

Dynamometer Basics

Dr. Horizon Gitano
University Science Malaysia

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DYNAMOMETER OVERVIEW

A **dynamometer** is a load device which is generally used for measuring the power output of an engine. Several kinds of dynamometers are common, some of them being referred to as “breaks” or “break dynamometers”: dry friction break dynamometers, hydraulic or water break dynamometers and eddy current dynamometers.

Dry friction dynamometers are the oldest kind, and consist of some sort of mechanical breaking device, often a belt or frictional “shoe” which rubs a rotating hub or shaft. The hub or shaft is spun by the engine. Increasing tension in the belt, or force of the shoe against the hub increases the load on the engine.

Hydraulic dynamometers are basically hydraulic pumps where the impeller is spun by the engine. Load on the engine is varied by opening or closing a valve, which changes back pressure on the hydraulic pump.

Eddy current dynamometers are electromagnetic load devices. The engine being tested spins a disk in the dynamometer. Electrical current passes through coils surrounding the disk, and induce a magnetic resistance to the motion of the disk. Varying the current varies the load on the engine.

The dynamometer applies a resistance to the rotation of the engine. If the dynamometer is connected to the engine’s output shaft it is referred to as an **Engine Dynamometer**. When the dynamometer is connected to the vehicles drive wheels it is called a **Chassis Dynamometer**. The force exerted on the dynamometer housing is resisted by a strain measuring device (for example a strain gage).

DYNAMOMETER OPERATION

Several components are typically packaged together in a dynamometer: the shaft with bearings, the resistance surface, the resistance mechanism in a “free” rotating housing, a strain gage, and a speed sensor (see figure 1 for a schematic of an Eddy Current Dynamometer). Generally some method of cooling is also required, and this may require either a heat exchanger or air or water circulation, this is not shown in figure 1. The entire assembly is typically mounted on a stout frame, which is mechanically linked to the frame of the engine being tested.

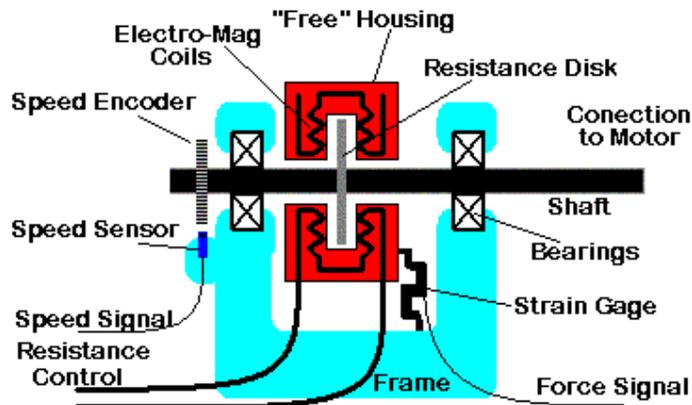


Figure 1. Eddy Current Dynamometer

The force signal (F) from the strain gage may be converted into a torque (T) by multiplying by the distance from the center of the shaft to the pivot point of the strain gage (R):

$$T = R \times F$$

If the units are in Newton-meters and shaft speed (S) is measured in radians per second, then the shaft power or **break power** (P) of the engine can be calculated by multiplying the speed and the torque:

$$P = T \times S$$

Obviously if you are using different units than you will need to use the appropriate conversion factors.

DYNAMOMETER CONTROLERS

In order to test the engine it is generally necessary to use a dynamometer controller. This is usually an electronic unit which has the capability of controlling the load on the dynamometer (i.e. it controls the current to the resistance coils in an eddy current dynamometer) and can measure or sense the load and speed. Dynamometer controllers generally operate in two modes: **Speed Controlled** operation or **Load Controlled** operation.

In **Speed Controlled mode** a **set speed** is given to the controller (either as a voltage or a setting on the front panel of the controller, see figure 2). If the measured speed of the shaft is less than that of the set speed, the load is decreased. If the measured speed of the shaft is greater than that of the set speed, then the load is increased. Assuming the engine has sufficient torque to attain the set speed, this will maintain a constant speed.

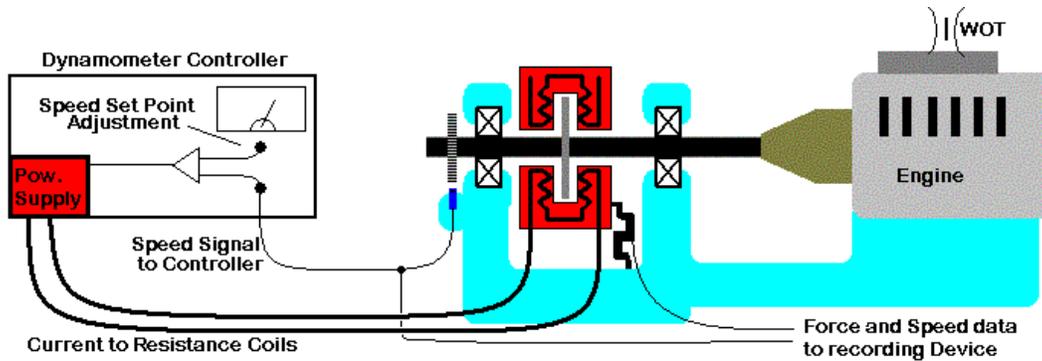


Figure 2. Schematic of a Speed Controlled test of engine at WOT

In **Load Controlled mode** a **set load** is given to the controller (either as a voltage or a setting on the front panel of the controller). If the measured load on the dynamometer is greater than that of the set load, the load is decreased. If the measured load on the dynamometer is less than that of the set load, then the load is increased. Assuming the engine has sufficient torque to attain the set load, this will maintain a constant load while the speed varies.

ENGINE TESTING: POWER CURVE

Several different tests can be performed with good engine dynamometer. The most common is an **Engine Power Curve** (or Engine Torque Curve). In this test the engine is run at wide open throttle (WOT), and the dynamometer is operated in Speed Controlled mode. The speed set point is initially set to a low value, perhaps twice the idle speed. Engine speed and dynamometer torque are measured, and the speed set point is then increased, perhaps 500 rpm, and once the engine stabilizes at the new speed, the new speed and torque are measured. This is repeated up to the maximum desired speed. Break Power can then be calculated from the data, and you will have curves for the WOT torque and power as a function of engine speed.

Please note: great care should be taken when testing the engine at WOT as any mistake in the testing could lead to an over-speed engine, possibly resulting in engine destruction.

ENGINE TESTING: DRIVE CYCLE

To test an engine in a simulated drive cycle it may be best to use the load-controlled mode. Generally both the engine speed and load will vary as a function of time, so the dynamometer controller needs to be programmable, or have a load control voltage sent to it from a programmable voltage source (i.e. DAC). Typically a human operator is given the “speed schedule” (i.e. the speed versus time) of the test, and can view the actual speed of the engine. His job is to maintain the engine as close to the operating speed as possible during the course of the testing by operating the throttle. This step can alternatively be done by a programmable speed-sensing throttle controller (very similar to a dynamometer controller) and throttle actuator.

POWER TESTING: Further Explanation and Data

To test a motorcycle engine under load and measure its power output it was connected to a dynamometer via the drive shaft sprocket. An eddy current type dynamometer was used for control and measurement of engine power. The dynamometer consists of a drive shaft rotating a 60 tooth speed wheel and an induction disk as seen schematically in figure 3. The induction disk rotates inside a housing which contains electromagnetic coils. The housing pivots freely about the shaft. Rotation of the housing is resisted by a strain gauge connected to the frame of the engine.

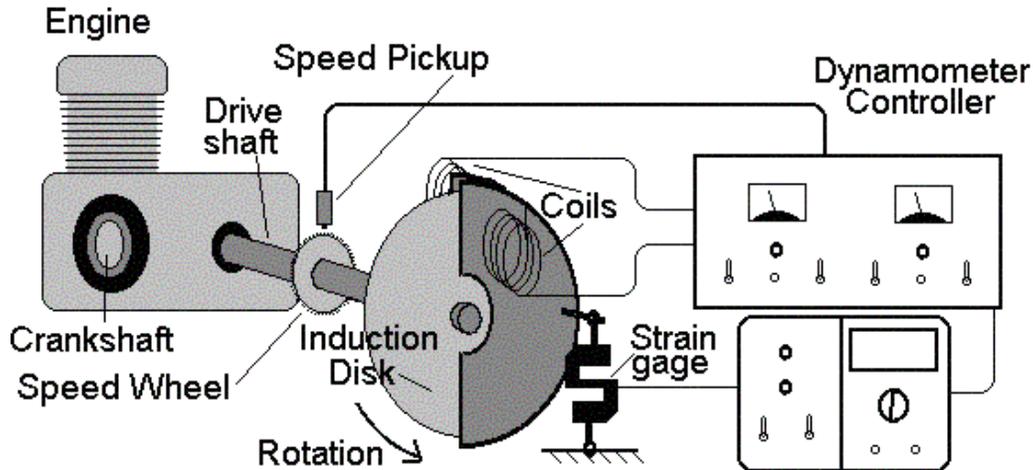


Figure 3 Schematic of a motorcycle engine and eddy current dynamometer

Current running in the coils induces drag in the induction disk, resisting rotation of the drive shaft. The torque produced in the housing is measured by the strain gauge and was recorded. The dynamometer controller measures the speed of the engine, and compares it to a speed set point which is either adjusted via the front panel of the dynamometer controller, or an external voltage. If the speed of the shaft is greater than the speed set point the current in the coils is increased thereby increasing the drag on the drive shaft and slowing the engine. If the speed is below that of the set point the current in the coils is reduced. Very near the set point the controller outputs a Pulse Width Modulated (PWM) control signal to the coils. This allows the controller to vary the load on the engine in order to maintain a given shaft speed.

The SAJ eddy-current type dynamometer, shown in figure 4 is rated at 30 kW and controlled by a modified Digalog dynamometer controller. Modifications of the controller consisted of rewiring it to operate the lower voltage coils (30V DC each) of the SAJ dynamometer, rather than the 130V initially supplied by the controller.

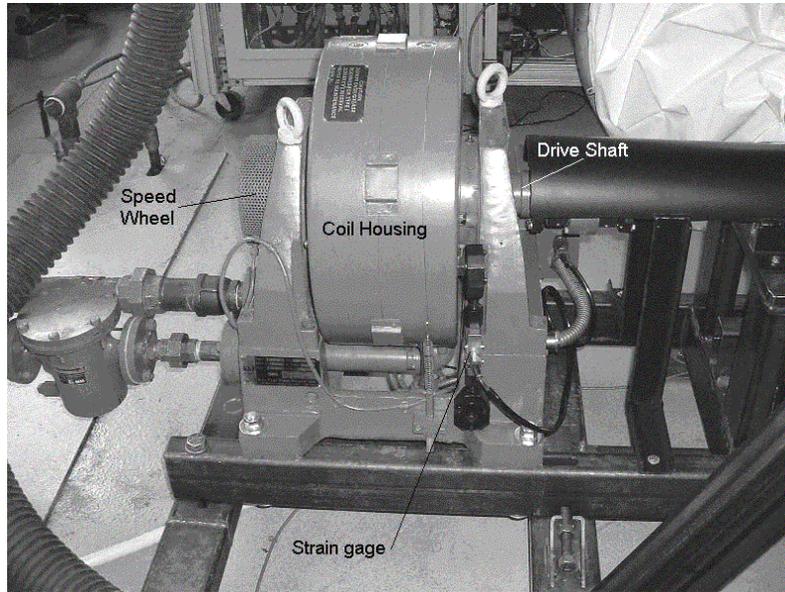


Figure 4 The SAJ eddy current dynamometer used for engine testing.

During power measurements it necessary to provide sufficient cooling air to the engine to avoid overheating. This was supplied by a large fan and cowling which provided airflow over the engine at approximately 40 km/h. The temperature of the head was monitored continuously via a head mounted thermocouple throughout testing to ensure it did not overheat. The dynamometer also required cooling to dissipate the heat generated by the induction wheel and coils. This was provided by circulating water through the dynamometer housing via the pipes seen in the left of figure 5.



Figure 5 A Kawasaki HD-III mounted to the SAJ dynamometer.

The dynamometer controller could vary the load on the engine and measure the drive shaft's speed, and torque. Typically the engine was operated at a given throttle setting, and the dynamometer was controlled to maintain a constant shaft

speed. All measurements were taken from the transmissions final drive sprocket. These numbers could be converted back to actual engine numbers by dividing the torque by the gearing ratio, and multiplying the speed by the gearing ratio. Note, however, that this does not account for the efficiency of the transmission, which for a typical motorcycle can be expected to be on the order of 90%. All of the power and torque numbers presented here are the raw numbers, uncorrected for transmission losses.

A plot of the power and torque produced by the engine is shown in figure 6. This plot shows the results of several different runs performed in second, third, and fourth gears. The peak power is just over 5kW at 6000 rpm, and the peak torque is approximately 9 Nm at about 4200 rpm. Variation of the results taken at different times is on the order of +/- 5% for both power and torque for all of the systems tested.

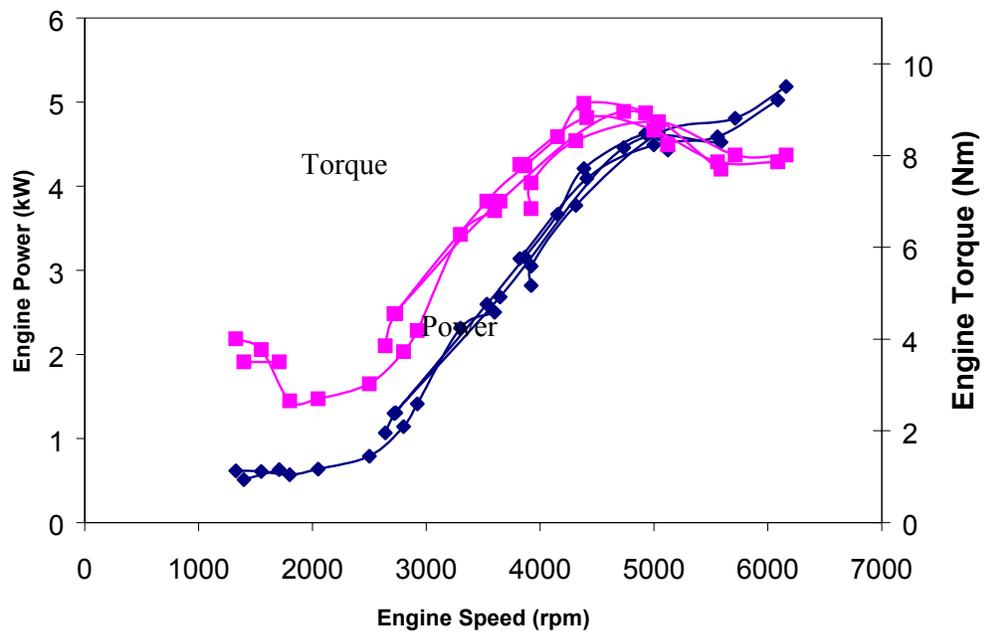
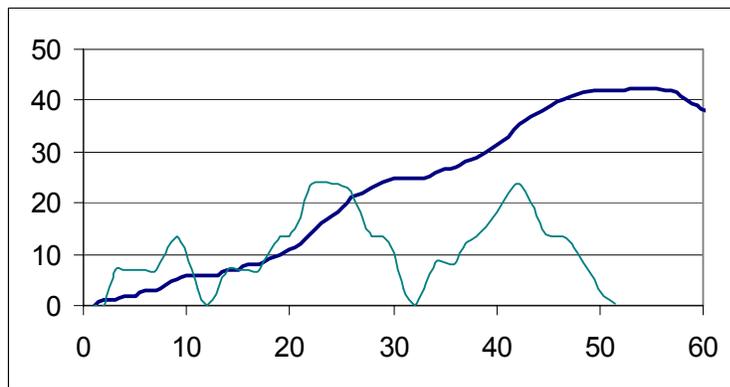


Figure 6 Power and Torque as a function of engine speed, WOT.

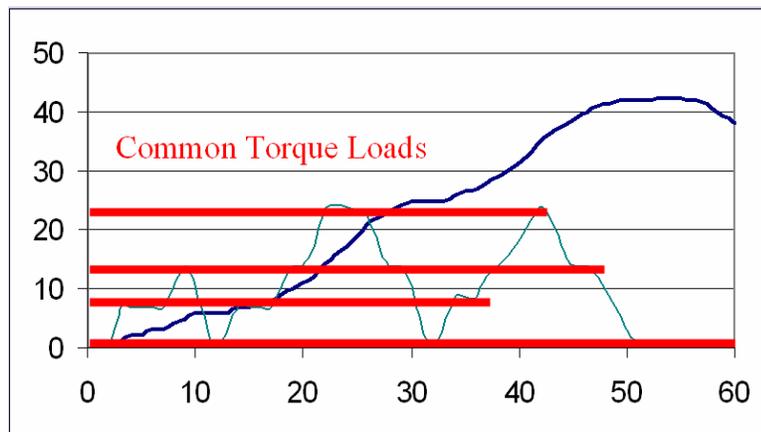
DRIVE CYCLE SIMULATION

It is often more convenient to measure the fuel consumption and emissions of a vehicle in the lab rather than during operations in the field. The point of drive cycle simulation is to determine what test points (engine speed and torque) to test at in order to simulate actual driving conditions. This is how we determine what test points to use.

First we start by measuring a typical drive cycle of the vehicle in question. Engine speed and torque are calculated and recorded.



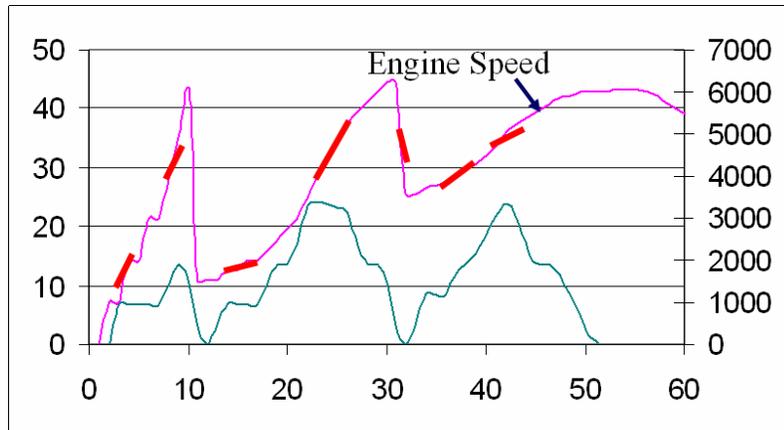
This is a plot of vehicle speed (dark thick line) in km/h versus time in sec, and Engine torque (in Nm) versus time for a test drive cycle. Notice that the engine operates at some torque loads more than others.



Common Torque loads (highlighted in red) on this drive cycle are:

0 Nm (idle, or coasting), 7 Nm, 14 Nm, and 22 Nm.

NOTE: We have neglected rolling friction and wind friction in the model



This is a plot of the engine speed superimposed on the previous torque curve. The red highlights indicate common speeds for some common torques: 7 Nm at 1800 rpm, 14 Nm at 4750 rpm, 24 Nm at 5000 rpm

Including an idle point our test points for this drive cycle might be:

Test Point	Torque	Engine Speed
1	0 Nm	Idle
2	7 Nm	1800 rpm
3	14 Nm	4750 rpm
4	24 Nm	5000 rpm

If an appropriate weighting factor is applied to each test point, fuel consumption and emissions data from the dynamometer testing may be used to predict the numbers from the actual drive cycle. In our testing in Manila we were able to get agreement (based on fuel consumption) to within better than 5% between our Dynamometer testing and the actual field data based on a 5 point cycle simulation.