing compaction and lessening the amount of wet soil and weed seeds brought to the soil surface. Water loss is also often reduced with shallower tillage, resulting in a longer period before first irrigation is necessary and/or better overall early plant growth.

4. Matching Implement Size to the Tractor.

Using a large tractor for light loads is inefficient because extra horsepower is used to move the larger tractor. Producers should consider using a smaller tractor if possible. On the other hand, using a smaller tractor to perform operations that require more horsepower can overload a smaller tractor, reducing its overall efficiency.

5. Selecting the Optimal Engine and Travel Speeds.

Most tractor engines have the highest fuel efficiency when operated at or near rated speed and load, or maximum power. For primary tillage implements properly matched to the tractor, the best fuel efficiency in the field is achieved by pulling loads at the fastest speed possible within the acceptable speed range for the implement. Increasing the gear and lowering the throttle speed can lead to fuel savings. Make sure to not overload the engine; excessive black smoke indicates overloading.

6. Optimizing Wheel Slippage

Some wheel slippage is needed to reduce excess wear on the tires. The optimal level is generally 10 percent, but the actual level depends on the type of tractor, the speed and the implement being used. Properly ballasted tractors with recommended tire inflation rates can improve fuel consumption and increase tractor efficiency by creating the required amount of tire slippage for the specific tractor, implement and field conditions.

7. Fuel Storage and Alternative Fuels

Proper storage can save fuel before it goes into the tractor. Keep above-ground fuel storage tanks shaded and paint them a light color to reduce the loss of fuel by evaporation. Use of biodiesel or other bio fuels will reduce reliance on petroleum products.

Lesson 30. Alternative Fuels for IC Engines

1. Biomass based alternate fuels for IC engines:

Considerable research has been conducted and is still being carried in different disciplines of science and engineering to find alternate renewable fuels for Internal Combustion (IC) engines. However, agricultural scientists are more concerned about the biomass-based fuels, as the use of biomass appears to be a viable alternative, especially for the on-farm use of fuels in tractors, combines, and stationary diesel engines. Many biomass-based fuels have been tried in the IC engines, either as a partial or complete substitute to the gasoline/diesel fuel. These include alcohols derived from grains and starchy/sugar crops/plants/trees, biogas produced by the anaerobic fermentation of biomass (dung, refuge etc.), producer gas prepared by the partial burning (i.e. with less quantity of oxygen) of carbon rich biomass in a gasifier, and straight or modified plant oils derived from oil-rich seeds/nuts of farm crops/trees.

Engines or fuel modifications are required to exploit alcohol fuels in compression Ignition (CI) because of poor self-ignition characteristics of these fuels,. The extent and magnitude of modifications was dependent upon the proportion of diesel fuel substitution by alcohol. Thus, it has been found to be an expensive option. Biogas has been used satisfactorily in CI engines. However, in case of CI engines, it cannot replace the diesel completely. Because of its poor self-ignition characteristics, some minimum amount of diesel is required to start the ignition. Its use in IC engines for mobile operations could not be practically exploited due to very high liquefaction pressure of methane, the main combustible constituent of biogas. Like biogas, producer gas has also been used satisfactorily in CI engines. This gaseous fuel too has poor self-ignition characteristics and as such is not regarded as a complete substitute of diesel fuel in CI engines. It also has very high liquefaction pressure.

2. Plant oils as CI engine fuels:

Plant oils, straight or modified, are known to offer several advantages as engine fuel. These include better self-ignition characteristics, compatibility with fuel injection system of the CI engine, high-energy content, safe processing and handling. Above all, production of most plant oils can be realized within a short period after the need is felt. For most of the cultivated oilseed crops, the lead period is only few months. Due to relatively simple and low-cost technology for expelling and filtering, the plant oil can be processed on the farm itself, thus saving the transport cost, time, and energy. Based on simple calculations, researchers have indicated that one hectare of an oil-seed crop can fetch adequate oil to meet the energy needs of an 8 to 10 hectare farm (Bruwer et al., 1980).

In countries with shortage of edible oil, only non-edible oil need to be considered as an alternative fuel. However, during period of petroleum shortage, it might be unavoidable to perform certain urgent farm operations such as irrigation, plant protection, harvesting etc. Under such circumstances, a farmer might be compelled to use even edible oil as an engine fuel to prevent the loss/damage to the crop. As a strategy, the farmers should be encouraged to attain self-sufficiency in their fuel needs by exploiting all alternative energy sources. They must be encouraged to grow the most promising oil seed crops. Even if there is no short fall in the fuel supply from conventional sources, the additional production of oil can be utilized to meet the needs of edible oil in an area.

It has been reported that in diesel engines, crude plant oils can be used as fuel, straight as well as in blend with the diesel (Shyam, 1984). However, during extended operation of the engine, problems of injector coking, dilution of engine oil, deposits in various parts of engine, etc. have been reported. These problems are found to be rather serious in the direct injection CI engines. High viscosity of the plant oils was the major constraint although high acid value and presence of gums/wax etc. also adversely affected the engine performance. Different methods have been tried by different researchers to modify the plant oils. These include cracking of the plant oils, blending of the plant oils with appropriate additives like alcohol, heating of the plant oils before injecting into the combustion chamber, and chemically transforming the plant oils to convert into the esters (i.e. bio-diesels) by alcoholysis.

3. Bio-Diesel as CI engine fuel:

Based on the economic and other considerations, trans-esterification of plant oils by alcoholysis seems to be an effective way to reduce their viscosity. It converts them into methyl esters (known as bio-diesels) thereby making them more appropriate for use in the CI engines. This process also enhances the volatility of the fuel, which aids in better atomization of the fuel. Various problems faced, while using the plant oils straight as fuel, like injector coking, unusual carbon deposition on piston, cylinder head, exhaust manifold, etc. are thus eliminated to large extent by the use of bio-diesels. The glycerol, which is a by-product of this reaction, may be traded in the market.

There are also many environmental benefits of bio-diesel. There is a clear contribution to the reduction of greenhouse gases at least 3.3 kg CO_2-equivalent per kilogram of bio-diesel (Korbitz, 1998); those results have been improved since then by lower inputs in raw material production and by more efficient process technology. It is well established, that there are significant locally impacting emissions e.g. 99% reduction of SOx-emissions, and reductions of 20% for CO, 32% for HC, 50% for soot and 39% for particulate matter. But there is a slight increase of NOx-emission. However, with delayed injection timing a decrease of 23% can be obtained (Korbitz, 1998). Bio-diesel also appears to be an ideal synergistic partner for the oxidation catalytic converter (oxicat). Not surprisingly, as a plant derivative bio-diesel has a very low toxicity as a compound. This is also the reason for its high biodegradability (more than 90% within 3 weeks) and a substantial reduction of toxicity risks to fresh water organisms such as trout, daphnia, watercress and algae, which is of advantage in case of accidental spillage.

4. Preparation of Bio-Diesels:

There are four distinct stages in the preparation of plant oil bio-diesels. These are (a) heating of oil, (b) adding alkaline alcohol to oil, stirring and heating the mixture, (c) settling and separation of glycerol, and (d) washing of bio-diesel with water and removal of water. For preparing bio-diesel at farm scale, any procedure involving long time duration or requiring controlled temperature conditions might be unacceptable to the farmer.

Excessive reduction in the time required for bio-diesel preparation may result in decreased purity of bio-diesel i.e. lesser oil to bio-diesel conversion. It has been suggested that esterification yields be at least 90% if the esters were to be used in CI engines (Hawkins et al., 1982). It was, therefore, clear that for practical purposes, a small variation in oil to bio-diesel conversion would not matter much as long as this conversion is >90%. As such, it would be beneficial to save time and labour through a simplified process at the cost of small reduction in oil to bio-diesel conversion.

Most of the studies relating to plant oil bio-diesels have been confined to preparation of methyl esters either at laboratory scale or at commercial/large scale under controlled conditions. This requires complicated procedure as well as equipment. Considering the limitations and capabilities of a common Indian farmer and the requirements of a well prepared bio-diesel, a simple, inexpensive and less time consuming system has been developed at PAU for farm level bulk production of bio-diesels (Gupta, 1994). It requires not only less time but also less heating and the whole process is completed in about five hours.

In this method, oil is heated to a little below 60°C. On the other hand, alkaline methanol is prepared by dissolving 10 gms of sodium hydroxide pellets in 200 ml of methanol (for every one kg of oil). This alkaline methanol is added to the heated oil and the mixture is stirred manually for 5 minutes. The mixture is then kept for glycerol settlement. After four hours of settlement, glycerol is left at the bottom and bio-diesel is decanted from the top. Then the bio-diesel is washed two or three times with water to remove impurities like sodium etc. It also removes excess methanol. Use of warm water for washing gives better results and reduces the number of washings required. After each washing, water is allowed to settle for about 5 minutes and then it is removed from the bottom. At the end of last washing, water is allowed to settle for 15 minutes and is then removed leaving behind the bio-diesel. The washed bio-diesel is heated so that it becomes almost completely free of moisture.

The whole process for single batch production takes about five hours. If more number of containers are available (for heating oil and mixing it with alkaline methanol) different stages can be carried out simultaneously. Then the average time per batch will be quite less. However, the quantity of bio-diesel prepared in a batch will depend upon the size of the reaction vessel used. The process does not require any specialized equipment. Heating of oil could be done in any metallic container available with the farmer. Dissolving of sodium hydroxide in methanol can be done in a glass or a stainless steel container. The mixture can be stirred with the help of a wooden stick or plastic/stainless steel/glass rod. Glycerol settlement should be carried in an open stainless steel container, particularly at low ambient temperature (below 15 °C), because the glycerol solidifies and does not flow at low temperatures. At higher temperatures, final traces of bio-diesel in the glycerol can be separated using a separating funnel.

In case of farm level bio-diesel production, the mixing and settlement can be carried in one and the same container. But for commercial scale production, separate mixing will require mechanical stirrers and, therefore, separate container would be required for settlement to take care of the problems arising out of solidification of glycerol at low temperatures. Washing of bio-diesels with water and subsequent removal of this water can be carried in plastic bucket, again easily available with every farmer. For removing leftover traces of water in the washed bio-diesel, the separating flask, mentioned above, can be used.

As the esterification process developed at PAU is quite simple, less time consuming and inexpensive, it can be easily used by the farmer for preparing bio-diesels in bulk at a very short notice and without needing much additional equipment. Some precautions are, however, necessary to avoid any problems in bio-diesel preparation. Firstly, the oil should not be heated beyond 60°C otherwise there would be a chance of vaporization of methanol that has low boiling point (about 65° C). Secondly, sodium hydroxide pellets should be kept in airtight bottles. These should be properly mixed preferably in glass containers in the whole quantity of methanol to be used i.e. it should form almost homogeneous mixture, otherwise saponification may take place. Thirdly, the oil should have low acid value (<1.0) otherwise saponification may occur.

5. Characteristics of plant oils and Bio-Diesels:

Bio-diesels of several plant oils have been prepared, characterized, and used in diesel engines and tractors at PAU, Ludhiana. Some of the characterization results are given in appendix A2 and A3.

Kinematic viscosity of bio-diesels was reduced to about one sixth of that of the parent oil. The viscosity of the studied bio-diesels was about 1.28-2.16 times that of diesel. All the bio-diesels had quite high flash point compared to that of diesel, which is a beneficial safety feature. All the bio-diesels had a little lower gross heating value compared that of diesel. Esterification of linseed oil increased the heating value. Density was a little higher in case of bio-diesels than for diesel. Bio-diesels, in general, had lower pour point than of diesel. Distillation temperatures were higher for bio-diesels compared to diesel.

The sulphur-free plant oil is the reason for the very low SOx-emissions of bio-diesel. Generally the cetane number is higher for bio-diesel, resulting in a smoother running of the engine with less noise. Bio-diesel of rapeseed oil is by nature an oxygenated fuel with an oxygen content of about 10%. Oxygen is responsible for bio-diesel's favorable emission results, but it is also the reason for calorific value a little lower than conventional diesel (Korbitz, 1998).

6. Performance of CI engine fuelled with Bio-Diesels:

Soni and Verma (1993) used blends containing 10-25% HSD in rapeseed oil methyl ester as alternate fuel in 3.67 kW direct injection CI engine and compared their performance with that of HSD. Tests were conducted at fuel injection pressure of 210 Kg/cm^2 and 240 Kg/cm^2. All the fuel performed better at fuel injection pressure of 210 Kg/cm^2. At this pressure, the highest brake thermal efficiency values were recorded for blends containing 10% HSD in RME, 25% HSD in RME, unblended RME and HSD in that order. There was no significant difference in the exhaust gas temperature recorded for various fuels.

Gupta (1994) reported comparable performance of an unmodified, direct injection 3.67 kW diesel engine on bio-diesels of rice bran oil, cotton seed oil, linseed oil and raya oil. The effect of different injection timings and injection pressures on brake thermal efficiency was also studied. It was reported that the fuel injection timings had more pronounced effect on the brake thermal efficiency as compared to fuel injection pressure. Optimum values of fuel injection timing and pressure were found to be 25° BTDC and 25 Mpa respectively for all bio-diesels studied except rice-bran oil bio-diesel and unwashed linseed oil bio-diesel for which the optimum values of fuel injection timings were below the range studied. Higher compression ratio resulted in increased optimum value of fuel injection. Pandey (1996) reported that sunflower bio-diesel gave brake thermal efficiency comparable to diesel.

Gupta (1994) and Pandey (1996) reported that by using bio-diesel as fuel in 5 hp (3.72 kW) direct injection engine, the smoke number increased with load with higher rate of increase at higher loads. However, carbon monoxide (CO) concentration in exhaust gases increased abruptly with increase in load above 50 per cent of rated torque and hydrocarbon (HC) emission increased abruptly with increase in load beyond 75 percent of rated torque.

7. Related research at PAU, Ludhiana:

In an adhoc ICAR project (Verma et al., 1999), investigations on methyl bio-diesels of four plant oils, namely linseed oil, sunflower oil, rice-bran oil and Jatropha curcas oil were carried out. In addition to characterisation studies reported above, studies were also conducted on the following aspects:

Method for Estimation of Oil to Bio-diesel Conversion:

A spectrometric method was developed and standardized for estimating quantitatively the oil to bio-diesel conversion during the trans-esterification process used for preparing the bio-diesels. Oil bio-diesel conversion as well as recovery of bio-diesel was observed to be the highest in case of linseed oil (94% and 91% respectively) while the lowest values were obtained for rice-bran oil.

Bio-diesels could not be prepared from raw rice bran oil with very high FFA content. The oil tried had FFA > 25%. From parboiled rice-bran oil (FFA 3%), bio-diesels could be prepared but the percent oil to bio-diesel conversion and bio-diesel recovery were quite low (75% and 50% respectively). But for physically refined rice-bran oil, the values were 85% and 70% respectively. Presence of wax in rice-bran oil as well as its bio-diesels created problems in extreme winter during washing of bio-diesel. Use of warm water helped in effective washing.

Oil yield from Jatropha curcas seeds purchased from Rajasthan was quite low, possibly due to inferior quality of seeds and non-availability of proper extraction facilities for Jatropha curcas seeds in Punjab. However, the bio-diesel quality was quite good. Oil to bio-diesel conversion was 91% and recovery was 78%. The quality of Jatropha curcas oil purchased from Udaipur (Rajasthan) was not up to the mark resulting in only 85% oil to bio-diesel conversion and 70% bio-diesel recovery.

Storage Studies:

The FFA contents of the bio-diesels after a period of 1 to 1.5 years storage increased marginally. However, the oils had higher increase in FFA content as compared to their respective bio-diesels. During storage, the viscosity of the bio-diesels increased by 30-60%

over a period of seven months. The highest increase was observed in case of linseed and sunflower oil bio-diesels. The effect of storage time on weight gain of oils and their bio-diesels was also studied. Samples were kept in half and fully filled containers. In case of linseed oil, sunflower oil and sunflower oil bio-diesel, the weight gain was more in half-filled containers. But in linseed oil bio-diesel, weight gain was similar in both types of containers. There was no weight increase in case of Jatropha curcas oil and its bio-diesel. However, in case of rice-bran oil and its bio-diesel, the weight gain was more in case of fully filled container. Except linseed oil bio-diesel, the weight gain was partly due to absorption of moisture and partly due to reaction with air. But in case of linseed oil, it was mainly due to reaction with air. In case of linseed oil, linoxygen deposited on the rim of half filled container even after 15 days of storage.

Effect of bio-diesels on Engine Components

During the studies on the effect of plant oil bio-diesels on engine components, it was found that no significant change was observed in the dimensions of metallic components, namely copper washer, aluminium washer and piston rings. However, the colour of copper washer dipped in linseed oil bio-diesel and sunflower oil bio-diesel changed. The peach colour of precipitate layer was found deposited on copper washer in case of sunflower oil bio-diesel. Among non-metallic engine components, the maximum changes were observed in case of rubber washer followed by insignificant changes in case of plastic pipe. However, no change was observed in case of gaskets.

Use of Plant Oil Bio-diesels in Stationary as well as Tractor Engines

Fuel consumption tests were carried out in accordance with modified BIS engine Test Codes. The tests included the fuel consumption test, performance test and endurance test at the prescribed loads. The tests indicated that among the four bio-diesels, the specific fuel consumption was the lowest in case of linseed oil bio-diesel followed by sunflower oil bio-diesel. Specific fuel consumption was comparatively higher in case of rice-bran oil bio-diesel and Jatropha curcas oil bio-diesel. That is why brake thermal efficiency was the highest in case of linseed Oil bio-diesel followed by sunflower oil bio-diesel.

Long duration .testing of diesel engines using the methyl bio-diesels was also performed. Engines were run for endurance tests on bio-diesels of linseed oil, rice-bran oil and sunflower oil for 282, 243 and 272 hours respectively. Due to late availability of Jatropha curcas oil, endurance tests on its bio-diesel could not be taken-up. Standard measurements of engine components before and after the endurance tests with each bio-diesel indicated that there was no significant wear in various components.

Exhaust emissions namely CO, NOx and total combustibles were also monitored. NOx emissions were a little higher in case of bio-diesels compared to diesel particularly in sunflower oil bio-diesel. On the other hand, CO emissions were significantly lower in case of all the four bio-diesels compared to diesel. Combustible emissions were also lower in case of the bio-diesels as compared to diesel.

An Eicher tractor of 35 hp (26.1 kW) was run on rice-bran oil bio-diesel for seedbed preparation with a field cultivator and disc harrow. No visual smoke in the exhaust was observed with the use of the bio-diesels. NOx emissions were marginally lower with the bio-diesel than diesel.

On the whole, it was observed that the performance of the existing unmodified diesel engine run on all the four plant oil bio-diesels was quite promising. In fact better thermal efficiency was achieved and the bio-diesels were more environment-friendly as compared to diesel in terms of exhaust emissions.