# Certificate for Excellence in Teaching and Learning Project Report

Craig T. Evers, PhD, PE
Assistant Professor
Automotive and Manufacturing Engineering Technology
Minnesota State University – Mankato

## Course – AET 364 Chassis Engineering and Performance Testing
## Project Name – Principles of Dynamometer Operation

## Subject – Introducing students to dynamometers

In Automotive Engineering Technology (AET), one of the most looked-forward-to topics is the dynamometer. AET labs are equipped with a variety of dynos, from the small units that mount on a lawn mower engine up through the Mustang chassis dyno that allows testing of the entire vehicle. Once students pass the labs in AET 364, they are certified to use the dynos for their personal vehicles. It is a rite of passage in the AET program to finally get dyno privileges.

Dynos are fairly complex, and the students need to become familiar with how they work if they are to get realistic results from their tests. These principles of operation, and how to introduce the students to them, are the focus of this project.

## Former Method – Lecture

In the past, the principles of operation were introduced through PowerPoint slides in a formal lecture. There was no hands-on, and scarcely more understanding. The result was a testable block of material, but no transfer of useful knowledge. The material was boring to the students, and didn't excite the professor much, either. There had to be a better way.

## New Method – Study and Do It

Research into the basics of dyno operation uncovered the first machine that could be called a dynamometer, the Prony brake. Two articles in particular (attached to this report) discussed how a Prony brake works, and how two were built to test steam engines at steam fairs and tractor pulls. These units were a bit on the large side for class use, but they exposed the inner workings so that the operation could be clearly seen. This was the start of the project. These articles can be found at http://www.buckleyoldengineshow.org/HorsePower/horsepower.htm and Steam Traction, Vol. 57, No. 3 (Jan-Feb 2003) also found at http://www.steamtraction.com/article/2003-01-01.

A mechanical engineering class (ME244L – Dynamic Systems and Controls Lab) at the University of Texas at Austin had already designed a form of teaching apparatus to demonstrate how a Prony brake dynamometer worked. Their lab assignment (http://www.me.utexas.edu/~lotario/me244L/labs/pmdc/pronybrake.html) became a part of the new method. The apparatus was modified somewhat, but the basic operation was the same.

The equipment used in the lab as designed for AET 364 consists of a cordless drill, a tool bit holder to fit in the drill chuck, a furniture clamp, a fishing scale, and a pair of jaws machined from oak. The method of assembly and use is detailed in the lab assignment (attached).

The students self-selected into teams of three each. The lab itself could not easily be conducted with less than three, and there is no room for four around the apparatus. The equipment was available for checkout in the AET lab, and the teams did their assignment at their own schedule. A report and class presentation finished the lab.

## Results – Student Comments

There were suggestions for improvement from some of the students. These concerned doing the task more efficiently in most cases. Efficiency was actually not the goal of the task, and the inefficiencies were designed into the system to help them understand the operating principles. Making it to easy would most likely hide some of the important points being taught.

As far as helping to achieve understanding of the way a dyno works, the lab was judged a success by all students. It was more fun than a lecture, and even better than a demo. Each team came up with different data due to a variety of process variables, and that made for some interesting discussion when the presentations were given. The level of discussion demonstrated the new understanding the class had. Such a level of comprehension could not have come from a lecture.

## Future Plans – Where to Next?

There are other areas in the AET 364 course where similar methodology could be used. These areas will be dealt with in turn with some form of active learning. This lab will not be the subject of redesign until many of the other areas have been addressed. This one may not be perfect, but it's a whole lot better than it was, and it is deemed preferable to bring other topics up to this level before taking this one to the next level.

## Attachments:

In order starting with the next page:

- Lab assignment – Principles of dyno operation
- Article – Working Prony Brake Measures Power
- Article – Horsepower Testing

**Name______________________** **(30 Points)**
**Due Date: April 16, 2007**

## Required reading for this lab:

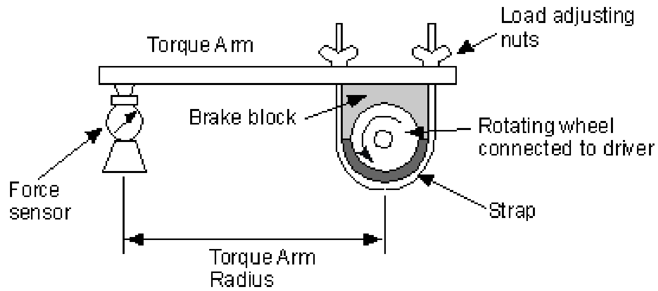
Prior to starting to work this lab, please read the two articles "Horsepower Testing" and "Working Prony Brake Measures Power". These articles will provide the background needed to perform this lab successfully.

## Lab Outline:

This lab will require the combined efforts of three students to make it work. One will operate the motor being tested (Skil drill). One will secure the measuring instrumentation (fishing scale). The third will adjust the variable resistance braking unit (furniture clamp), run the tachometer and record readings from the test instruments. The three team members will work together to prepare their report and class presentation. Presentations will be given in class on Monday, April 16th.

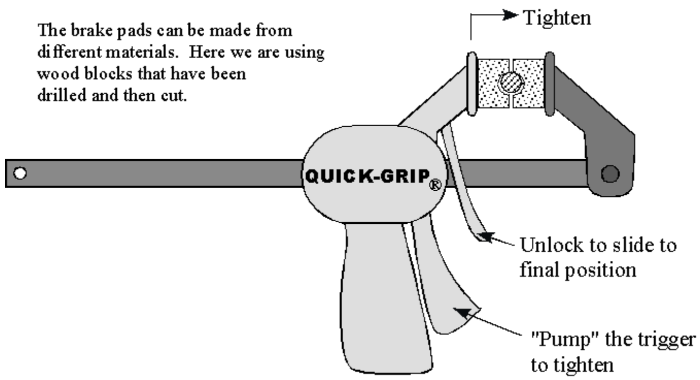
## Making a hand-held Prony Brake:

The Prony brake was invented in 1821 by French engineer Gaspard Prony (1755 - 1839). A Prony brake, shown below, provides a means for applying an adjustable load torque to the output shaft of a prime mover (e.g., IC engine, electric motor, etc.). The power output is dissipated as heat in the braking material. By adjusting the 'brake force', the torque level can be changed. By combining the measurement of this torque with a speed measurement, the power output can also be measured and this is a common combination in a dynamometer setup.




Standard Prony Brake Arrangement

For this laboratory, we have constructed a 'home-made' Prony brake using an off-the-shelf furniture clamp and two wooden brake pads. This arrangement is illustrated below. For the relatively low power and torque application with the Skil cordless drill used in this lab, this quick solution works well. The drill will turn the bit adapter mounted in the chuck as a brake drum between the pads.




Although the drawing shows a different clamp being used, the principles are the same. The fishing scale is hooked through the hole at the other end of the clamp and measures the force exerted by the motor on the brake pads. Select a pair of brake pads (A, B or C) and make sure you run all your tests with the same pads to eliminate a variable in your data.

## Lab Deliverables:

1) How does the power of the drill when set to the “High Torque” level compare to the “High Speed” level?

2) Using the adjustable torque collar (numbers 1 – 25) construct a curve for the drill’s power at various evenly-spaced settings. Explain your results.

3) What is the peak power measured? What were the drill settings and RPM for this level?

4) How long were you able to operate the brake before heat build-up limited your research?

5) Before starting your experiments, place the spare battery in the charger. After you determine your best power settings, switch batteries and repeat your best settings with a fresh battery. How much difference does it make in power having a fully-charged battery? Leave the used battery in the drill when you put the equipment away.

6) What recommendations would you make to improve this lab for next semester’s students?

7) A 10 minute presentation on what you learned about dynamometers as a result of this exercise. The presentation duties will be shared equally among all three members of the team.

http://www.steamtraction.com/article/2003-01-01

## How Much Power Does That Engine Really Produce?

## A Working Prony Brake Provides the Answer

Working Out Design Considerations and Initial Details:
Part One of a Two Part Series

**By Bruce E. Babcock**

### A Short History of the Prony Brake

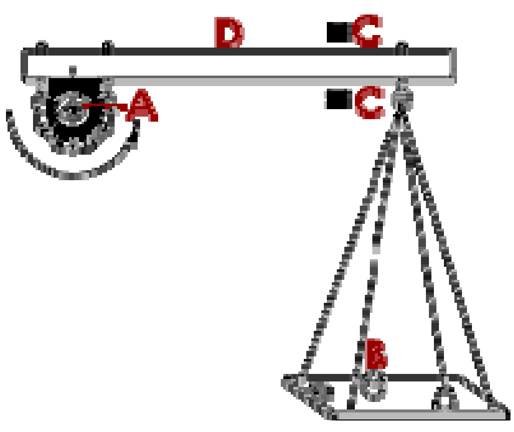
About three years ago, I built a small Prony brake to take to engine shows so people could see how small hit-and-miss gas engines perform working under a load. A Prony brake belted to an engine not only supplies a uniform load on the engine, it also measures the engine's horsepower output, and it demonstrates how horsepower was measured 100 years ago. Running my small Prony brake, I noticed it wasn't just engine owners who were interested in the brake - many spectators stopped to examine the device, ask questions and watch it in operation. At the first show where I exhibited the brake, I recall an elderly gentleman proclaiming, "Now I know what they mean when they say 'brake' horsepower!" My small Prony brake is described in detail in "The Design, Construction and Use of a Small Prony Brake" in the July 2000 issue of *Gas Engine Magazine*. The concept of rating engines, water wheels and windmills in terms of horsepower dates back to the early 1700s, but it wasn't until the late 1700s that anyone made a real effort to determine just how many foot-pounds per minute a horse was capable of producing. Fittingly, it was James Watt, the father of the modern steam engine, who was the first person to make this determination. Watt was selling steam-pumping engines, and he needed a reliable way to calculate the output of his engines so potential customers would have an idea of their capacity. Watt studied mine ponies lifting coal at a coal mine, and he found that, on average, a mine pony could perform 22,000 foot-pounds of work every minute. Put another way, he found that a horse exerting one "horsepower" could lift 220 pounds of coal 100 feet in one minute.

Watt, however, wanted to make sure customers would have no reason to complain of the power output of his engines, so he arbitrarily increased this figure by 50 percent. His final formula determined that one horsepower was equal to 33,000 foot-pounds of work a minute. This meant a five horsepower Watt engine would do significantly more work than five horses. It's interesting to note that Watt's number inflation created at least a certain level of trouble for users of gas and steam engines for over 125 years, as builders of engines continued the practice of under-rating their engines.

Watt applied his horsepower formula to his pumping engines, and by using the number of gallons pumped, the height the water was raised and the time required for a given volume he was able to calculate equivalent horsepower output. However, when Watt began building "rotative" engines (engines with a crank and flywheel) he did not have a reliable method of calculating power output. Some time around 1800 his assistant, John Southern, invented the steam engine indicator, and Watt may have used this to calculate the input horsepower of his engines. But because of the low efficiency of his engines and the primitive construction of the indicator, he could probably only get a rough estimate of the power delivered to a rotating load. It is, however, from this exercise that we get the term "indicated horsepower."

## How the Prony Brake Measures Horsepower

The problem of how to measure the horsepower of a rotating shaft was solved by Gaspard de Prony in France in 1826, when he invented the first friction brake. This device came to be known as the Prony brake. The following sketch, (below) shows the simplicity of Gaspard de Prony's invention. In use, the stationary lever (D) is clamped around a rotating shaft (A) and the two bolts above the shaft are tightened until the engine is working up to full load. Weights (B) are then added to the scale pan until the lever (D) drops slightly away from the upper stop (C). To calculate horsepower the only things needed to be known are the length of the lever (D), the weight of the lever (D) at its right hand end, the additional amount of weight (B) added to the scale pan and the speed of the shaft (A) in rpm.




The calculation is:

**Foot Pounds per Minute = Pi x 2 x Length of D x RPM x Weight**

And because Watt's figure of 33,000 foot-pounds per minute per horsepower has survived through both the 19th and 20th centuries, we end up with:

Horsepower = Pi x 2 x Length of D x RPM x Weight / 33,000

## Designing With the Spectator in Mind

Because of the interest spectators showed in my small Prony brake, I decided that should I build a larger brake I would build it not only to measure horsepower but also to show, as clearly as possible, how the brake is constructed and how it works.

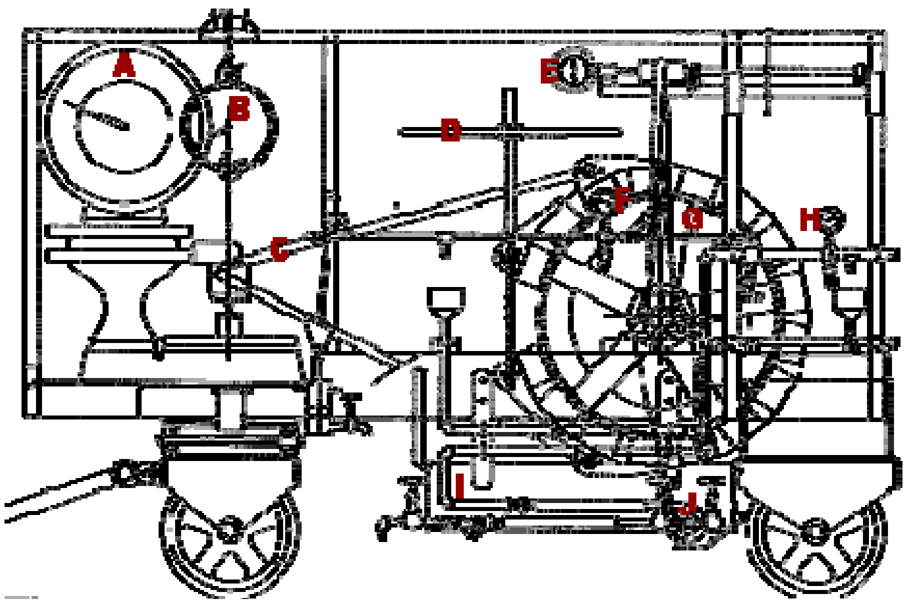



**Figure 1 - Schematic of Bruce Babcock's Prony Brake shows major elements.**

**A**. Toledo Scale

**B**. Hydraulic Scale

**C**. Arm

**D**. Brake Control Wheel

**E**. Tachometer

**F**. Outlet Water Temperature

**G**. Brake Drum

**H**. Inlet Water Temperature

**I**. Water Reservoir

**J**. Water Recirculating Pump

**http://www.buckleyoldengineshow.org/HorsePower/horsepower.htm**

# HORSEPOWER TESTING
# &
# The Prony Brake

Horsepower testing is the mechanical measuring of the units of **Power** that an engine or machine is capable of producing. More specifically we are measuring Brake Horsepower - the effective horsepower or the amount of work that is produced at its final output. One method of doing this is by the use of a dynamometer. A dynamometer is a device that measures **Force.** In one common type of dynamometer, the force is measured by braking action. One of the first such dynamometers was developed by the French mathematician, Gaspard de Prony (1755-1839) and is called a Prony Brake. The principle of the Prony Brake is that an engine or motor is directly coupled to a drum that has a tensioned, friction belt around it. As the drum revolves, the frictional force is measured. Before we explain the operation of the Prony Brake any further, lets define Horsepower and understand the equations we will be using.

## Straight Line Horsepower

Horsepower is a British unit for **Power** defined as the equivalent to the force needed to move 550 pounds, one foot, in one second or one pound, 550 feet, in one second.

**Power** is defined as the rate of doing **Work** or work divided by time. **P = W** / t and the unit is (ft-lb/s)

**Work** is defined as the product of an applied **Force** and the distance through which the force acts. **W = F**d

**Force** is more difficult to understand, it is defined as a push or a pull that tends to cause motion or tends to prevent motion. Force has both a quantity and a direction. Force equals mass times acceleration. **F =** ma

The British system is said to be a gravitational system and the unit of force or weight is the pound (lb). The unit Pound is then defined as a given mass called a slug, times the acceleration of gravity, equals 32 pounds. Force $_{weight}$ equals mass times acceleration of gravity. $\mathbf{F}_W$ = mg or 32 lb = (1 slug)(32 ft/$s^2$)

or 1 lb = (1 slug)(1 ft/$s^2$).

In the Metric system the unit of force is the Newton. One might think that it would be the kilogram but the kilogram is actually a unit of mass.

The results: $$\mathbf{P} = \frac{\mathbf{F}\text{ (in pounds)} \times \mathbf{d}\text{ (in feet)}}{\mathbf{t}\text{ (in seconds)}}$$

If we factor out (time) and make distance a rate (distance per time), or **velocity**, we have: **P** = **F** (in pounds) x **v** (in feet/second)

Then: $$\mathbf{HP} = \frac{\mathbf{F}\text{ lb} \times \mathbf{v}\text{ ft/s}}{550\text{ ft - lb/s}}$$

# Origin of Horsepower

The unit, horsepower, was originated by James Watt (1736-1819), the Scottish engineer who developed the first practical steam engine. When Watt offered to sell his steam engines to farmers and miners, he was probably asked how many horses they would replace. The value of the horsepower was based on his experiments with strong dray horses that were able to do about 50 percent more work than a standard horse in a working day. He concluded that an average draft horse could steadily exert a 150 pound force while walking at a speed of 2.5 miles and hour. The horse thus performed work at the rate of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Watt defined this rate as 1 horsepower.

In the Metric system the unit of power is the Joule/second or Newton-meter/second (J/s = N-m/s). However the derived unit is **watt** (**W**), in honor of James Watt.

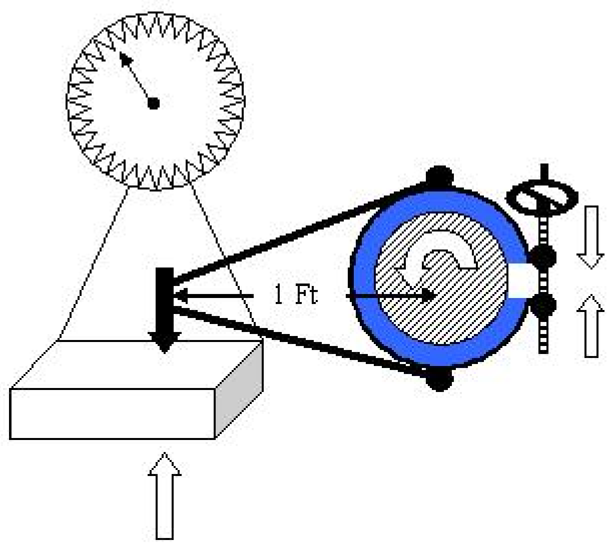
1 hp = 550 ft-lb/s = 33,000 ft-lb/min = 746 N-m/s = 746 J/s = 746 W

# The Buckley Prony Brake

The Prony Brake used at the Buckley Show was constructed in 1988 by Larry Wichern and Nick Lederle, and other club members. Amos Rixmann had a love for the Prony Brake and for many years enjoyed announcing the action of tractors and steamers that were belted-up to the brake, to show their stuff. The Buckley, Prony Brake has been so successful that it has been used at other shows and used as a pattern for brakes built by other clubs. In recent years, many tractor shows use the Prony Brake as a means of competition, where owners will modify and soup up their tractors, to see who can develop the most horsepower. At Buckley however, the purpose of the test is to demonstrate the quality of the preservation or restoration of a tractor by attempting to achieve the rated horsepower based on the original Nebraska Tests for that model of tractor. In 1919, Nebraska passed a law that no tractors could be sold in that state unless one had been tested to provide unbiased information about its performance. The University of Nebraska Tractor Test Laboratory is the officially designated tractor testing station for the United States and tests tractors according to the codes of the Organization for Economic Co-operation and Development. Twenty-eight countries now participate in the tractor test codes. (Test Reports), requires Adobe Acrobat Reader. In 1996 a PTO input was added to the Prony Brake for testing later model tractors that no longer have a belt power take-off.

## Horsepower from a Rotating Shaft

In determining horsepower from a rotating shaft; the same basis exists as in straight line horsepower. In a straight line system we define **Force** as a push or a pull. In a rotational system, we have a "twist", which we call **torque**. Torque is the tendency to produce change in rotational motion, it is equal to the applied force times the length of the torque arm. Torque is measured in foot-pounds (ft-lb) in the British System.




On a Prony Brake we can determine the input force or horsepower by measuring the opposing braking force applied. If we apply a brake band around a rotating shaft, with a tensioning device and an arm extending one foot from the center of the shaft, attempting to stop the rotation, we can measure the applied force on a weight scale. If this arm was allowed to rotate it would travel a distance of $2\pi r$ (pi times twice the radius), or 6.2832 feet with each revolution. Since the speed of a rotating shaft is usually measured in revolutions per minute, we are going to use the HP rate of 33,000 ft-lb/min (550 ft-lb/s times 60 s/min). If we have this shaft turning at 500 RPM and apply a braking force of 100 lbs, we have;

$$\mathbf{HP} = \frac{\mathbf{F}\ \text{lb} \times \mathbf{d}\ \text{per rev} \times \text{RPM's}}{33{,}000\ \text{ft - lb/min}} = \frac{100\ \text{lbs} \times 6.2832\ \text{ft/rev} \times 500\ \text{rev/min}}{33{,}000\ \text{ft - lb/min}}$$

$$= \frac{100\ \text{lbs} \times 3141.6\ \text{ft/min}}{33{,}000\ \text{ft - lb/min}}$$

= 9.3 HP of braking being applied.

To simplify the equation we can factor out the fixed distance of the rotation (33,000/6.2832 = 5252.10084 or just 5252).

The equation becomes; $$\mathbf{HP} = \frac{\mathbf{F}\ \text{lb} \times \text{RPM's}}{5252}$$

At Buckley we simplified things even further; we made the length of the arm 63 inches or 5.25 feet. Multiply that by 2 pi and you get 32.98680. Divide that into 33,000 and you get 1000.42442 or 1000.

Therefore the equation used at Buckley is: $$\mathbf{HP} = \frac{\mathbf{F}\ \text{(in lbs)} \times \text{RPM's}}{1000}$$

Note: don't be confused and try to insert the values from the example into this last formula and expect to get the same braking horsepower. Remember we have increased the length of the arm, and if the RPM and the brake tension remained the same the force required to prevent the arm from rotating would be less.

The maximum horsepower of an engine is determined by achieving a braking horsepower equal to the output of the engine and basically stalling the engine. During the test, tension is increased on the brake drum to increase the braking force in 10 pound increment for small tractors and engines, and up to 100 pound increments for large tractors and steam engines. Engines with good governors will maintain a reasonably constant RPM until the maximum Horsepower has been reached and then the speed will drop sharply. The highest Force and RPM gives the maximum HP for the engine.