Small Engine Test Stand Proposal

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Report
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1. Introduction

1.1 Overview

One of the main pieces of equipment used in testing engines and motors is a test stand containing a dynamometer. They are a valuable addition to any testing facility because of the versatility that they provide. A dynamometer can be used to measure engine power, fuel efficiency, thermal efficiency, and many other things. Because of their widespread use throughout the industry, it is important that students going through classes are exposed to the operation of a dynamometer and are shown the wide array of tests one can run.

A number of different types of dynamometers are available for purchase. These are divided into different types based on how the braking is accomplished. Some examples of these are mechanical prony brakes, eddy current brakes, hydraulic brakes, and inertial brakes. Commercial dynamometers that can handle the required engine size are often cost several thousands of dollars. Because of this, most universities cannot afford to purchase one of the many products available commercially. Due to the limited resources, the main objective of this project was to design a dynamometer and test stand that is cheap to build and yet accurate enough to run tests and use in several different Agricultural Systems Management and Agricultural Engineering classes.

1.2 Applications

An engine test stand and dynamometer setup of this type will have a large number of different applications. There are several courses that would benefit from having it on hand, including ABEN 473 and ASM 373. Also, having this would be a major showcase item for the Agricultural and Biosystems Engineering Department when giving tours to the potential students, college administration, and the public.

In addition, the research potential is large. With this setup, a number of different tests can be run, including engine performance curves, torque verses rpm, and power verses rpm.

2. Specifications

The requirements as given by the collaborator, Dr. Thomas Bon, were as follows:

- **Able to test engines and motors from approximately 7.5 to 30 kW (10 to 40 hp)** - *This power range contains the common engine size used by the Quarter Scale Tractor team to power their pulling tractor. By designing to this range, it allows for the team to test the engines for loading before installing.*
- **Handle operating speeds from 900 to 3,600 rpm. (ideally +/- 5 rpm)** – *This speed range is the common operating range for the small engines with the power range listed in the previous requirement.*
- **Apply and measure torque load to the engine (ideally +/- 0.1 hp)** – *Measuring the torque that an engine produces is the main use of any type of dynamometer. By*

measuring the torque, it can be run through equations and used to find actual horsepower generated by the engine.

- **Be computer (or other system) controlled for automated test and data acquisition** – *By placing the dynamometer and sensors under the control of a computer or other electronic system, it would allow for extended duration tests to be run without having to be under constant supervision. In addition, it could be set up to automatically cycle loads applied to the engine to create more in depth, real-world based tests.*
- **Monitor fuel consumption** – *By measuring the fuel consumption, it becomes possible to determine the operating efficiency of the engine at different loads and speeds.*
- **Monitor operating parameters such as engine temperature, speed, etc** – *The measurement of operating parameters allows for the correction of the data collected. At different temperatures and pressures, the results will vary, and by measuring all of the variables, it allows for the correction so that direct comparison can be done between tests.*
- **Shut-down the system if parameters go out of specification during a test** – *This is important so that if the tests begin to go wrong, the system will be shut down so that nothing will be damaged.*
- **Have the capability of running varying speed curves such as full load vs. rpm or maintain a specified speed and torque for the duration of a test.**
- **Be capable of handling Otto cycle and diesel cycle engines and electric motors** – *By making it capable of running these three different types of motors, comparisons of efficiency between different fuel types or fuel and electricity can be performed.*

- **Monitor input conditions including air temperature, atmospheric pressure, etc** – *By monitoring the input conditions, data corrections can be performed.*
- **Have the potential to record data, display graphs of recorded data (possibly near real time.)** – *By having the ability to record data and display it graphically, the data can be accurately and quickly analyzed and compared to look for trends and anomalies in the data.*
- **Be able to fit in the machinery laboratory, ABEN 123** – *This is the room where the test stand and dynamometer will be housed upon completion. The stand must be designed so that it fits and doesn't hinder any other operations that occur in the same room.*
- **Have provision to be movable, both within the laboratory and possibly to other locations (forklift compatible)** – *By making the stand movable, it allows for possible relocation in the future, in addition to enabling it to be stored and taken out only when in use to reduce clutter in the lab.*
- **Isolate fuel system sufficiently from the main portion of the stand so fuel consumption can be accurately determined** – *Isolating the fuel system insures that the fuel weight readings are not biased by vibrations that result from running the engine and dynamometer.*
- **Measure airflow into internal combustion engines.**
- **Measure exhaust temperatures**
- **Have the ability to set either the load and measure rpm or set rpm and adjust load to bring the engine or motor to that rpm.**
- **Recommend surface treatments for a good looking test stand**

3. Design

3.1 Type of Dynamometer

One of the biggest decisions that had to be made was the selection of the type of dynamometer to use. There were a number of types to choose from, each with distinct advantages and disadvantages. Each of these is listed in the decision matrix shown in Figure 1.

Dynamometer Types	Eddy Current	Prony Brake	Electrical Motor	Water Brake	Hydraulic Brake
Cooling Needed	+	-	+	-	-
Environmental Safety	+	+	+	+	-
Simplicity	-	+	-	+	+
Cost	-	+	-	-	-
Weight	-	+	-	+	+
Size	-	+	-	+	+
Frequency of Repairs	+	-	+	+	+
Cost of Repairs	-	+	-	+	-

Figure 1. Dynamometer Selection Decision Matrix

Using this matrix, it was decided to use the mechanical prony brake. A mechanical prony brake works by simply applying friction to the engine and thereby loading it to the desired load. There are a number of ways to do this, and it was decided to use a braking system similar to those on a car to apply the load. A rotor would be attached to the shaft connected to the engine or motor to be tested. The brake pads, calipers, and related assembly would be free to rotate while connected to a steel beam that rests on a load cell in order to measure force and from there calculate torque and horsepower. Figure 2 shows a depiction of a simple prony brake. Figure 3 shows how a disk brake off of a vehicle was modified to create a mechanical dynamometer for the test stand.

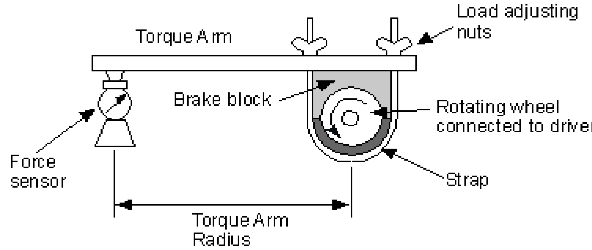

Figure 2. Simple Prony Brake Setup

(http://www.me.utexas.edu/~dsclab/labs/pmdc/pronybrake.html)

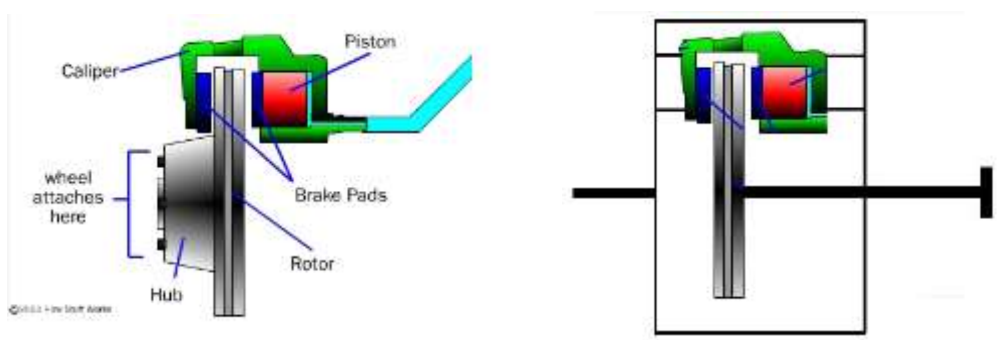

Figure 3. Modification of a Disk Brake

(http://auto.howstuffworks.com/auto-parts/brakes/brake-types/disc-brake1.htm)

The largest advantage this type of system has is simplicity, and with that simplicity comes low cost. The mechanical prony brake can be built, maintained, and repaired with parts that can be purchased from a local hardware store, thus making this type of brake economical and cost effective for universities that have limited funding.

One great disadvantage with using a mechanical prony brake is that long term testing cannot be sustained without some sort of cooling system due to the amount of heat generated from the friction of the brake pads. In addition, long term tests can lead to wearing of the pads and make replacement of the pads needed on an extremely regular basis.

3.2 Data Acquisition System

The reason for using a dynamometer is to measure and calculate specifics about the engine in question. These specifics include fuel efficiency, torque produced at certain loadings, operating temperatures, maximum torque, etc. However, these cannot be determined without adequate measurement of certain pieces of data, such as torque produced, air temperature, fuel consumption, along with numerous others. To collect this information, it is necessary to have some sort of data acquisition system included with the test stand. For the sake of data analysis after it's collected, this system must have the ability to interface with a computer at some point so that the data can be viewed and organized. A few different options were considered when trying to decide the type of data acquisition system to use.

The first option that was considered was to use a laptop computer dedicated solely to the test stand and to use an Analog to Digital Converter. The computer software that was considered is made by Taylor Dynamometer and called DynPro. This software allows for real time viewing of the data streaming from the test. In addition, it allows for the tester to change the parameters of the test, such as adjusting the loading or the engine speed. In addition, the on screen working environment can be modified to show the desired measurements. The biggest disadvantage with this setup is that the computer used with this program cannot be used for anything else. Setting up the data acquisition system in this way results in the computer being permanently installed on the test stand. Also, the software can sometimes cost several thousand, if not tens of thousands, of dollars.

The second option that was considered was to use a datalogger to be programmed at the start of the test to collect the desired data. By using one of the CR 1000 dataloggers, produced by Campbell Scientific, already owned by the Agricultural Engineering department on campus, several thousand dollars can be saved. Additionally, this CR 1000 can be programmed to run tests and record data without a computer being present, thus allowing for automated tests to be run.

The biggest disadvantage is that in order to retrieve the data, a computer must be found and connected in. In addition, there is no way for the data to be viewed graphically in real time. Through the program used to monitor the CR 1000, PC400, the researcher can view the incoming data numerically, but not in the form of a graph. Once the data is collect and the test is over, the data can be copied into Microsoft Excel where it can be manipulated however is needed.

3.3 Stand Design

For the stand, it was decided to construct something completely new and not used other stands already owned by the department. This was decided because it would allow the stand to be constructed exactly for the dynamometer and for testing engines on. This will maximize the ergonomics surrounding using the dynamometer and working on the engine in question, and also maximize the usability of the stand.

The frame of the stand is constructed out of 2” x 2” angle iron with the top being made out of ¼” steel plate. The top of the stand is split into two tiers, with the engine sitting on one side and the dynamometer sitting on the other. The side with the engine sits four inches above the side with the dynamometer so that the output shaft from the engine is closer to level with the input shaft on the dynamometer. Where the engine sits, a 12” square hole is cut out and over this a 14” square plate is bolted. This is done because no two engines have the same bolt pattern. By mounting the engine to a removable plate, it makes it easier to drill holes for bolts and secure the engine to the stand.

Also, running the length of the stand is a pair of 6” x 2” x ¼” steel tubes. These are placed there to allow for the stand to be moved by pallet forks or a forklift. Also, at each of the four corners of the stand are vibration-isolating feet to minimize the vibration caused by the engine and the dynamometer. The exact dimensions of the stand are shown in Appendix B. Figure 3 is a representation of what the stand looks like.

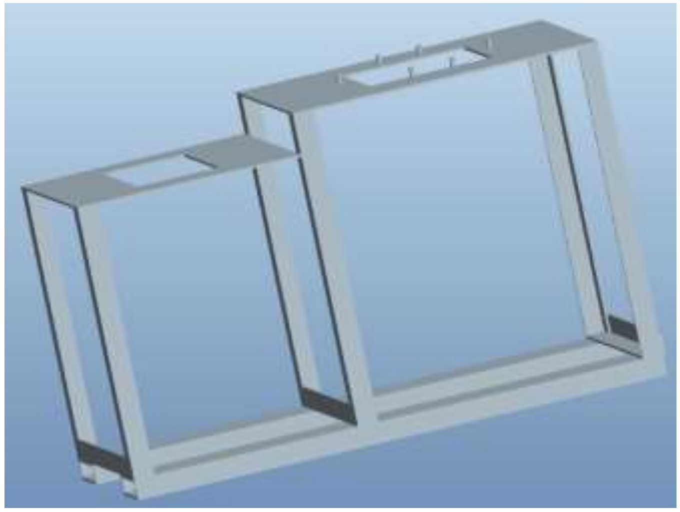

Figure 4. Stand Model

3.4 Fuel Stand Design

Fuel consumption measurements are one of the important pieces of data measured using an engine dynamometer. This allows for the efficiency of the engine to be tested and determined at different loadings and engine speeds. In addition, it can be used to run comparison tests of between different fuel types such as ethanol verses gasoline, in addition to testing fuel additives. A rendering of the fuel stand is shown in Figure 4 and the exact dimensions are shown in Appendix B.

Figure 5. Fuel Stand Model

3.5 Throttle and Load Control

One of the big tests that test stands are used is to produce torque curves and horsepower curves. The only way to do this is to set the load at a certain level and then change the engine speed by running the accelerator. In order to make this an electronic process, an actuator was added to a cable that's attached to the throttle on the engine. This allows for the complete automation of the throttle control, making it controllable by a simple electric switch for increased accuracy or even by the PLC. The loading on the dynamometer is controlled by the amount of volume in the master cylinder. This volume can be changed by running a low speed electric motor that runs a threaded rod that pushes the plunger of the master cylinder in and out. The motor also allows for automated operation and increases the accuracy.

3.6 Cooling

Because of the friction caused by the pads rubbing on the rotor as the load is applied, the rotor, if left uncooled, will heat up and could permanently deform from intense heat. To combat this, a common garden hose fitting was placed on the top and bottom of the rotor housing of the dynamometer. By simply running water over the rotor, it can be kept cool to reduce the effects of prolonged clamping of the brake pads.

4. Measurements

4.1 Torque

The main variable that dynamometers are used to test for is torque output by the engine. With that value, a number of different calculations can be derived, such as horsepower, stress, strain, etc. As a result, it was important to make sure that the torque could be measured accurately. It was decided that the best way to measure the torque output would be use an S type steel load cell and a metal beam that is attached to the rotor housing box. As the pads are clamped down on the rotor, the housing begins to want to turn and causes the beam to push against the load cell. This causes the load cell to change its voltage output. The data acquisition system can be programmed to read this output voltage and convert it to the equivalent force being applied to the cell. From there, this force is multiplied by the distance between the load cell and the center of the rotor to give the value of the torque being produced. On the stand, the distance between the center of the rotor and the load cell is one foot, thus giving the reading of force and the value of torque being produced a one to one ratio, making calculations easy.

4.2 Temperature Measurement

One of the requirements for the design was for the ability to record and display desired temperatures throughout the test. The two temperatures that are of the most concern are the temperatures at the intake and exhaust locations of the engine. Small engines pull air from the surrounding environment into the carburetor, resulting in the intake temperature being equal to the room temperature in which the test is being performed. To record this temperature, a type T thermocouple will be place on the engine block relatively close to the air intake port of the engine. A type T thermocouple was chosen because it is able to record temperatures with great accuracy and within the specifications desired by our collaborator. A type T thermocouple is made up of two wires, one being copper and the other constantan. The range of a type T thermocouple is -328^{O}F to 662^{O}F, which will be well within room temperature conditions during a test. The exhaust that leaves the small engine exhaust ports can reach temperatures as high as 1500^{O}F. This much higher temperature means a different type thermocouple will have to be used to record exhaust temperature. We have selected a type K thermocouple which can accurately record temperatures between -328°F and 2462°F. The intake thermocouples will be placed near the intake valves of the engine, the exhaust thermocouples will be placed near the exhaust ports of the engine to insure accurate results. Both of these thermocouples measure temperature the same way. Each is made of two separate wires of different metals. As temperature changes, these metals react and produce a variable voltage. The CR 1000 can easily be programmed to read this temperature and convert it to a temperature reading.

4.3 Engine Speed Measurement

Engine rotational speed will also need to be constantly monitored during the testing of the small engines. The two traditional ways to measure engine rotational speed are use of an induced current counter and a Phototac laser sensor.

The induced current counter is simply a sensor that can detect and measure the electromagnetic field produced by the engines electronic system or, more specifically, the ignition coil. Every time the field switches, the sensor reads that and sends a voltage to the CR 1000. The CR 1000 can then record each time the pulse comes through and produce a value for engine speed. The biggest advantage had by using an induced current counter is the fact that the chosen sensor can detect the change in field from up to a foot away from the engine, meaning that nothing has to actually be connected to the engine itself.

A Phototac laser sensor is another option for determining engine rotational speed. The laser from the Phototac is placed to shine on a piece of reflective tape, which is placed either on the engines fan or crankshaft. The Phototac laser then records the number of times the reflective tape interrupts the laser beam. Much like the spark ignition counter, the data acquisition system will be able to determine the engine rotational speed based on the number of rotations produced by the engine’s fan or the crankshaft.

It was decided to use an induced current counter because it is easier to install and doesn't require anything to be changed from one test to another because there is nothing that connects to the engine itself.

4.4 Pressure Measurement

Another measurement that is vital to study small engines in intake and exhaust pressure. Both pressures can be measured using a pressure transducer placed at the intake and exhaust ports of the engine. It was decided to use two identical pressure transducers, each capable of reading pressures from 0-250 psi gage pressure and both of which have an accuracy of 1%. The transducers produce different voltages as different pressures are applied. These voltages can be read through the data acquisition system and then displayed as a pressure on the computer read out.

4.5 Fuel Measurement

Fuel consumption is a characteristic that must be known to conduct good quality engine tests. The use of a removable external fuel tank and stand will be incorporated into the design. The fuel tank connects directly into the fuel line on the engine and sits high enough to allow for the fuel to be gravity fed to the engine. The fuel tank sits on a compression type load cell called the iLoad. This cell is able to read weights of 0-200 lbs. By connecting the load cell to the CR 1000 to read the voltages, the initial weights and the final weights of the fuel can be measured to find out how much fuel was consumed over a set length of time, thus allowing for the calculation of fuel efficiency.

5. Safety

Safety is a very important design aspect when designing a dynamometer for public and school use. Not only will there be a large number of people using the stand over its lifetime, it will also have a large number of bystanders, people just walking by while a test is being run or simply observing. Safety is the most important factor in the entire design of the small engine test stand and dynamometer. The output shaft on the engine rotates at speeds upwards of 4000 rpm. These high speeds require safety guards to be in place. A protective cover will be placed over all rotating shafts to make sure that the operator's clothing or appendages will not be caught. In addition, the use of a CR 1000 for data recording purposes and the actuators for adjusting engine speed and load allow for the operator the be located some ways away from the stand or even in a neighboring room. This keeps the operator safe in case something comes loose while running the test and also keeps the computer cleaner by not having to have it there while the test is being run.

6. Economic Impact

The major economic impact that this project has is, if constructed as planned, it can save the department thousands, if not tens of thousands, of dollars over buying a commercial dynamometer and test stand.

7. Environmental Impact

The major environmental impact the designed test stand and dynamometer will have is involved in the use of the stand and dynamometer while running tests. The areas of concern are the use of water for cooling, the brake fluid, and exhaust fumes from combustion.
The water that is run over the brake rotor to help keep operating temperature low will contain small particulates including pieces of the brake pads and minute metal fragments from the brake rotor. This water is to be run only into the sewer and is not to be reused without filtering.

The brake fluid needs to be treated like any other hazardous chemical. In case of a large scale spill, make sure to evacuate the area and personal wearing protective clothing need to work to contain the spill from entering waterways and sewers. Also, the fluid will have to be replaced over the life of the stand. When the fluid removed, proper disposal protocol must be followed. The fluid is not to be discarded to the sewers and all disposals must comply with federal, state, and local regulations.

Exhaust fumes from the combustion of gasoline can have adverse effects on the environment. These effects are always present when operating a gasoline or diesel powered internal combustion engine and the only thing that can be done is to work to reduce them by insuring that the engine is receiving fresh air to insure the most efficient combustion possible.

8. Sustainability

The test stand and dynamometer are being designed so that it will continue to operate for many years with minimal regular maintenance. This is achieved by using water to cool the brake rotor and regular changing of the brake fluid and pads.

9. Manufacturability

The manufacturability of the test stand and dynamometer that have been designed is quite good. Quite a few of the parts being used for the construction are from local automotive parts shops and of the parts that must be ordered, none require a special order or construction. Each dealer has the respective part in stock and no advanced manufacturing techniques are required for any part of the construction process.

10. Ethical Impact

There are no known ethical impacts from the design of the test stand and dynamometer.

11. Political Impact

There are no known political impacts from the design of the test stand and dynamometer.

12. Conclusion

The main goal of this project was to design a small engine test stand that is both useable and accurate enough to be used to run tests and at the same time have a low enough construction cost. With the design that was produced, all of the requirements given were met and the cost was kept low enough that it would be economically feasible to build for use in classes and experiments. This low cost can be seen in Bill of Materials in Appendix A.

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