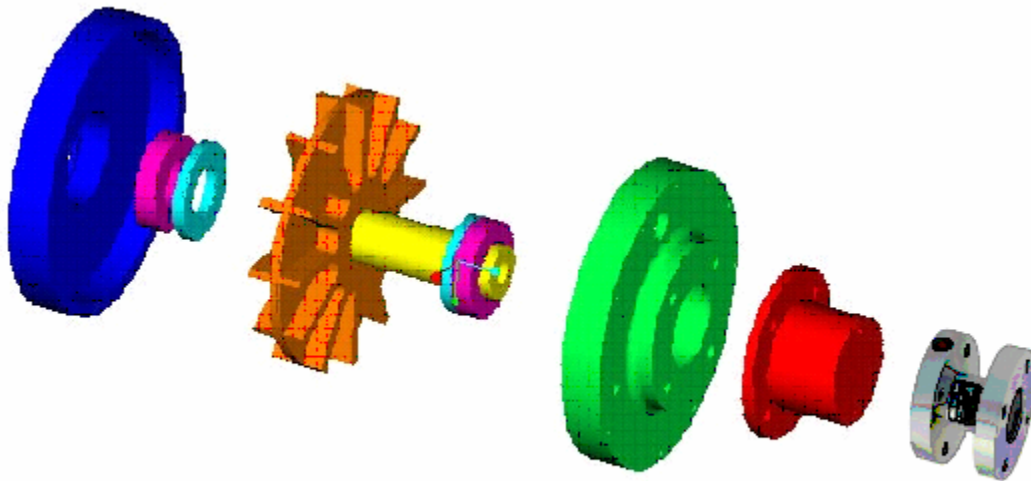


Dynamometer Redesign and Build for Future RIT Automotive Laboratory

Project 05105



Executive Summary

The mission of Project 04006, Automotive Laboratory Development: Small Engine Dynamometer System Design was to “design and fabricate a working pilot production system.” In developing a design, the project team considered three design concepts: a fluid braking system, a mechanical braking system and an electrical braking system. After feasibility testing, the team proved the fluid braking system to be the best option. The feasibility testing involved comparing the concepts to the baseline concept, the previously purchased Land & Sea water brake dynamometer, by the following factors: technical, performance, schedule, economic and resource. After this decision was made, the team began designing the dynamometer setup, which included a torque arm, impeller, housing and sensor package. With the completion of the Preliminary Design Review, the team was looking forward to the production of a fully functional prototype.

The second quarter work proved challenging, especially in regards to the data acquisition system (DAQ). Without any electrical engineers, the team struggled to interface the purchased sensors with a LabVIEW program they developed. Sensors were connected to the engine and dynamometer but no data was acquired for analysis, because the LabVIEW program was not functional. Also, a few obstacles were met when machining the housing and impeller in regards to constraints and slippage, but changes were made accordingly. Nylon washers were implemented to constrain the impeller in order to keep it centered within the water brake housing. A second problem for the team was that the collar adaptor was slipping along the drive shaft of the engine under load,

which did not allow for the dynamometer to completely stall the engine. A keyway and dowel pin were used in the mounting of the collar which reduced the chance of the collar and assembly to slip. Even with these modifications to their design, after the 22 weeks of Senior Design were over, team 04006 failed to produce a functioning prototype with corresponding DAQ system.

Project 05105, Dynamometer Redesign and Build for Future RIT Automotive Laboratory, has been implemented in order to improve upon the failed design. With the groundbreaking of the Automotive Laboratory drawing near, a working prototype of a reproducible dynamometer is imperative. This team must overcome the challenges faced by team 04006 in order to do so.

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1 Needs Assessment

1.1 Project Mission Statement

The mission of this design project team is to improve upon current designs of the dynamometer such that the design is functional and can be reproduced to create 4-6 units in the future RIT Automotive Laboratory. The final design must be safe, reliable, and simple to operate in order to be a successful learning tool.

1.2 Product Description

Last year's senior design team 04006 attempted to design from the ground up a small engine dynamometer, similar to the Land & Sea unit currently used in the automotive laboratory at the Rochester Institute of Technology (RIT). This dynamometer was an effective learning tool to supplement thermodynamics and fluid mechanics courses offered by Kate Gleason College of Engineering. The team's primary goals were to create a new design that was easily reproducible at a cost far below that of a comparable Land & Sea dynamometer. The aim of our design group is to improve upon the prototype of last year's team. It is our intention to fulfill not only previous goals set, but also a new set of requirements determined by discussions with our customer Mark Steinke. The purpose of a dynamometer is to load an engine in order to measure its performance. The application of this load causes the engine to perform work. The goal of a dynamometer is to determine the amount of work done by the engine. Our design must facilitate our test engine, A Kohler Command engine rated at 5 horsepower and 8 ft-

lbs of torque. This single cylinder, air cooled, four stroke power plant is both robust and reliable.

Our dynamometer must completely stall the engine in order to fulfill our goals. Since the primary goal of our design group is to redesign the existing dynamometer prototype, we will retain most of the original design and concentrate on its shortcomings. Our design shall consist of a water brake to apply a load to the engine, a reactor torque sensor to measure the torque generated by the engine, and a data acquisition package capable of recording data generated by the torque sensor and other various sensors including mass air flow, temperature, and pressure. In designing the dynamometer, it was important to facilitate our customers and users of the unit. For this reason, ease of operation and safety were two very prevalent issues considered during the design phase.

1.3 Scope Limitations

The scope of this design team is to redesign and produce a fully functional prototype of the Automotive Laboratory Small Engine Dynamometer by the end of the spring quarter. Being that this project is a continuation of last year's progress, the main goal of the team is to improve on the existing design by focusing on correcting any shortcomings of the previous design.

Responsibilities for the conclusion of Winter Quarter 20042:

- Revised Needs Assessment
- Benchmarking Current Dyno Design
- Concept Development
- Feasibility Assessment
- Revised Drawing Package

- Analysis of Redesign
- Revised Bill of Material
- Budget

Responsibilities for the conclusion of Spring Quarter 20043:

- Fully Functional Prototype
- Complete and Operational Data Acquisition System (DAQ)
- Operation and Maintenance Manual
- Final Report

1.4 Stake Holders

The primary stake holders are the students and professors of the coming years who will use the soon to be completed Automotive Laboratory. The secondary stakeholders are the current senior design team working on the project.

1.5 Key Business Goals

In order for the project to be successful, the following key business goals must be met by the conclusion of the design:

- The dynamometer design will meet the educational and financial requirements given by the RIT staff.
- The dynamometer will be easily reproduced to meet the expansion needs of RIT's Kate Gleason College of Engineering.
- The project will help develop the professional demeanor of the students involved in the project.

1.6 Top Level Critical Financial Parameters

- The total dynamometer cost has to be less than that of the current Land & Sea DNYO-mite dynamometer.
- The dynamometer system needs to be easily reproduced; this is to be done by using common parts and simple machining.
- Annual maintenance and repair is to be minimal, so design is to be robust but cost effective.

1.7 Financial Analysis

A target budget of \$3000 has been set for the redesign project. The major aspects of the budget include:

- Mechanical components of the dynamometer including machined parts, bearings, seals, etc.
- Data Acquisition System including all necessary equipment and interface software
- Sensor package
- Workstation or cart with engine mounting hardware
- Computer system to run DAQ software

1.8 Primary Market

The primary market of the small engine dynamometer system is RIT's Kate Gleason College of Engineering. This includes both the students and the staff mainly in the Mechanical Engineering Department.

1.9 Order Qualifications

The senior design team will produce a functional prototype of the small engine dynamometer with a working DAQ. This design will fill all of the needs desired by the Mechanical Engineering Department of Kate Gleason College of Engineering. This design will take into consideration that the system must be able to be duplicated along with including an operation and maintenance manual.

1.10 Order Winners

- Built in accordance with the OSHA safety standards
- More cost effective than the current Land & Sea dynamometer
- Easy to use design for both the professors and the students
- Will meet the educational parameters set by the staff in the department
- Easily maintained and repaired if necessary
- Easily reproduced

1.11 Innovation Opportunities

The redesign of the small engine dynamometer will incorporate a Reactor Torque Sensor rather than an industry standard torque arm design which makes a new benchmark in torque data acquisition. Also the design will be more of a learning tool than a raw data collector.

1.12 Background



Fig. 1.12-1 DYNO-mite dynamometer

A dynamometer in its simplest sense can be defined as a device for measuring the power output of a source. Figure 1.12-1 is an example of a Land & Sea dynamometer. Dynamometers typically work by applying some type of load or measurable resistance to a power source. The power source in the case of this project is a small 4-stroke engine. This load can be measured several different ways relative to the engine so in turn there are several different types of dynamometers.

The first type is a DC generator dynamometer. This type of dyno uses a DC generator with a computer moderated excitation to load the engine. With this type the power output of the engine is dissipated as heat. DC generator dynamometers work well for very precise RPM control but this type of dyno has a very large moment of inertia on the power source; this heavy rotating mass makes it harder for the engine to accelerate. In return this heavy rotating mass will allow the engine to regain a lot of stored horsepower from the engine when the engine is ramped down, which in turn will alter output data .

Another draw back is that the overall cost of these systems makes it inadequate for the application of this project.

The next type is an Eddy current brake dynamometer which is very similar to that of a DC generator type; it too dissipates the engine's power as heat. Where this type differs from a DC generator is that an Eddy current does not actually generate electricity. Eddy current dynamometers use a magnetic field controlled by a power supply to control the load on the metallic rotor that is attached to the engines output shaft. The main draw back of this type of dynamometer is that heat is a major issue. The rotor that spins inside the magnetic coils of the dyno creates large amounts of heat and in order to cool the rotor complex cooling systems have to be incorporated. These systems add to the overall cost and complexity of operation to the system again making it difficult to incorporate for this project.

The last types of dynamometers applicable to this project are two standard brake types. The two different types are mechanical brake and water, or fluid, brakes. The mechanical brake is the simplest of all the different types that will be discussed. This type uses a mechanical brake very similar to the ones found on late model cars to load the engine. A rotating drum is attached to the output shaft of the engine and a brake pad is used to load the drum. Measurements in this case were taken using a calibrated mechanical linkage. This is all well and good but the draw back of a mechanical brake is friction brakes make it hard to accurately regulate load due to heat fluctuation of the system and brake pad wear.

The last type of dyno is a water or fluid brake. A fluid brake is exactly what the name suggests; it is a dyno that uses fluid to regulate the load requirements. A fluid brake

is also very simple in design, it uses an impeller or veined rotor that is rigidly mounted to the engine output shaft which is then encased by a free floating sealed housing. The fluid level inside the housing, which resists the movement of the impeller, is what creates the load on the engine. So, in turn the higher the fluid level, the more the load. This system also changes the engines power to heat by creating hot fluid due to the friction inside the housing. The heat is carried away in this system by constantly pumping fresh cool fluid in and forcing the hot fluid out. This action is regulated by a control valve.

The actual torque output measured in this type of dyno can be taken by several different methods. One method is by restricting the motion of the free floating housing by a restraint arm with a strain gauge or load cell mounted to it, this type of restriction is commonly referred to as a “torque arm.” In this case as the housing wants to move due to the friction created by the impeller on the fluid inside, the arm restricts that movement so in turn the arm will see all of the torque applied. Another way to measure the output is by using a reactor torque sensor (RTS) which also works in a similar manner to that of the torque arm. Where the RTS differs from the torque arm is that its torque is measured in accordance to the relative twist of two conjoined plates, where one plate is mounted to the free floating housing and the other to a rigid mount. Regardless of which torque measuring device is used, a fluid brake dyno having very low moment of inertia and few moving parts is a very cost efficient and effective tool for small engine application.

2 Design Objectives and Criteria

The team acknowledges that certain objectives and specifications must be determined so that it can measure the performance of the engine dynamometer system. These objectives and specifications are discussed in this section.

2.1 *Design Objectives*

There are a number of design objectives that require the attention of the team. These objectives need to be specified in order for the team to have a set list of goals to achieve. These objectives are listed below.

- 1) The most important goal that the team has to achieve is the production of a functional, accurate engine dynamometer. The design elements must include this objective at every phase.
- 2) The engine dynamometer must be an effective learning tool. This goal lies at the core of the project, for the engine dynamometer's prime function is to facilitate learning at the Kate Gleason College of Engineering.
- 3) Another objective that has been incorporated into the design of the engine dynamometer is accuracy. In order to fulfill the previous two design objectives, the acquisition of data must provide a high level of accuracy for the engine dynamometer to be a functional lab tool.
- 4) Our team will take great care to ensure that the design is reliable and more importantly poses no safety threat to its users. This objective is essential to not only the safety of the students but also to the effectiveness of the engine laboratory and therefore essential for the dynamometer as a teaching tool.

2.2 Performance Objectives

Our team has decided that a number of performance specifications must be met in order for the project to be successful. These specifications are based on the requirements set forth by our customer. Table 2.2-1 provides a list of these requirements in engineering units. The final product must meet these requirements so that the basic objectives of the project are fulfilled. The following specifications were kept in mind while designing the engine dynamometer:

- 1) The engine dynamometer shall be capable of absorbing *at least* five horsepower (3.7 Kilowatts) of power. In essence the dynamometer must be able to completely stall the five horsepower Kohler Command engine. If this objective cannot be fulfilled, complete analysis of the engine will not be possible.
- 2) The sensors and data acquisition system must be accurate and reliable and capable of handling the conditions that occur during engine operation (high temperatures, pressures). For example, the in cylinder pressure transducer must be able to withstand 10,061 kilopascals; the exhaust thermocouple must be able to withstand 1,500 degrees Celsius; the mass airflow sensor must be able to withstand 11.44 cubic feet per minute. The sensors also must be able to come close to continuous sampling (i.e. have/handle high frequencies and high resolutions in order to ensure accurate results).
- 3) We must also be sure to suppress engine vibrations such that they do not interfere with the performance of the water brake or the data acquisition system.
- 4) The engine dynamometer will have minimal inertia. We are not designing an inertial dynamometer; therefore any non-liquid additional inertia is not necessary

and would be intrusive upon our overall accuracy. Careful consideration will be taken in optimizing the impeller properties, most importantly impeller diameter and material selection.

	Customer Demands	Engineering Requirements
Major Demands	Engine Capacity Easy Operation Low Maintenance Low Cost Small Footprint Portable DAQ System User Manuals	At least 5 hp & 8 ft*lbs 1 to 2 person operation Less than \$2000 total cost Less than 5' x 5' footprint N/A N/A N/A
Sensors / Outputs (Measurable)	Intake temperature (thermocouple) Exhaust temperature (thermocouple) Combustion temperature (thermocouple) RPM (Hall effect sensor) Intake pressure (transducer) Combustion pressure (transducer) A/F Ratio (O ₂ sensor) Mass Air Flow (MAF) Intake Air Fuel pressure Torque (strain gauge)	0-100 F 0-2000 F \pm 100 0-2500 F \pm 100 0-4000 RPM \pm 100 0-1 bar 0-10 bar 10 -20 \pm 2 0-2 bar (gravity feed) 0-10 \pm 1 ft*lbs
(Calculated)	Horsepower Horsepower vs. RPM Plot Torque vs. RPM Plot	N/A N/A N/A

Table 2.2-1

2.3 Design Practices Used By the Team

The team discussed a number of design practices to be considered when designing the engine dynamometer. These practices are provided below.

- 1) Design for Manufacturability – The team has designed the engine dynamometer such that many of the parts are readily available “off the shelf.” The few parts

that are designed specifically for this project are simple to reproduce with machine shop tools already at the disposal of RIT.

- 2) Design for Assembly – The team designed the engine dynamometer such that few assemblies and sub-assemblies exist in order to make the overall assembly much simpler.
- 3) Design for Minimal Cost – The team designed the engine dynamometer such that the cost of producing the dynamometer is kept to a minimum. Options that are not crucial to the learning process were omitted for this reason.
- 4) Design for Reliability – The team has selected materials and parts that will make the engine dynamometer as reliable as possible without compromising cost.

2.4 Safety Objectives

Our team discovered set safety standards for this project's handling of combustible fluids and byproducts of operation such as exhaust. There also exist guidelines related to rapidly moving parts.

- The most important safety issue of an indoor engine dynamometer is related to the handling of combustible fluids. ASME standards require gasoline to be contained in a suitable manner. The gas tank that feeds our engine meets ASME requirements.
- Another important safety issue concerning the use of an indoor engine dynamometer is related to the handling of exhaust emissions. OSHA requires that exhaust emissions be ventilated from all indoor rooms to the outside. A vacuum ventilation system will be crucial to the safe operation

of the dynamometer indoors. The engine lab cell can facilitate this type of system.

- Thirdly, the nature of mechanical systems with fast moving parts requires all exposed moving parts to be guarded for operator safety. Any exposed moving parts will be shielded to protect the operator and observers.

3 Concept Development

The Dynamometer Redesign Team developed a significant list of solutions that would satisfy the customer requirements. These ideas were generated from team meetings, and then feasibility assessments were conducted. The purpose of each system is to place a load on the engine large enough to be able to gather torque readings at every RPM level. Three main concepts were proposed and evaluated closely to see if each would meet the requirements of cost, time, and customer expectations. The choices were between a water braking system, an Eddy current braking system, and an electric brake system.

3.1 Water Braking System

The water braking system is considered a very inefficient pump. The water brake housing is directly connected to the shaft of the engine. Water enters the housing through the inlet hose and begins to fill it up. The water places a load on the engine which causes the RPMs to drop. The load placed on the engine is largely dependent upon the impeller size, and inlet and exit hole size.

There are two ways this type of system can be set up: an open loop system and a closed loop system. An open loop system is the simpler of the two choices. It has water

coming from a source and exiting into a drainage system. There is no recirculation of the water and can be contained in a smaller overall package. The closed loop system requires a feedback of exiting water to the inlet. A cooling system is required due to the increased temperature of the outgoing water.

3.2 DC Generator Braking System

In this system, the engine shaft is coupled to a generator. Based on the power output of the engine, a specific current is produced. It is a very accurate but expensive and complex system. Changes in RPM cause the data to be inaccurate with this type of system due to the high moment of inertia of the generator.

3.3 Eddy Current Braking System

This system uses an electric motor to place the load on the shaft of the engine. The shaft of the engine is directly coupled to the shaft of the motor. A current is supplied to the motor to create a resistance to the motion of the engine shaft. The motor tries to turn in the opposite direction of the engine shaft and causes a load to be placed on the engine. The advantage of this type of system is that it has a very fast response time to the desired loading.

3.4 Torque Measurement Device

3.4.1 Torque Arm



Fig. 3.4-1

A torque arm, such as the one in Figure 3.4-1, is a bar that is attached to the casing of the water brake. As fluid enters the casing, the shear causes the casing to rotate with it. Strain gauges are attached to the arm. Since the material properties of the arm are known, the strain of the arm can be converted into a torque.

3.4.2 Reactor Torque Sensor



Fig. 3.4-2

A reactor torque sensor, such as one pictured in Figure 3.4-2, measures angular displacement. It is a cylindrical shaped object which is attached to the outer half of the impeller housing. The other edge of the sensor is rigidly mounted. The side of the torque

sensor that is connected to the housing rotates with the housing and there is a displacement. Each displacement is calibrated to coincide with a specific torque.

3.5 Data Acquisition Package

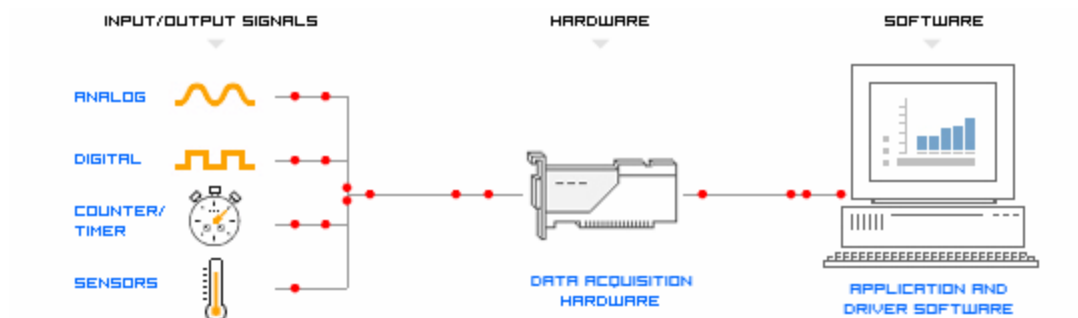


Fig. 3.5-1

The main objective of building the dynamometer system is to place a load on the engine. The above mentioned concepts all deal with the placement of the load, whether mechanical or electrical, on the engine itself. The most important and integral part of the dynamometer is the data acquisition, or DAQ, which is represented by the picture in Figure 3.5-1. Data acquisition involves gathering signals from measurement sources and digitizing the signal for storage, analysis, and presentation on a personal computer. There are four components to be considered when building a DAQ system: transducers and sensors, signals, signal conditioning, and DAQ software.

3.5.1 Transducers and Sensors

The sensor design is independent, or generic, of the dynamometer concept used. Most of the sensors and thermocouples used were installed by the previous senior design team. However we did change the design for measuring torque, and were unable to find the old Hall Effect sensor. The sensor package is designed according to the needs

assessment. The educational purpose of the dynamometer system is to relate experimentally how the internal combustion Kohler engine operates, and compare those attributes to theory learned in the classroom.

This goal can be achieved by measuring a fundamental set of data points. Intake temperature and exhaust temperature will be used with cylinder pressure to model the thermodynamic cycle in the engine cylinder. A thermocouple placed in the intake manifold, before the combustion chamber will record an average intake temperature. A thermocouple placed in the exhaust flow will determine the average temperature of the gasses exiting after the combustion cycle. A pressure transducer mounted in the cylinder head of the engine will record the dynamic pressure throughout the thermodynamic process. A second pressure transducer will be used to measure intake pressure.

A mass air flow sensor used in conjunction with an oxygen sensor will be used to calculate the amount of fuel flowing into the engine. A wide-band oxygen sensor uses a chemical reaction to output a voltage that is related to the air and fuel mixture in the exhaust. The output voltages of the sensor can be measured and can be related to corresponding air-fuel ratios. The mass air flow sensor measures the amount of flow into the engine. Using the flow rate of air and the air-fuel ratio the flow rate of fuel can be found using Equation 1.

$$\frac{\textit{Flow Rate of Air}}{\textit{Air - Fuel Ratio}} = \textit{Flow Rate of Fuel} \quad (1)$$

To relate emissions to the laboratory, a hydrocarbon measuring device will be placed in the exhaust flow. This device measures the average concentration of

hydrocarbons. This reading can be used to relate emissions to engine speed and load.

The sensor is mounted in the exhaust flow path and outputs a voltage that corresponds to specific hydrocarbon concentrations.

Engine speed will be measured using a Hall-Effect sensor. As mentioned above, this sensor was missing from the previous design. This sensor is used in conjunction with one or more small magnets. An output voltage is created when the magnets pass the sensor. The magnets are mounted on the driveshaft, as the driveshaft turns the sensor will measure the engine speed. Using the data acquisition system to read the amount of voltages output from the sensor over a given period of time the engine revolutions per minute can be recorded and displayed.

The load applied from the dynamometer is dependant on the style of system used in the final design. The previous design used a torque arm to measure the rotational force, torque. A strain gauge was mounted on the torque arm to convert the mechanical load into a measurable voltage. Instead of this design we will use a reactive torque sensor. The sensor will be mounted on the housing. The sensor will output a voltage corresponding to the measured torque.

3.5.2 Signals

Each of the sensors and thermocouples being used will output a signal based upon the measurement it makes. Different signals need to be measured in different ways.

Signals can be categorized into two groups, analog and digital. An analog signal can be at any value with respect to time. All analog signals must be converted to digital signals before being transported to the computer. The signals outputted from the sensors are

either low voltages or low currents, in millivolts or milliamps respectively. These signals are too low to be accurately interpreted.

3.5.3 Signal Conditioning

Signal conditioning is offered in both modular and integrated forms. We have chosen the modular form because of its ability to isolate signals. The signal is transported from the sensors to the signal conditioning modules. The output signals from the sensors are too low to be measured with accuracy. The signal conditioning modules maximize the accuracy of a system, allow sensors to operate properly, and guarantees safety. The signals are amplified by the modules and outputted to the computer. The modules also digitize incoming analog signals so that the computer can interpret them. These modules will be mounted in the base of the cart.

3.5.4 DAQ Software/User Interface

The data acquisition, DAQ, subsystem is independent of concept choice. Due to the request of the Kate Gleason College of Engineering, National Instruments equipment and LabVIEW Software will be used. This software is standard for industrial data collection. The DAQ equipment will interpret the readings taken from the modules and relate them to data and measurements understandable by the users. The output of each module is a voltage. The DAQ will be programmed for each sensor to read the electrical output and display or record various measurements.

The constraining requirement of the DAQ is the sampling rate for the in-cylinder pressure transducer. Due to the nature of the Kohler engine and its speed, the DAQ system and pressure sensor must accurately record in-cylinder pressure at speeds up to

6000 RPM. This requires a sampling rate of at least 100 samples per second. Intake and exhaust temperatures do not require a high sampling rate. These properties change gradually over time depending on atmospheric and loading conditions.

The engine speed will be read by the DAQ as an input voltage. Within the software a scale factor will be programmed with a timer to display and record engine revolutions per minute. The load placed on the engine by the dynamometer will be output through the torque reactive sensor. LabVIEW will be programmed to interpret the voltage, display, and record a value for torque. This torque value can be used to calculate the power by using Equation 2.

$$Power = Torque * EngineSpeed \quad (2)$$

LabVIEW can be programmed to calculate the power produced by the Kohler engine as well.

4 Feasibility Assessment

4.1 Mechanical Feasibility Conclusion

The system our team decided to pursue is the water brake dynamometer. The main reason for this decision is cost. For both the Eddy current and electric generator type systems, an electric motor with the same horsepower output as the engine is necessary. The cost of such a motor would put the project over budget. Likewise, dangerously high voltages are created when the engine is run and pose safety hazards.

Also, with the size and weight of one of these units, the water brake dyno is a much more appealing option.

After deciding upon the water braking system, the next choice was to decide what type of torque sensor to go with and whether or not to use a closed loop or open loop design. The reactor torque sensor was chosen because of its accuracy and repeatability. The torque arm design is far less accurate than the reactor torque type. The assumption that the torque arm has equivalent strain at every point throughout is not accurate. Also, the amount and placement of the strain gauge or gauges can have quite an effect on the readings. Figure 4.1-1 shows how the reactor torque sensor will be incorporated into the design.

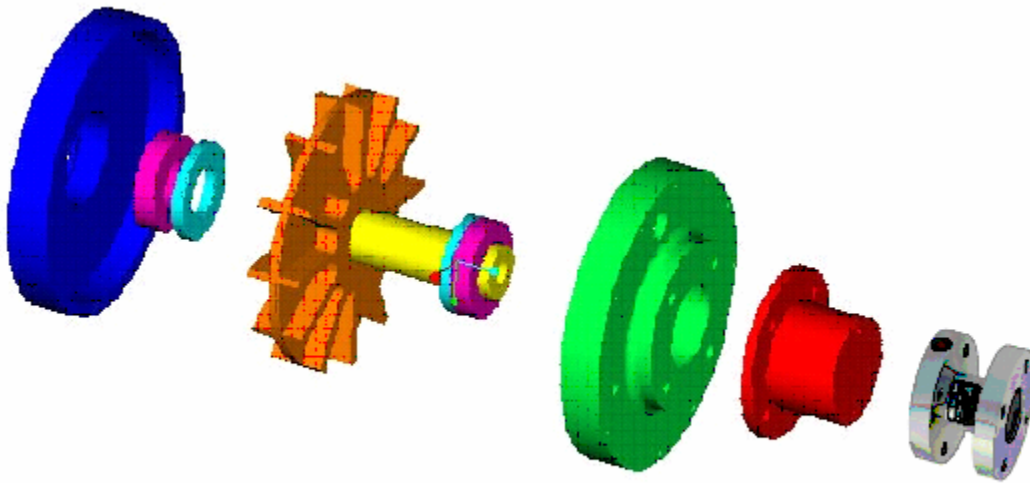


Fig. 4.1-1

The choice of sensor had a lot to do with customer wants, as well. The combination of all these factors led us to choose the reactor torque sensor as the better of the two choices, even though the price of a unit like this can be quite significant.

An open loop type system was chosen for many reasons. The main factor was cost. Adding more parts to a system adds more cost, weight, and size. Scheduling constraints also steered us away from this option.

4.2 Electrical Feasibility Conclusion

As stated above, the previous team did the feasibility assessment and already had most of the sensors in place. Because of this, it is more feasible to re-use their sensors. Reusing these sensors would be more cost efficient. It is also more feasible given the time constraint.

When choosing a signal conditioning form, two forms were considered, modular and integrated. It would be cheaper to use the integrated form on this project because it is already available and would not have to be purchased. However, reproduction is a major part of this project. This design is to be reused multiple times. Overall the modular form of signal conditioning is cheaper than the integrated form. The modular form is also safer. If a high voltage signal is generated, the modular form would protect the DAQ system. It would also isolate the damage to that particular module. For these reasons it is better to go with the modular form.

5 Analysis of the Problem and Synthesis of Design

The motor mounting hardware was designed and specified to effectively isolate the inherent vibration caused by the engine. Without this feature an undesirable amount

of electrical noise would be created. This effect would interfere with sensor and DAQ equipment, rendering the system inaccurate if not useless.

The signal conditioning unit was designed to take the signals from the various sensors, and output a signal that the data acquisition system can interpret with clarity. The input signals will be low voltage or current signals. The output signals will be voltages readable by the computer. Each inputted signal will be treated independently by its individual module.

The data acquisition equipment was specified to meet the requirements of the needs assessment. The equipment did not need to be designed, rather procured. The DAQ software, LabVIEW, will be programmed next quarter as part of the build-phase.

The controls and user-interface were designed to be intuitive and straightforward. An engine speed control and variable load control must be incorporated into the final system. The user-interface design includes both the LabVIEW display on the system computer monitor as well as a visual tachometer.

5.1 Sensor Placement and Mounting

Pressure sensors was mounted and placed in the engine to measure intake pressure and combustion pressure. Measuring intake pressure will be done by placing a pressure transducer in the intake runner. A hole will be drilled and tapped for the size of the transducer to screw it in just after the carburetor. The location of the hole is easy to access along with plenty of material to work with. The pressure transducer for measuring combustion pressure is located in the cylinder head next to the spark plug. Again, a hole was drilled and tapped to the size of the transducer where there is plenty of material to

mount the transducer while leaving easy access. The combustion pressure transducer will not interfere with the valves, spark plug, piston, or cooling fins. Figure 5.1-1 depicts the approximate position of the in-cylinder pressure transducer.



Fig. 5.1-1

Type-K thermocouples are mounted in the engine to measure temperatures of oil, intake and exhaust. The oil temperature sensor is placed in a drain plug in the bottom of the crank case. A hole was drilled and the thermocouple was mounted in the plug with a high-temperature epoxy. Both intake and exhaust thermocouples were mounted in the intake runner and exhaust pipe by drilling holes and sealing them with an epoxy.

The engine's air flow will be measured with an air flow meter and Mass-Air-Flow (MAF) sensor. This is done by modifying the air flow meter pipe and the engine's air cleaner so they can be attached or detached if needed. Within the air cleaner the MAF sensor will be mounted with a small bracket so as to not disturb air flow into the engine.

An Oxygen (O_2) sensor and Hydro-Carbon sensor will be mounted in the exhaust pipe to tell what air-fuel ratio the engine is running at and the amount of Hydro-Carbons

going out of the exhaust pipe. To do this, the pipe will have a hole drilled and a threaded bung will be welded in place. With the bung welded in place the O₂ sensor can easily be screwed in and tightened down. The Hydro-Carbon sensor will be mounted inside the exhaust pipe or muffler.

Measuring engine speed (RPM) will be done using a Hall-Effect sensor. The Hall-Effect sensor consists of small magnets and a pick-up sensor. The collar on the water brake will have four equally spaced counter-bores drilled. The magnets will be pressed into the counter bores. The pick-up sensor for the Hall-Effect will be mounted to the housing of the water brake near the rotating collar where the magnets are. To measure torque from the engine a reactive torque sensor will be used.

5.2 Data Acquisition Design and Setup

The DAQ for the pilot production dynamometer system is to be provided by the Kate Gleason College of Engineering. Currently RIT owns a number of DAQ carts for coursework and research. These carts meet and exceed all requirements of the needs assessment and data collection. The equipment is all National Instruments brand. Table 5.2-1 shows the sensors and DAQ modules that will be included on the cart.

Sensors	Modules and other supplies
Intake temperature (thermocouple)	Signal conditioning Network FP
Exhaust temperature (thermocouple)	Thermocouple Module
Combustion temperature (thermocouple)	other Modules (2)
Crankshaft thermocouple	module Base
Oil temperature sensor	Isolated terminal base
intake Pressure Transducer	Power supply for the modules
Combustion Pressure Transducer	module rail
Oxygen sensor	Enclosure
Hydrocarbon Sensor	Mass airflow meter Cable
Hall-Effect sensor	
Mass airflow meter	
Reaction torque sensor	
Hall-Effect sensor	

Table 5.2-1: Sensors and other modules that are to be included on the cart

The team will use the thermocouple input module to record the intake, exhaust, and engine temperatures. The strain gauge input module will record torque output of the engine. The pressure transducers, Hall-Effect sensor, oxygen sensor, mass air flow sensor, and emissions equipment will all be directed into the DAQ system through the signal conditioning modules.

Also included in the cart setup is a desktop computer running National Instrument's LabVIEW software. A portion of the DAQ system will be to construct a program within LabVIEW to interpret all the readings from the system sensors. Preliminary goals of the design process, consulting with RIT and National Instruments staff, have ensured that the DAQ system is capable of these requirements. During the next phase of the design process all programming will be implemented.

The main goals of the DAQ software interface include:

- Obtaining all required measurements as addressed in the needs assessment and project specifications.

- Creating an output file of data that can easily be analyzed and interpreted by the user. This will most likely be a Microsoft Excel spreadsheet.
- Building a graphical-user-interface, GUI.

5.3 Controls and User-Interface Design

The needs assessment requires the dynamometer system to be easily operated and intuitive to its users. The main user-interface will be the LabVIEW GUI. The GUI will display on screen virtual gauges. These gauges will show current characteristics of the engine and dynamometer including: engine speed, engine torque and power, intake and exhaust temperature, engine oil temperature, air-fuel ratio, and emissions hydrocarbon concentration.

Starting up the entire dynamometer system will include powering up all electronic equipment, turning on the flow into the water brake at the tap, and starting the engine. The electronic equipment will be started by plugging the DAQ cart into a conventional 120VAC outlet and turning on the computer and DAQ equipment. A valve will start and stop the water flow into the system. A globe valve, downstream of the main valve and before the water brake inlet, will be used to control load placed on the engine by the dynamometer. The engine will be pull started by the user using a recoil controlled by the throttle.

Operating the dynamometer system will involve varying engine speed, water brake load, and recording data. The engine speed will be controlled by a push-pull cable and lever assembly. This system will be connected to the Kohler engine throttle. The Kohler engine throttle is outfitted with a torsion return spring; this design automatically

closed the throttle when there is no external force applied. As the lever is pulled and pushed the throttle will open and close changing engine speed.

The dynamometer load is controlled by regulating the amount of fluid allowed into the water brake. A globe valve allows more fine tuning control than a conventional gate valve. Closing the globe valve will reduce the amount of load; a fully open valve will produce maximum loading conditions. The throttle push-pull assembly and globe valve will be mounted next to one another to allow safety and ease of operation. Data logging will be triggered using the LabVIEW GUI and computer. Using the computer mouse to click an on-screen button will begin data collection.

6 Budget

Table 6.1 summarizes the budget breakdown for the required parts thus far.

Part	Quantity	Source	Mfg Part #	Cost (ea.)	Total Cost
Reactor Torque Sensor	1	Interface	5330	1560.00	1560.00
Aluminum	1	Metal Supermarkets		111.43	111.43
Steel	1	Metal Supermarkets		10.00	10.00
Signal Conditioning Network FP	1	National Instruments	FP1000	355.00	355.00
Thermocouple Module	1	National Instruments	TC-120	315.00	315.00
Other Modules	2	National Instruments	AI-110	315.00	630.00
Module Base	1	National Instruments	TB-1	171.00	171.00
Isolated Terminal Base	1	National Instruments	TB-3	157.00	157.00
Power Supply for the Modules	1	National Instruments	PS-1	45.00	45.00
Module Rail	1	National Instruments	DIN	7.20	7.20
Mass Airflow Meter Cable	1	TSI Incorporated	1303775	19.00	19.00
				Total	3380.63

Table 6-1

7 Future Plans

At this point the senior design team has completed the first six facets of the automotive laboratory development project. The team is now ready to begin building, assembling, and testing of the open-loop water brake dynamometer system.

All machining and assembly will be conducted in-house using the RIT machine shop facilities. All work will be conducted by team members eliminating cost of hired machinists and labor. As soon as the raw material is in stock and accounted for, all required machining can begin immediately.

Software programming of LabVIEW can begin immediately. The first task of the DAQ team is to setup the system to record the outputs from the system sensors. Upon completion the sensors will be calibrated prior to mounting. After calibration the GUI will be constructed.

A final experiment will be run with the entire assembly. The dynamometer system will be used to conduct the experiment carried out in the Thermal Fluids Laboratory class offered by the Mechanical Engineering Department. Accurately completing this experiment along with addressing all product specifications in this report will declare the design successful. An operational and maintenance manual will be created. This document will be used to address questions by future users. The design package, experimentation results, and manual will provide adequate knowledge for replication and future use of the dynamometer system.