Chapter 3

Engine and Vehicle Testing

Power Measurement Methods

- *Power* – the rate of doing work. A unit of power is a newton meter per second (watt).
- *Brake power* – the power output of the engine crankshaft. The engine may be stripped of part or all of its accessories.
- *Power take-off power* – the power delivered by a tractor through its pto shaft.

Power Measurement Methods

- *Drawbar power* – the power of a tractor measured at the end of the drawbar.
- *Friction power* – the power required to run the engine at any given speed without production of useful work. It is usually measured with a suitable electric dynamometer that runs or “motors” the engine. It represents the friction and pumping losses of an engine.

Power Measurement Methods

- *Observed power* – the power obtained at the dynamometer without any correction for atmospheric temperature, pressure, or water vapor.
- *Corrected power* – obtained by correcting observed power to standard conditions of sea-level pressure, 15.5^{o}C temperature, and zero vapor pressure.

Power Measurement Methods

- *Dynamometer* – an instrument for determining power, usually by the independent measure of force, time, and the distance through which the force is moved. Dynamometers may be classified as brake, drawbar, or torsion, according to the manner in which the work is being applied. Also, they may be classed as absorption or transmission, depending on the disposition of the energy.

Dynamometers

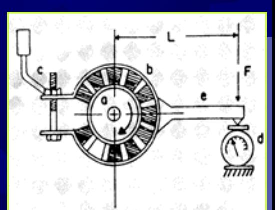
- A dynamometer for testing engines must include the following four essential elements:
  - A means for controlling torque
  - A means for measuring torque
  - A means for measuring speed
  - A means for dissipating power

Prony brake

- It is the simplest type of dynamometer – an example of an absorption-type dynamometer.
- The rotor is connected to the crankshaft of the engine and rotates at engine speed. Surrounding the rotor are brake shoes that create torque drag on the rotor. The torque is controlled by tightening or loosening the hand lever. The torque is measured by a scale located at the end of the lever arm. A tachometer must be provided for measuring the rotor speed. After the torque and speed are measured, the power can be calculated.

Prony Brake Dynamometer

- $P = (2\pi * L * F * n) / 60{,}000$; kW
- Torque is determined by the prony brake through measuring Force and Length.
- $P = 2\pi nT / 60{,}000$; kW



Goering et. al., 2003, Off-road Vehicles, ASAE

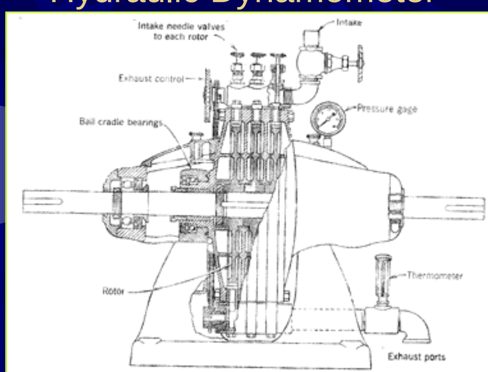
Hydraulic

- The hydraulic dynamometer operates like a hydraulic turbine/pump. The working medium, usually water, is circulated within the housing creating frictional resistance to turbine rotation. The engine power is converted to heat and the liquid exits at a higher temperature than when it entered. The outer case, which is free to rotate about the input shaft, is connected to and restrained by the torque arm. With the exception of bearing friction, the torque measured is equal to that supplied to the dynamometer.

Hydraulic con't

- The power-absorbing capacity for any given type of design varies approximately as the cube of the speed of rotation and the fifth power of the diameter (Culver 1937). The power equation is the same as for the prony brake.
- The accuracy of the hydraulic-brake dynamometer can be expected to be somewhat better than that of the prony brake and should fall between it and the cradled electric type.

Hydraulic Dynamometer

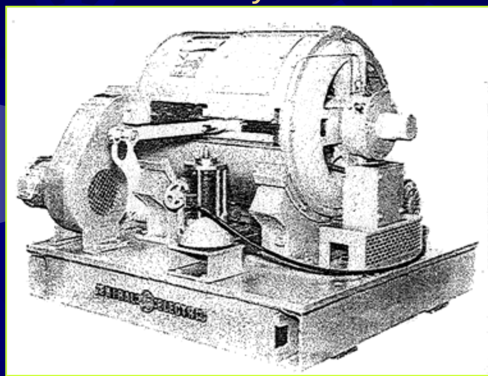


Goering et. al., 2003, Off-road Vehicles, ASAE

Electric Direct-Current Dynamometers

- The direct-current cradle-mounted dynamometer is a shunt-wound generator with separate field excitation. The field frame is free to rotate, and since any effort to turn the armature causes the field to attempt to revolve, the resultant torque will cause a force to be registered on the scales. The accuracy is independent of the electrical efficiency of the machine. Accuracy within 0.25 percent is possible.

DC Electric Dynamometer



Goering et. al., 2003, Off-road Vehicles, ASAE

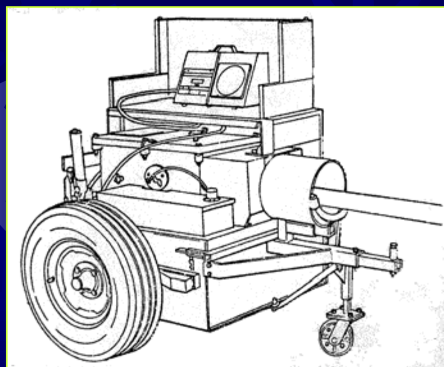
Shop-Type Dynamometer

- It is often desirable to measure the PTO power of a tractor in the field or in an implement dealer's repair shop. Since dynamometers are much too expensive and difficult to use except in labs, several inexpensive and portable devices generally classified as shop-type or agricultural dynamometers have been developed.

Shop-type Dynamometers con't

- The principle of operation of shop-type dynamometers is generally similar to a hydraulic or a prony brake dynamometer. Hydraulic pumps are also sometimes used.
- Shop-type dynamometers generally employ a pressure gage to measure the force on the resisting torque arm.

Shop-type Dynamometer



Goering et. al., 2003, Off-road Vehicles, ASAE

Spring Dynamometer

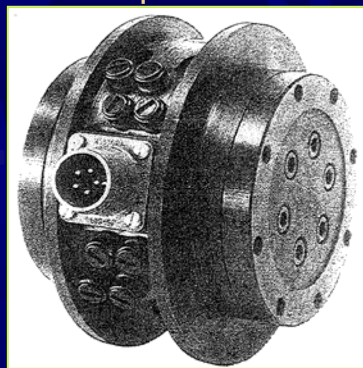
- The simplest and most obvious type of drawbar unit consists of a spring that elongates under tension or shortens under compression. Such a dynamometer is suitable for rough measurements of forces.

Goering et. al., 2003, Off-road Vehicles, ASAE

Torsion Dynamometers

- With the advent of machinery operated by tractor power-take-off shafts a great deal of interest has been displayed in devices for the measurement of power as transmitted by rotating shafts.
- *Torque Meter, Strain-Gage Type*:
  - The development of the electrical resistance strain gage has made practical the measurement of torque and force on farm tractors and machines. Many torque meters employing strain gages have been developed.

Torque Meter

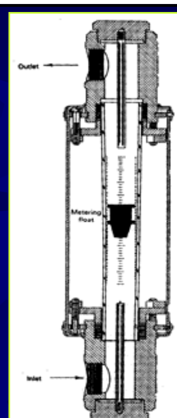


Goering et. al., 2003, Off-road Vehicles, ASAE

Volume-Based Fuel Flowmeters

- Fuel consumption is frequently measured during an engine test; the measurement can be on a volume or mass basis.

- This *rotameter* measures fuel consumption on a volume basis. The transparent tube has a slight taper (its diameter increases toward the top). Fuel enters the bottom of the tube, flows upward around the float in the tube, and exits at the top. The higher the flow rate, the higher the flow must rise to allow sufficient space around the edges of the float to allow fuel to pass. Thus, a scale inscribed directly on the outside of the tube can be calibrated directly in terms of volumetric flow rate.



Goering et. al., 2003, Off-road Vehicles, ASAE

Standardized Tractor Tests

- Data from standardized tests may be used in comparing the performances of various makes and models of tractors. When comparative test are administered by agencies independent of the tractor manufacturers, the resulting competition among the manufacturers also tends to promote improvements in tractors design. The original independent agency to do tractor testing was the University of Nebraska Tractor Testing Laboratory (NTTL).

Standardized Tractor Tests

- Three standard test procedures are now widely recognized for testing tractors. They include the standard ASAE/SAE/ISO test, the OECD restricted test, and the OECD long test. The OECD tests are described by code designations, as follows:

- Compulsory Tests:
  1. Main PTO
  2. Hydraulic power and lifting force
  3. Drawbar power, ballasted tractor
  4. Turning area and turning circle
  5. Position of center of gravity
  6. Braking (wheeled tractors only)
  7. External (bystander) noise (wheeled tractors only)

- Tests performed and reported at manufacturer's option:
  1. Engine
  2. Performance at the belt or belt pulley shaft
  3. Performance in a hot atmosphere
  4. Low temperature starting
  5. Drawbar power and fuel consumption for unballasted tractor

POWER TAKE-OFF PERFORMANCE

Power HP (kW)	Crank shaft speed rpm	Gal/hr (l/h)	lb/hp.hr (kg/kW.h)	Hp.hr/gal (kW.h/l)	Mean Atmospheric Conditions
MAXIMUM POWER AND FUEL CONSUMPTION					
Rated Engine Speed—(PTO speed—1003 rpm)					
94.02 *(70.11)*	2099	5.40 *(20.44)*	0.402 *(0.244)*	17.42 *(3.43)*	
Maximum Power (2 hours)					
95.06 *(70.88)*	1900	5.21 *(19.71)*	0.383 *(0.233)*	18.26 *(3.60)*	
VARYING POWER AND FUEL CONSUMPTION					
94.02 *(70.11)*	2099	5.40 *(20.44)*	0.402 *(0.244)*	17.42 *(3.43)*	Air temperature
82.93 *(61.84)*	2184	5.02 *(19.00)*	0.423 *(0.257)*	16.52 *(3.26)*	80°F *(27°C)*
63.10 *(47.06)*	2209	4.29 *(16.24)*	0.475 *(0.289)*	14.71 *(2.90)*	Relative humidity
42.07 *(31.37)*	2227	3.39 *(12.83)*	0.563 *(0.343)*	12.41 *(2.45)*	65%
21.16 *(15.78)*	2245	2.53 *(9.58)*	0.836 *(0.509)*	8.36 *(1.65)*	Barometer
0.90 *(0.67)*	2260	1.72 *(6.49)*	13.266 *(8.070)*	0.53 *(0.10)*	29.06" Hg *(98.44 kPa)*

Maximum Torque 311 lb.-ft. *(422 Nm)* at 1400 rpm
Maximum Torque Rise 32.5%
Torque rise at 1700 engine rpm 20%

Location of Test: Tractor Testing Laboratory, University of Nebraska, Lincoln, Nebraska 68583-0832

Dates of Test: May 10 to June 1, 1994

Manufacturer: John Deere Tractor Works, P.O. Box 270, Waterloo, Iowa 50704

FUEL OIL and TIME: Fuel No. 2 Diesel **Cetane No.** 53.9 **Specific gravity converted to 60°/60° F *(15°/15°C)*** 0.8400 **Fuel weight** 6.994 lbs/gal *(0.838 kg/l)* **Oil SAE** 15W-40 **API service classification** SG/CE **To motor** 4.251 gal *(16.093 l)* **Drained from motor** 4.178 gal *(15.817 l)* **Transmission and hydraulic lubricant** John Deere Hy-Gard fluid **Front axle lubricant** John Deere GL-5 Gear Lubricant **Total time engine was operated** 20.0 hours.

ENGINE: Make John Deere Diesel **Type** six cylinder vertical with turbocharger **Serial No.** *TO6059T431193* **Crankshaft** lengthwise **Rated engine speed** 2100 **Bore and stroke** (as specified) 4.19"×4.331" *(106.5 mm×110.0 mm)* **Compression ratio** 17.8 to 1 **Displacement** 359 cu in *(5880 ml)* **Starting system** 12 volt **Lubrication** pressure **Air cleaner** two paper elements and aspirator **Oil filter** one full flow cartridge **Oil cooler** engine coolant heat exchanger for crankcase oil, radiator for hydraulic and transmission oil **Fuel filter** one paper element and prestrainer **Fuel cooler** radiator for inlet fuel **Muffler** underhood **Exhaust** vertical **Cooling medium temperature control** two thermostats and variable speed fan

DRAWBAR PERFORMANCE
FUEL CONSUMPTION CHARACTERISTICS

Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crank-shaft speed rpm	Slip %	Fuel Consumption lb/hp.hr (kg/kW.h)	Fuel Consumption Hp.hr/gal (kW.h/l)	Temp. °F (°C) cooling med	Temp. °F (°C) Air dry bulb	Barom. inch Hg (kPa)
Maximum Power—6th (C1) Gear									
82.70 *(61.67)*	6456 *(28.72)*	4.80 *(7.73)*	2101	5.9	0.457 *(0.278)*	15.31 *(3.02)*	196 *(91)*	70 *(21)*	28.73 *(97.29)*
75% of Pull at Maximum Power—6th (C1) Gear									
65.16 *(48.59)*	4838 *(21.52)*	5.05 *(8.13)*	2198	3.49	0.505 *(0.307)*	13.86 *(2.73)*	190 *(88)*	70 *(21)*	28.74 *(97.32)*
50% of Pull at Maximum Power—6th (C1) Gear									
44.39 *(33.10)*	3229 *(14.36)*	5.16 *(8.30)*	2221	2.33	0.603 *(0.367)*	11.60 *(2.29)*	186 *(86)*	70 *(21)*	28.74 *(97.32)*
75% of Pull at Reduced Engine Speed—8th (C2) Gear									
65.26 *(48.67)*	4843 *(21.54)*	5.05 *(8.13)*	1572	3.49	0.440 *(0.268)*	15.90 *(3.13)*	192 *(89)*	70 *(21)*	28.74 *(97.32)*
50% of Pull at Reduced Engine Speed—8th (C2) Gear									
44.34 *(33.06)*	3223 *(14.34)*	5.16 *(8.30)*	1589	2.41	0.491 *(0.299)*	14.23 *(2.80)*	184 *(84)*	70 *(21)*	28.74 *(97.32)*

ENGINE OPERATING PARAMETERS: Fuel rate: 37.3-40.3 lb/h *(16.9-18.3 kg/h)* **High idle:** 2225-2325 rpm **Turbo boost** nominal 8.7-10.2 psi *(60-70 kPa)* as measured 9.0 psi *(65 kPa)*

CHASSIS: Type front wheel assist **Serial No.** *RW7200S001437* **Tread width** rear 60.0" *(1524 mm)* to 100.3" *(2548 mm)* front 60.0" *(1524 mm)* to 88.0" *(2235 mm)* **Wheel base** 103.3" *(2625 mm)* **Hydraulic control system** direct engine drive **Transmission** selective gear fixed ratio **Nominal travel speeds mph (km/h)** first 1.43 *(2.30)* second 2.00 *(3.22)* third 2.64 *(4.25)* fourth 3.03 *(4.87)* fifth 4.24 *(6.82)* sixth 4.82 *(7.75)* seventh 5.59 *(9.00)* eighth 6.74 *(10.85)* ninth 8.90 *(14.33)* tenth 9.99 *(16.08)* eleventh 13.98 *(22.50)* twelfth 18.46 *(29.71)* reverse 1.75 *(2.81)*, 3.70 *(5.96)*, 5.89 *(9.48)*, 12.21 *(19.65)* **Clutch** multiple wet disc hydraulically actuated by foot pedal **Brakes** wet multiple disc hydraulically actuated by two foot pedals which can be locked together **Steering** hydrostatic **Power take-off** 540 rpm at 2080 engine rpm and 1000 rpm at 2093 engine rpm **Unladen tractor mass** 12522 lb *(5680 kg)*

REPAIRS AND ADJUSTMENTS: No repairs or adjustments

DRAWBAR PERFORMANCE
MAXIMUM POWER IN SELECTED GEARS

Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crank-shaft speed rpm	Slip %	Fuel Consumption lb/hp.hr (kg/kW.h)	Fuel Consumption Hp.hr/gal (kW.h/l)	Temp. °F (°C) cooling med	Temp. °F (°C) Air dry bulb	Barom. inch Hg (kPa)
2nd (A2) Gear									
60.51 *(45.13)*	12254 *(54.51)*	1.85 *(2.98)*	2201	14.66	0.553 *(0.336)*	12.65 *(2.49)*	186 *(85)*	63 *(16)*	28.77 *(97.43)*
3rd (A3) Gear									
78.25 *(58.35)*	11568 *(51.59)*	2.53 *(4.07)*	2156	9.67	0.480 *(0.292)*	14.38 *(2.83)*	190 *(88)*	66 *(19)*	28.76 *(97.39)*
4th (B1) Gear									
81.84 *(61.03)*	10856 *(48.29)*	2.83 *(4.55)*	2060	8.14	0.460 *(0.280)*	15.22 *(3.00)*	193 *(89)*	69 *(21)*	28.74 *(97.32)*
5th (B2) Gear									
83.18 *(62.03)*	8260 *(36.74)*	3.78 *(6.08)*	1903	5.25	0.438 *(0.267)*	15.95 *(3.14)*	197 *(92)*	70 *(21)*	28.73 *(97.29)*
6th (C1) Gear									
83.22 *(62.06)*	7209 *(32.07)*	4.33 *(6.97)*	1903	4.45	0.439 *(0.267)*	15.93 *(3.14)*	197 *(91)*	70 *(21)*	28.73 *(97.29)*
7th (B3) Gear									
83.14 *(62.00)*	6171 *(27.45)*	5.05 *(8.13)*	1901	3.81	0.440 *(0.268)*	15.90 *(3.13)*	198 *(92)*	75 *(24)*	28.68 *(97.12)*
8th (C2) Gear									
79.95 *(59.62)*	4876 *(21.69)*	6.15 *(9.90)*	1905	2.59	0.452 *(0.275)*	15.46 *(3.05)*	197 *(91)*	71 *(22)*	28.71 *(97.22)*
9th (C3) Gear									
79.14 *(59.02)*	3642 *(16.20)*	8.15 *(13.11)*	1903	2.50	0.452 *(0.275)*	15.46 *(3.05)*	196 *(91)*	71 *(22)*	28.73 *(97.29)*

REMARKS: All test results were determined from observed data obtained in accordance with official OECD, SAE and Nebraska test procedures. For the maximum power tests, the fuel temperature at the injection pump return was maintained at 156° F (69°C). This tractor did not meet manufacturers claim of 72.0 dB(A) cab sound level. The performance results on this summary were taken from OECD tests conducted under the Code II Restricted Standard Test Code procedure.

We, the undersigned, certify that this is a true and correct report of official Tractor Test No. 1678, Summary 150, July 21, 1994.

LOUIS L. LEVITICUS
Engineer-in-Charge

R.D. GRISSO
M.F. KOCHER
K. VON BARGEN
Board of Tractor Test Engineers

DRAWBAR PERFORMANCE AT 2100 RPM (Front Drive Engaged)
MAXIMUM POWER IN SELECTED GEARS

Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crank shaft speed rpm	Slip %	Fuel Consumption lb/hp.hr (kg/kW.h)	Fuel Consumption Hp.hr/gal (kW.h/l)	Temp °F (°C) cooling med	Temp °F (°C) Air dry bulb	Barom. inch Hg (kPa)
3rd (A3) Gear									
76.19 (56.81)	12039 (53.55)	2.37 (3.82)	2150	14.34	0.499 (0.304)	14.01 (2.76)	190 (88)	66 (19)	28.77 (97.43)
4th (B1) Gear									
82.36 (61.42)	10678 (47.50)	2.89 (4.66)	2103	7.84	0.461 (0.280)	15.18 (2.99)	192 (89)	68 (20)	28.74 (97.32)
5th (B2) Gear									
83.04 (61.92)	7419 (33.00)	4.20 (6.75)	2101	4.45	0.457 (0.278)	15.32 (3.02)	196 (91)	70 (21)	28.73 (97.29)
6th (C1) Gear									
82.70 (61.67)	6456 (28.72)	4.80 (7.73)	2101	3.97	0.457 (0.278)	15.31 (3.02)	196 (91)	70 (21)	28.73 (97.29)
7th (B3) Gear									
82.65 (61.63)	5529 (24.59)	5.61 (9.02)	2100	3.49	0.460 (0.280)	15.21 (3.00)	196 (91)	74 (23)	28.69 (97.16)
8th (C2) Gear									
79.64 (59.39)	4392 (19.54)	6.80 (10.94)	2099	2.83	0.472 (0.287)	14.82 (2.92)	196 (91)	71 (22)	28.72 (97.26)
9th (C3) Gear									
78.94 (56.87)	3293 (14.65)	8.99 (14.47)	2098	2.41	0.476 (0.290)	14.69 (2.89)	194 (90)	71 (22)	28.73 (97.29)

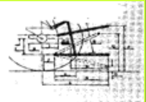
DRAWBAR PERFORMANCE (FRONT DRIVE DISENGAGED)
FUEL CONSUMPTION CHARACTERISTICS

MAXIMUM POWER IN SELECTED GEARS

TRACTOR SOUND LEVEL WITH CAB

TIRES, BALLAST AND WEIGHT

THREE POINT HITCH PERFORMANCE (SAE Static Test)



THREE POINT HITCH PERFORMANCE (OECD Static Test)

JOHN DEERE 7200 SYNCROPLUS DIESEL

Correcting Power for Atmospheric Conditions

- The density of air changes with temperature and barometric pressure. Such density changes affect the rate at which an engine can consume air and, since it is air consumption that limits engine power, the power output varies with atmospheric conditions.
- Power correction begins with the use of the ideal gas law to correct for atmospheric conditions: **pV = MRT**

Power Correction

- Because mass density is the mass per unit volume, the ideal gas law can be restated as:
  - **ρ = M / V = BP / RT**
  - Where ρ = air density, kg/m^3
  - BP = barometric pressure, kPa
  - T = absolute temperature of air, K
  - R = ideal gas constant
- This equation can be used to obtain the ratio of air densities at observed and standard conditions.

Power Correction

- The gas constant cancels out in obtaining the ratio, with the following result:
  - **$\rho_s / \rho_o = (BP_s / BP_o)(T_o / T_s)$**
  - Where ρ_o = air density at observed conditions, kg/m3
  - ρ_s = air density at standard conditions, kg/m3
  - Bp_o = barometric pressure at observed conditions, kPa
  - BP_s = barometric pressure at standard conditions, kPa
  - T_o = absolute temperature of the air at observed conditions, K
  - T_s = absolute temperature of the air at standard conditions, K

Power Correction

- Power correction factor:
  - $f_a = (BP_s / BP_o)(T_o / T_s)^n$
- Theoretically, the correction should be applied to the indicated power, then
  - $P_{bs} + P_{fs} = f_a (P_{bo} + P_{fo})$
- But $P_{fs} = P_{fo}$, because friction power is not affected by atmospheric conditions:
  - $P_{bs} = f_a P_{bo} + P_f (f_a - 1)$

Power Correction

- Because P_f is often much smaller than P_b and f_a is close to 1, the last term is usually dropped. The final power correction equation is then:
  - $P_{bs} = f_a P_{bo}$
- That is, the correction is applied directly to the brake power. The usual choice of standard conditions is B_{pa} = 99 kPa and T_s = 298 K (25^{o}C).