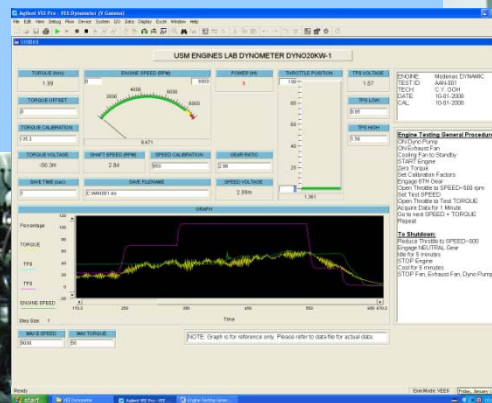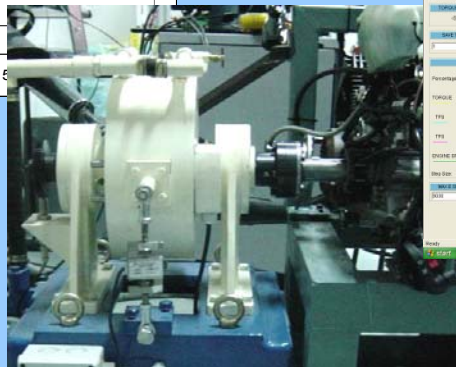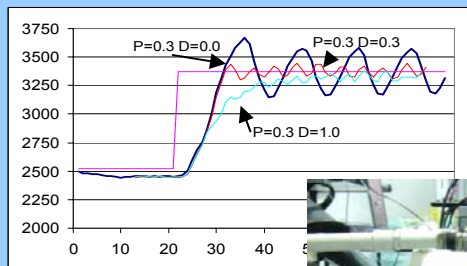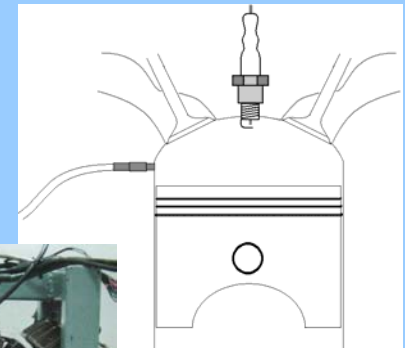# Dynamometry and Testing of Internal Combustion Engines

Seminar

June 26-2008

University Science Malaysia

Dr. Horizon Gitano-Briggs

UNIVERSITI SAINS MALAYSIA

OUTLINE

Part 1   Basics
What is a Dynamometer?   - The Basics
Dynamometer Designs
Mechanical Details

Part 2   Measurements
Measurements: Cycle Averaged vs. Crank Angle Resolved
Instrumentation Issues
Testing: Steady State vs. Transient
Controllers
Dynamometer Dynamics

Part 3   Drive Cycles Analysis
Drive Cycles
Test point Determination and Weighting

Part 4   Dynamometry Case Studies
USA
Philippians
Malaysia

OBJECTIVES

This course was designed for engineers working on engines testing

The hope is that after attending this course you will be better able to:

Understand the strengths and weaknesses of the various dynamometer designs

Interpret data from dynamometer testing, and how it applies to a vehicle

Design more effective dynamometer tests

Trouble shoot dynamometer problems more effectively

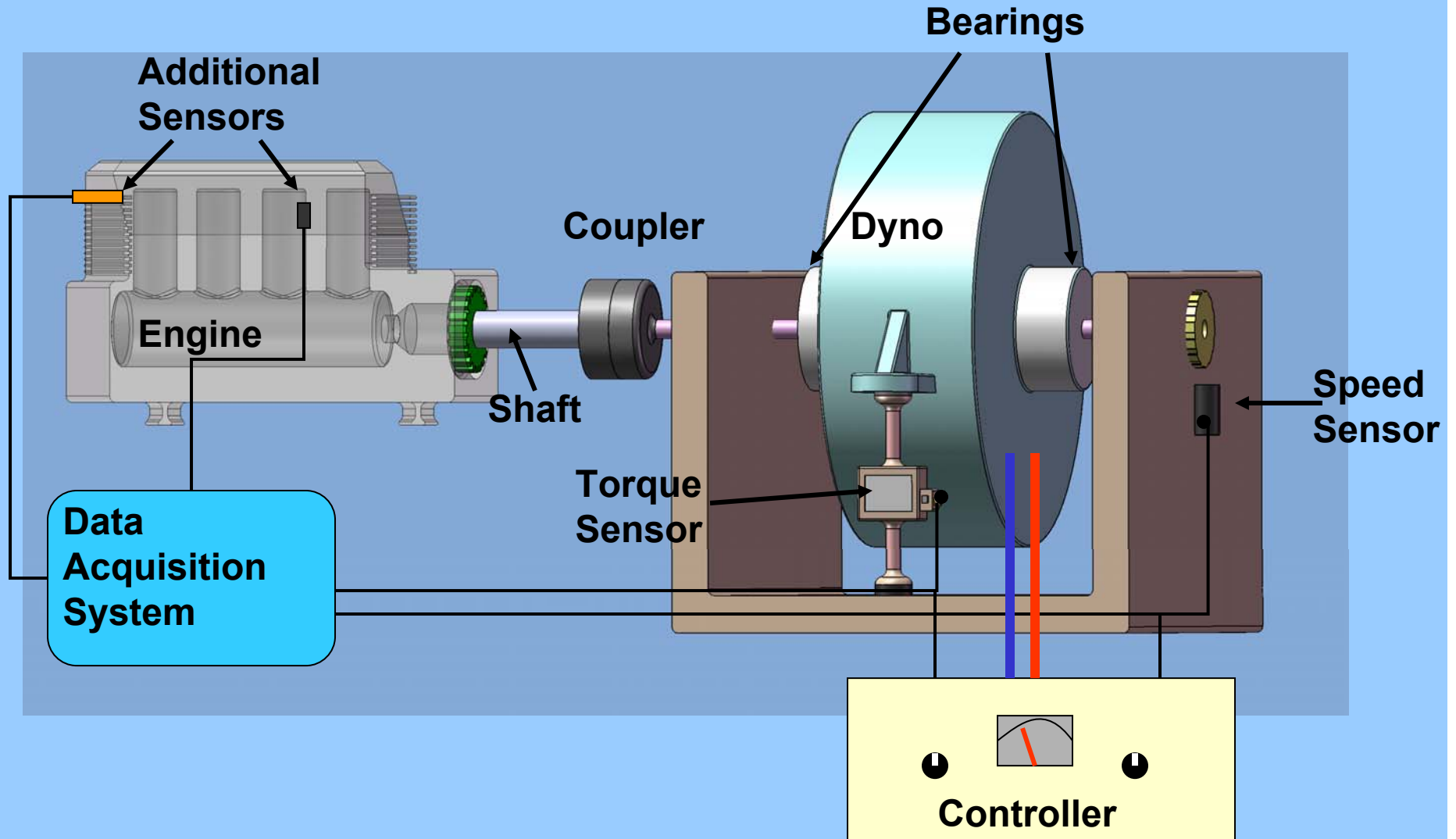Design and build dynamometer and Engine Test solutions

Part 1: Dynamometer Basics

A Dynamometer is a LOAD device
It applies a load to an engine so we can test the performance of the engine
under a variety of circumstances (Power, Speed)

Schematic Overview of Test System
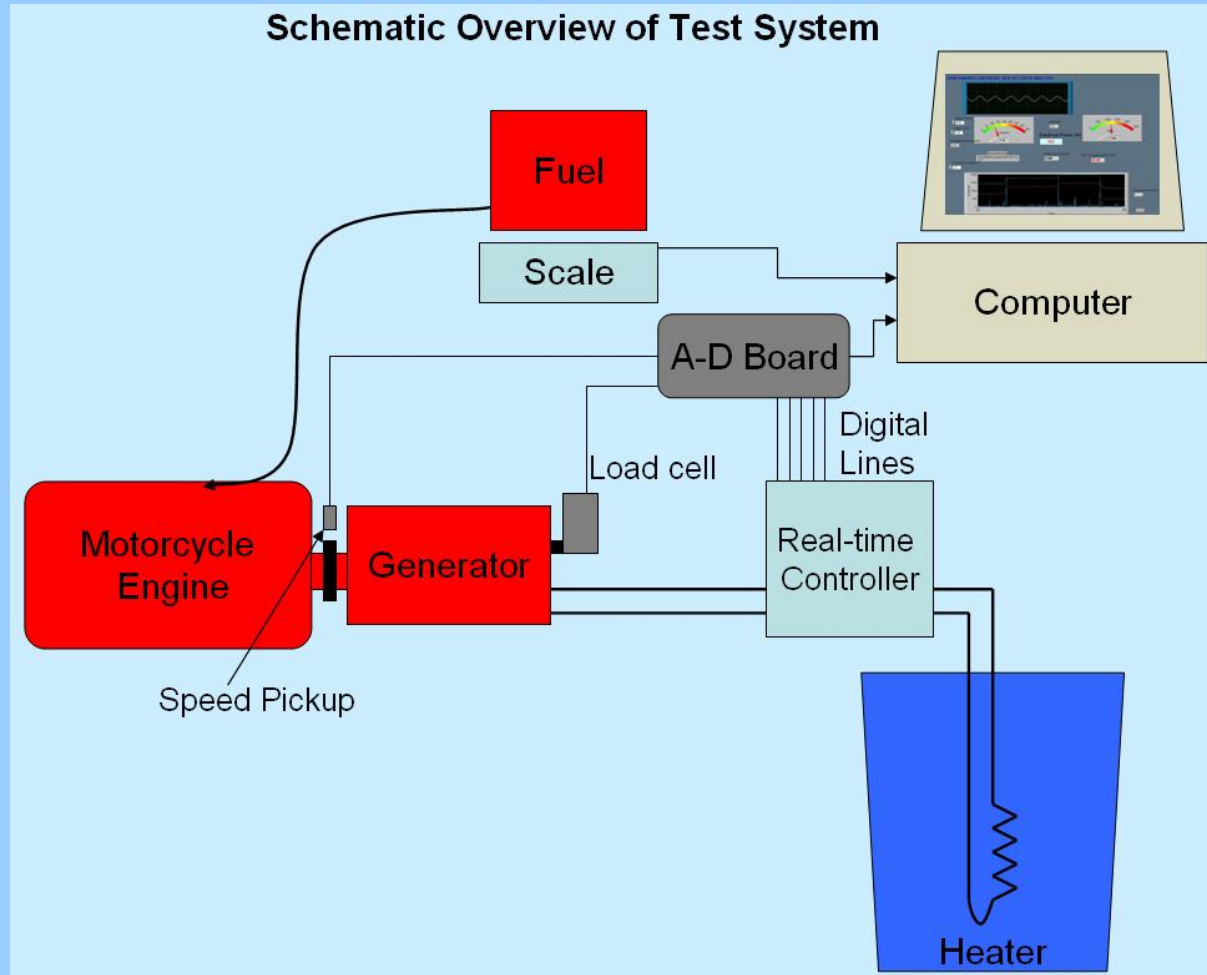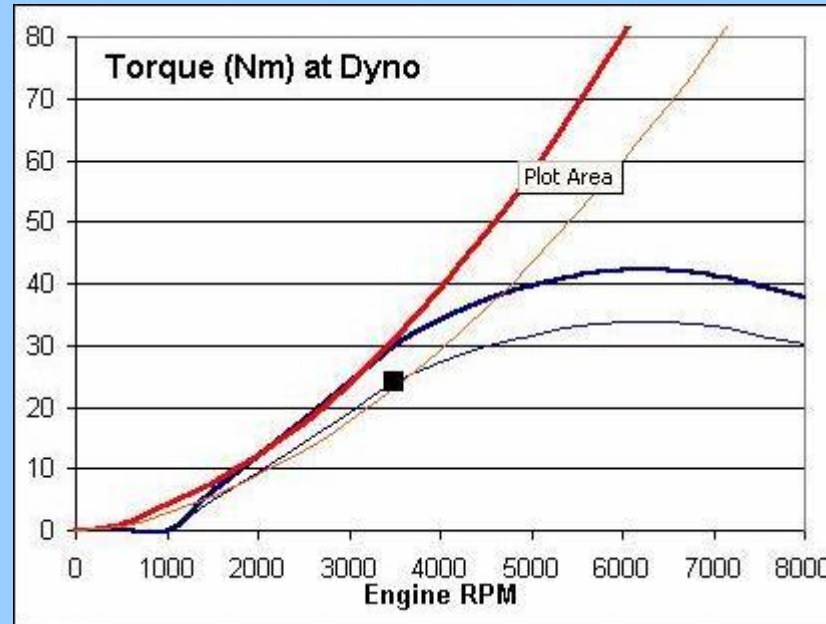
Dynamometer Components

Dynamometer Basics

Engine Torque Vs. Dyno Torque

The system operates where Engine Torque equals torque absorbed by the Dynamometer
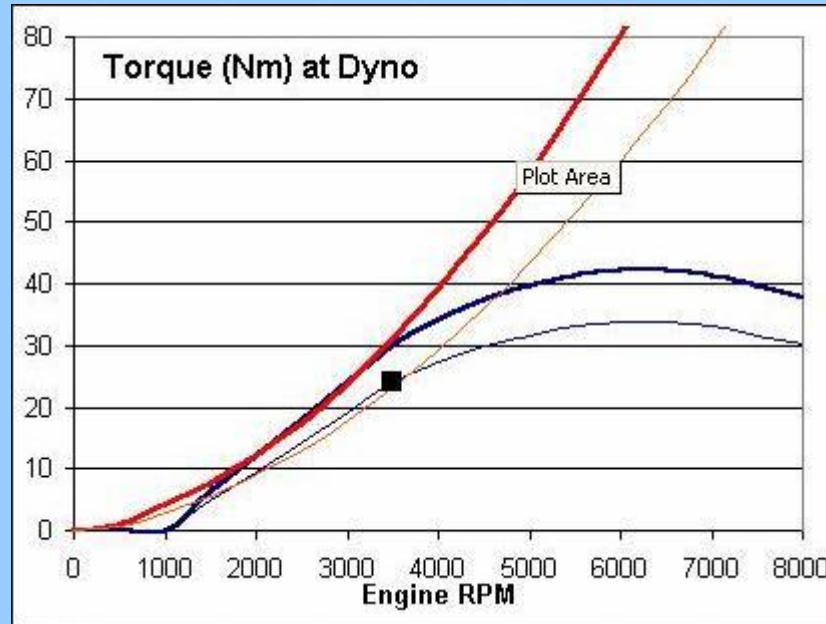
By varying the engine throttle and load we can test any point under the engine's max torque curve

Dynamometer Basics: Demo

Engine Torque Vs. Dyno Torque

The BOLD curves represent the full throttle torque curves of the Dyno and Engine. The finer curves are the throttled curves. The indicated box represents the operation point (Torque and Speed) of the system.

Why Dyno test an Engine?

At the USM Engines Laboratory we design and modify engines for improved fuel economy and emissions

WHY DYNO TEST?

We need DATA to quantify the improvements in Fuel savings and Emissions reductions. This data will be used to help us "tune in" our designs. It is also required as proof for customers, and government officials making policy decisions.

IT IS CRUCIAL THAT WE HAVE GOOD DATA!

It is *difficult* to get data on the road with sensitive lab equipment (Road conditions, weather, traffic vary over the time required for a given test point)

It is *easy* to gather this data on a Dyno BUT: It's not the same!
        Wind load, vibrations, temps, losses, H2O…

We need to understand the differences in order to properly interpret the results.

- A Dynamometer is load device used to measure an engines torque and speed. We often measure Fuel Consumption, Emissions and other parameters as well.

- A dynamometer can also be used to control the speed of the engine by varying the load placed on the engine.

- Dynos are often used to test different engine designs at the same load settings (Torque and Speed) for comparison purposes.

- We want to test the engine under conditions similar to the actual conditions (speed, torque) in the field, or even "simulate" an actual drive cycle with the dynamometer

Dynamometers

There are 2 basic kinds of dynamometers:

Absorption Dynamometers

These are devices that absorb the mechanical power from the test engine.

Transmission Dynamometers

These are basically torque measurement devices placed in a power transmission link (ie. a shaft). They can be used to measure torque and speed, and thus power.
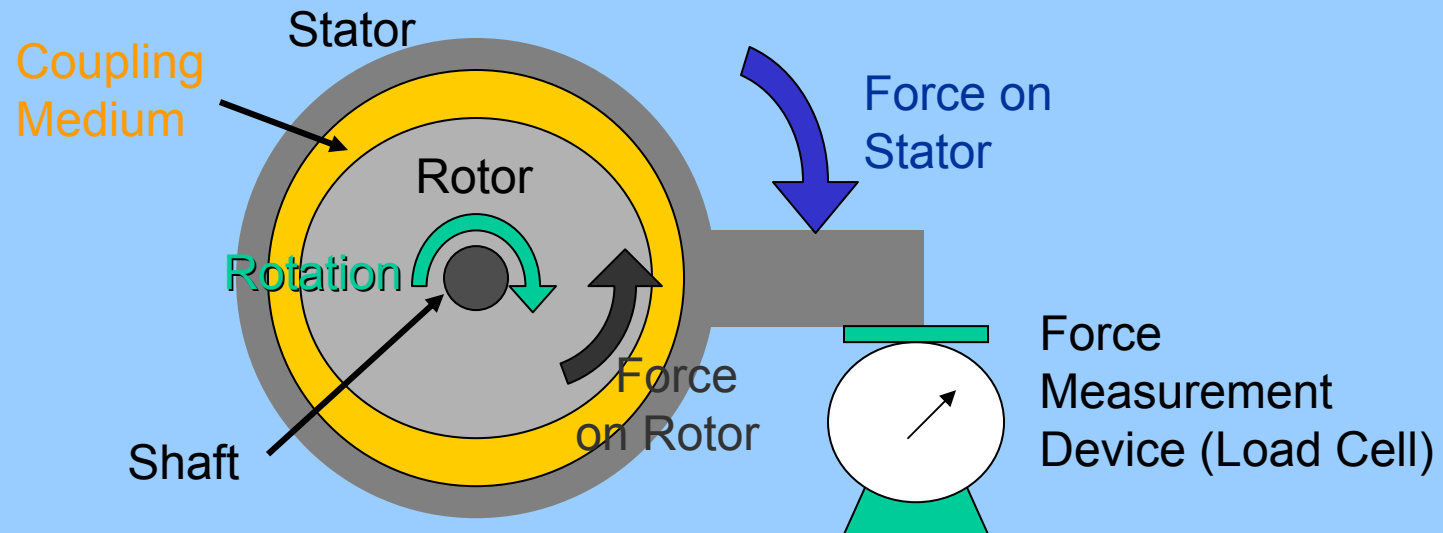
We will consider only Absorption dynamometers here.

Dynamometers

All Absorption Dynamometers share some basic features:

The shaft is connected to a Rotor housed in a Stator. There is some form of coupling (mechanical, hydraulic, aerodynamic, electromagnetic) between the Rotor and Stator.

Equal and opposite torques are induced on the Rotor and Stator:

Various Dyno Designs

There are many different designs used in dynamometers. Here are the most common ones (discussed below):

Frictional (Break)
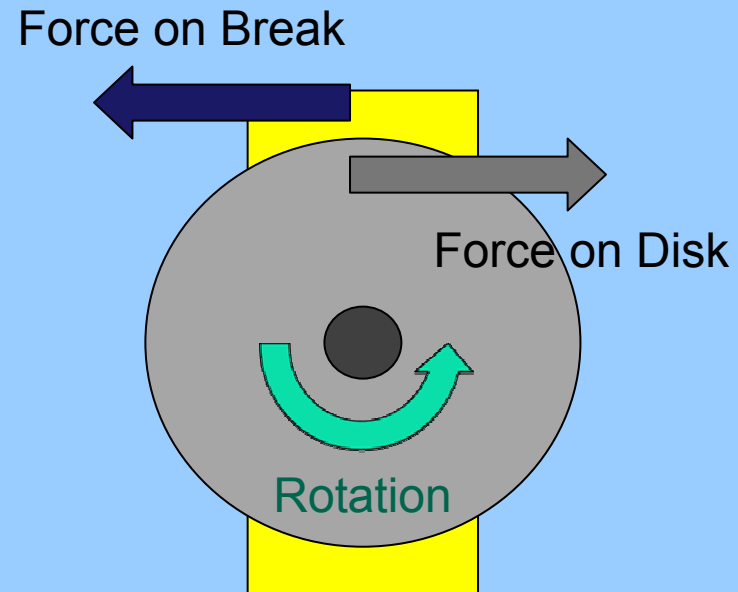
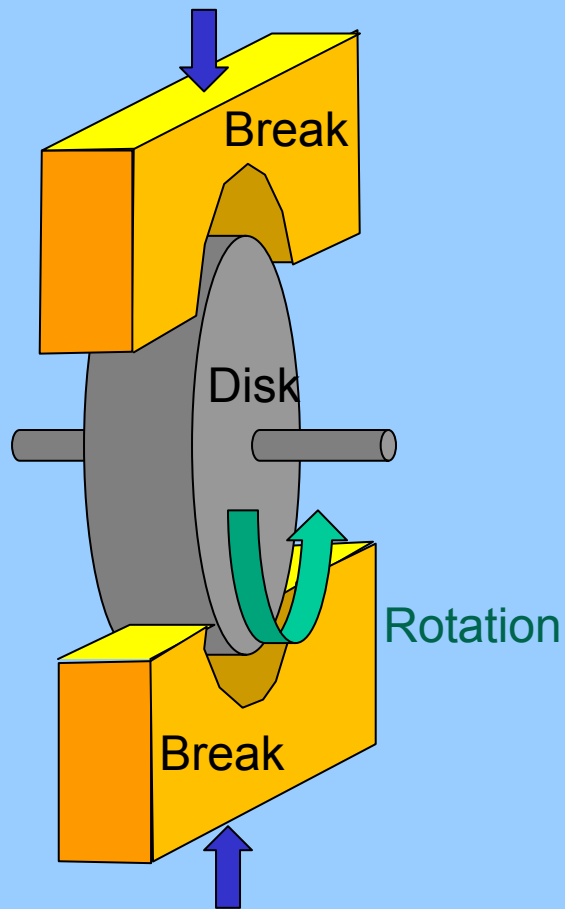Hydraulic

Generator

Eddy current

Fan

Vehicular

Motored Dynos

Frictional (Prony Break) Dyno

The shaft spins a disk or drum. A break pushes a frictional lining against the disk, resisting rotation. The force on the break is equal and opposite to the force on the disk. Sometimes a rope is wound around the drum as a break.

Break

Disk

Rotation

Break

Force on Break

Force on Disk

Rotation

Hydraulic Dyno

The shaft drives the impeller of a pump. The working fluid is pumped through a hydraulic circuit including a throttle valve. Hydraulic drag resists motion of the impeller. The throttle valve must be adjusted to vary the mechanical load.

Hydraulic dynamometers typically have the highest power densities.

Pump

Shaft

Inlet

Reservoir

Valve
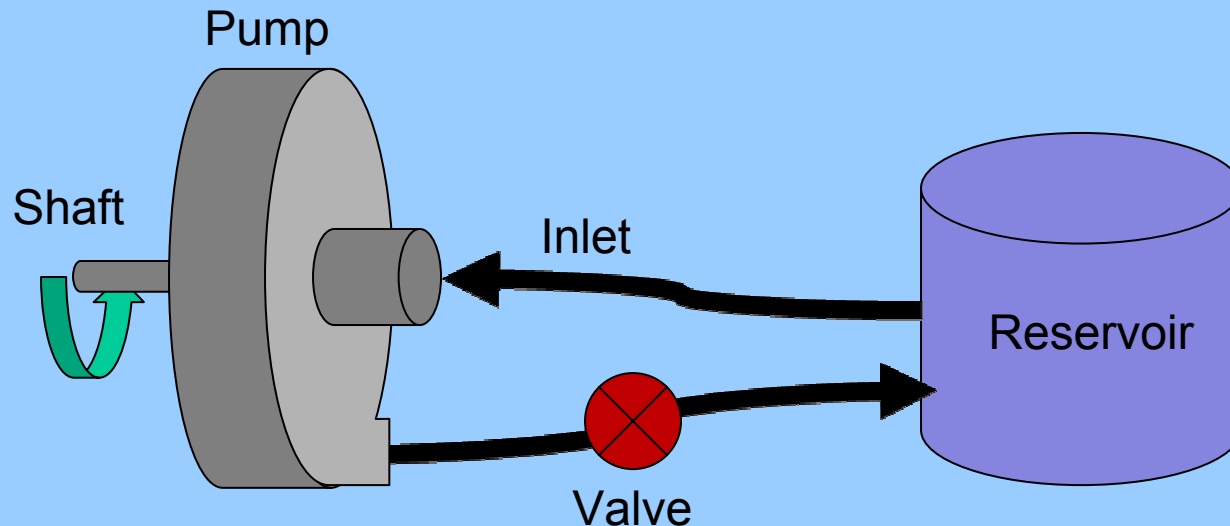
Generator Type Dyno

The shaft spins the rotor of a generator. As electrical load is applied to the output of the generator, an electromagnetic force resists motion of the rotor rotation. The load is usually a resistor bank (heater) either air or water cooled. Generally the field winding current is controlled to vary the mechanical load.

Field Windings

Power Supply

Generator

Stator Windings

Rotation

Heater

Water Tank
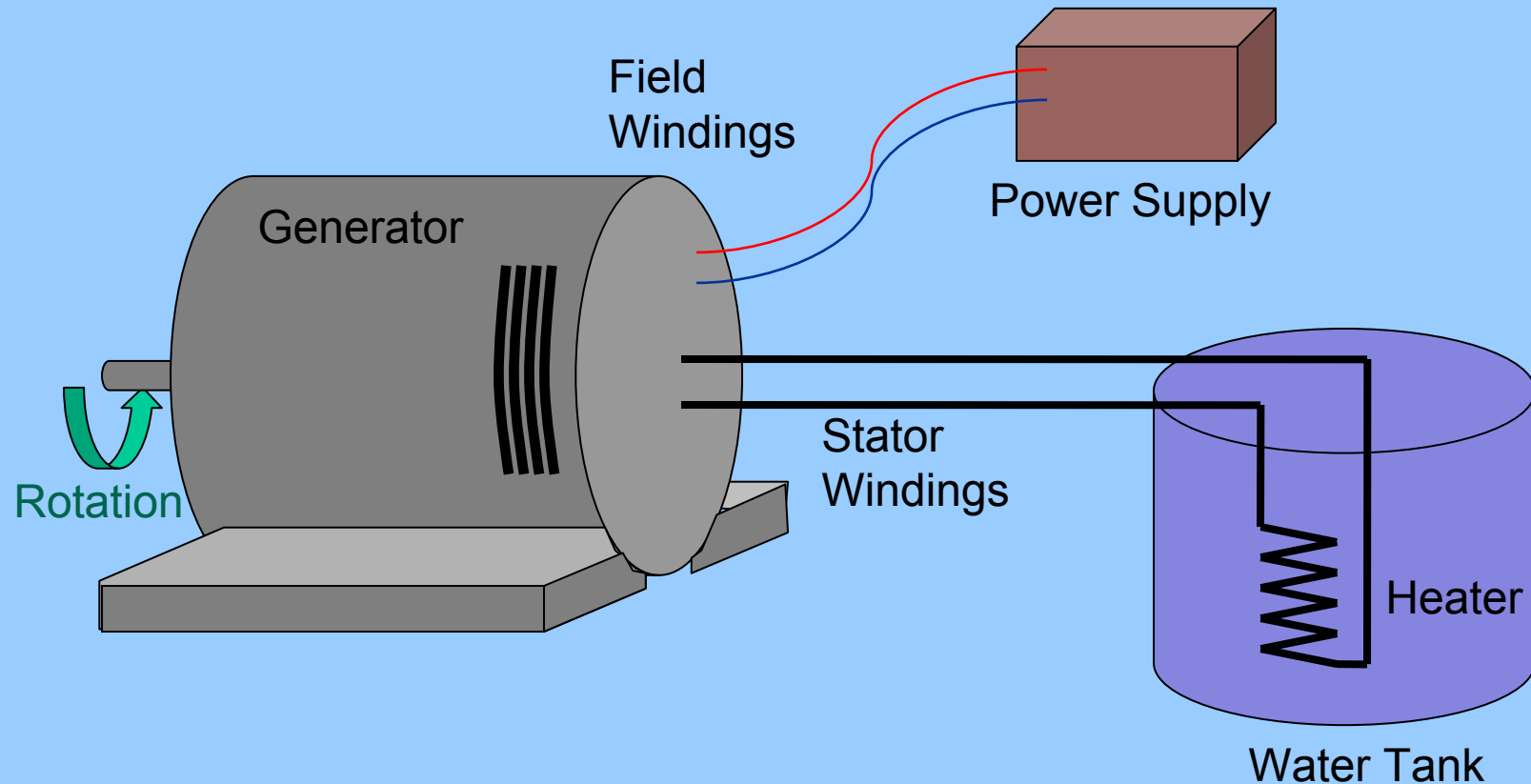
Eddy Current Dyno

The shaft spins a disk located inside a housing containing large electro-magnet coils. When current passes through the coils they create a strong magnetic field in the disk. This creates "eddy currents" in the disk, which resist rotation, creating a torque between the housing and the disk. Varying the current varies the torque.

Electromagnet

M

Eddy Current

Coil Current

Rotation

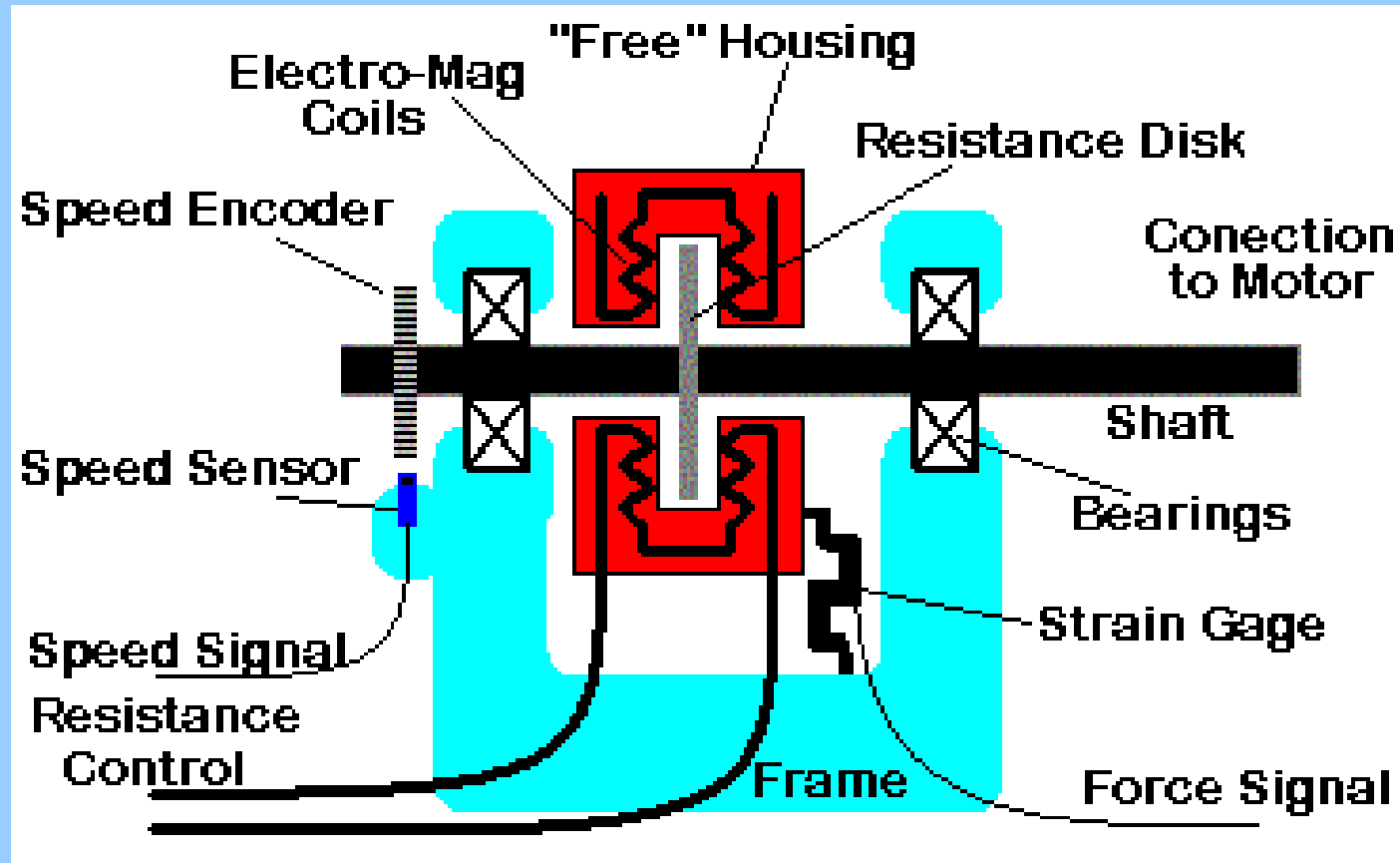**Force on Disk**

Force on Coil

Rotation
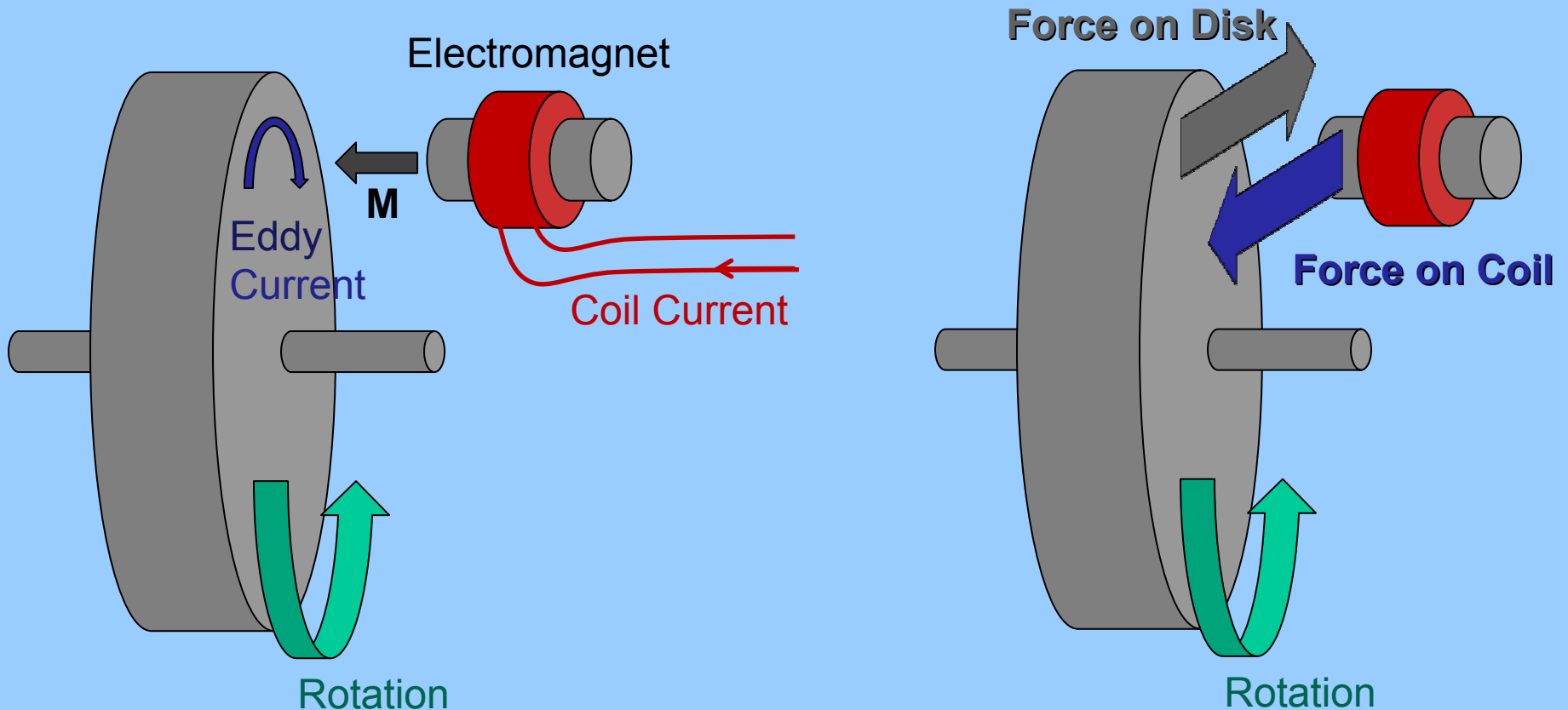
Eddy Current Dyno

Current is typically 1 to several amps, at 50 to 200 Vdc.

The response is almost instant. These dynos are the easiest to control and quickest to respond.
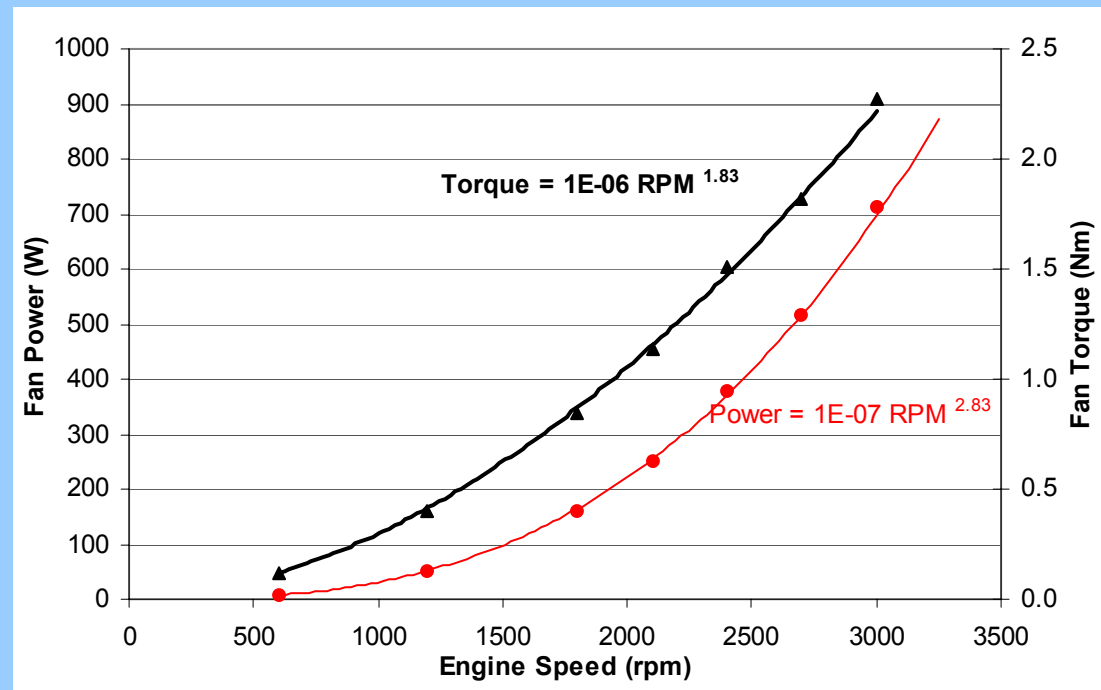
Fan Dynamometer

The shaft spins a fan which moves air. The fan must be calibrated on a frictional dynamometer before use, and its load is a function of temperature, barometric pressure and humidity.

Torque goes as the square of the shaft speed.

These dynos are typically not adjustable, but are very inexpensive.

Torque = $1E{-}06 \; RPM^{1.83}$

Power = $1E{-}07 \; RPM^{2.83}$

Fan Dynamometer

Fans have 2 orientations: High load (normal) and low load (reversed).

In the Normal orientation it efficiently pumps air, dissipating more energy.

In Reversed orientation the blades move less air because they are less efficient.

So there are 2 possible load curves:

Air Flow   Normal Rotation

Air   Reversed Rotation
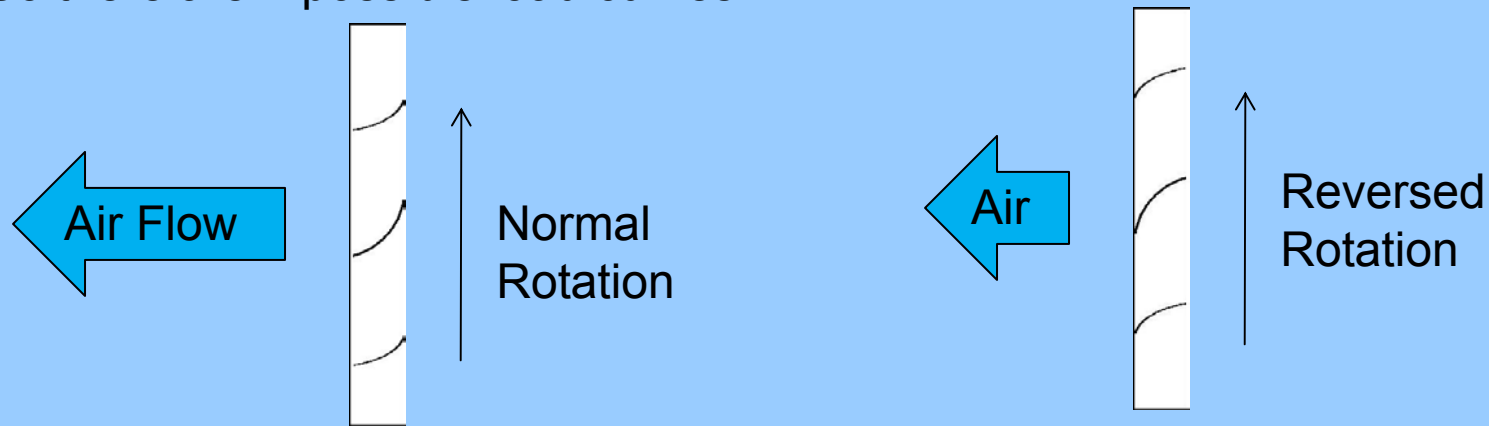
During calibration the air flow should be blocked similar to what it will be during use

Test Engine   Air Flow

Dummy cowling

Frictional Dyno   Air Flow
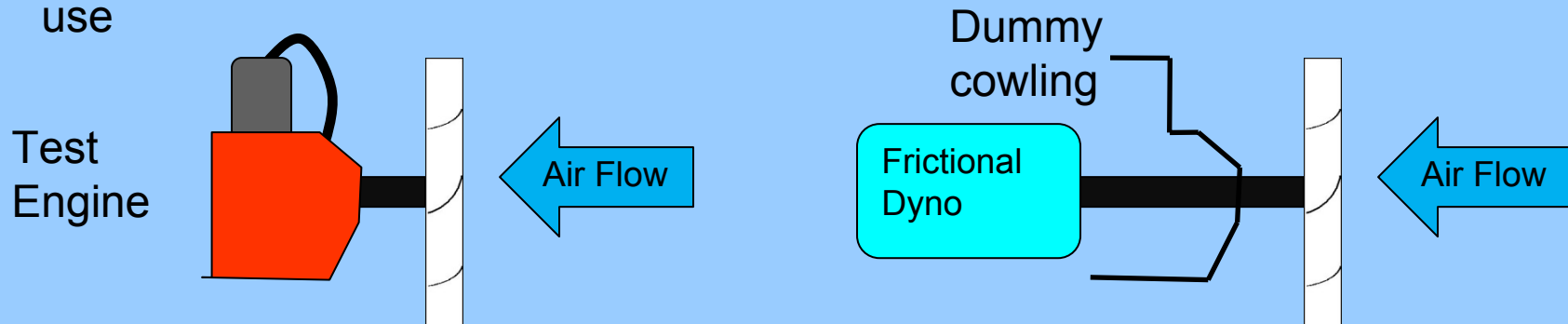
Fan Dynamometer

Torque Curve from same fan in Normal and Reversed orientations
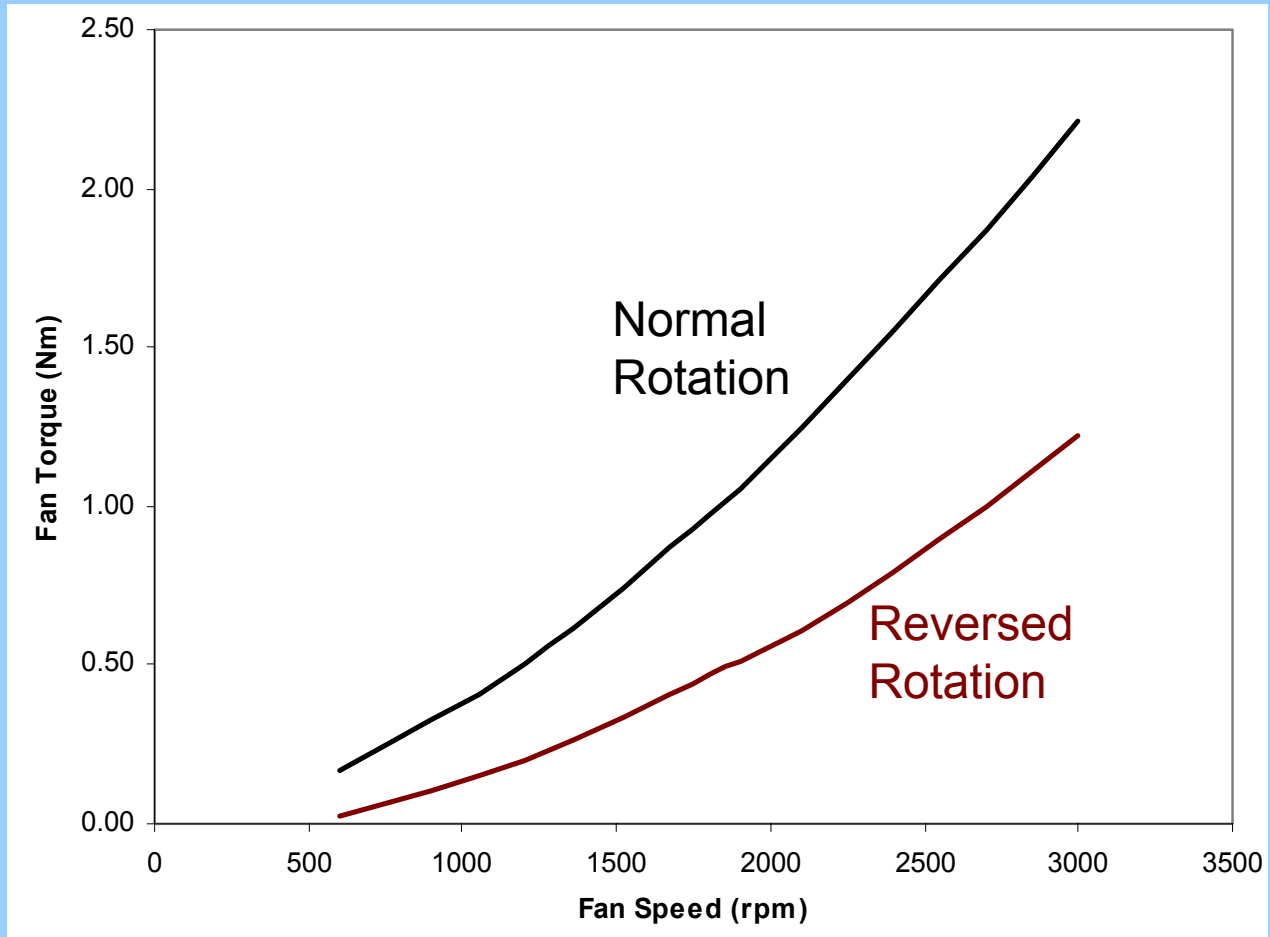
Vehicle Dynamometer

A vehicle may be weighed and instrumented to measure speed and acceleration. Knowing the acceleration and velocity of the vehicle and the gear ratio we can calculate the torque and speed of the engine. This technique requires a large area for testing and is usually only used for coarse measurements of maximum engine power/torque.

This is a good way to confirm engine level testing.

T_1, V_1 T_2, V_2
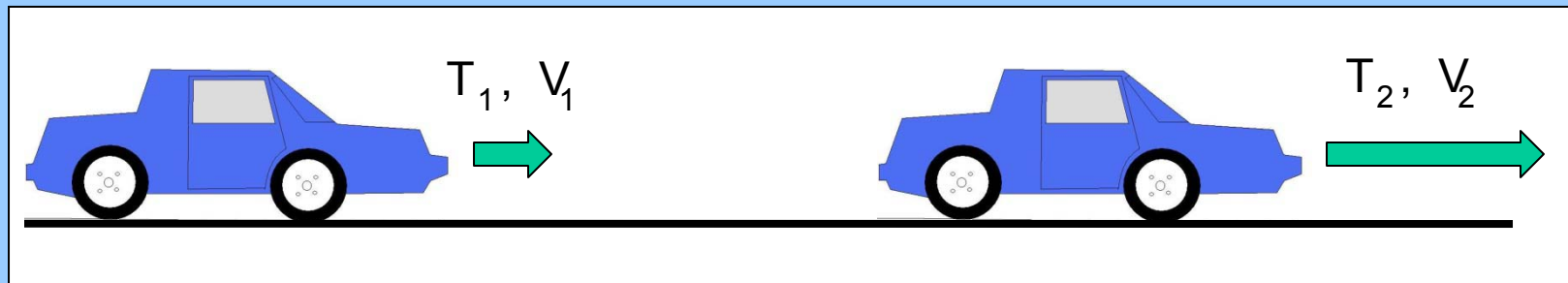
$$A = (V2-V1)/(T2-T1)$$
$$F = M \times A$$
$$T = R \times F$$

Vehicle Dynamometer

This "Torque Sprocket" is a type of transmission Dynamometer. As torque is transmitted through it the inner and outer races (which are separate) rotate relative to one another. This shift can be sensed by a speed pickup placed near by as the sprocket rotates. This allows simultaneous recording of both speed and torque on a moving vehicle. It is therefore a type of vehicle dynamometer.
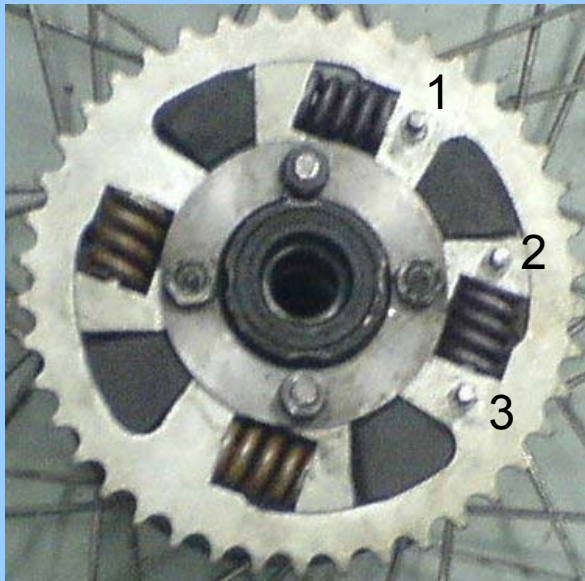
No Load
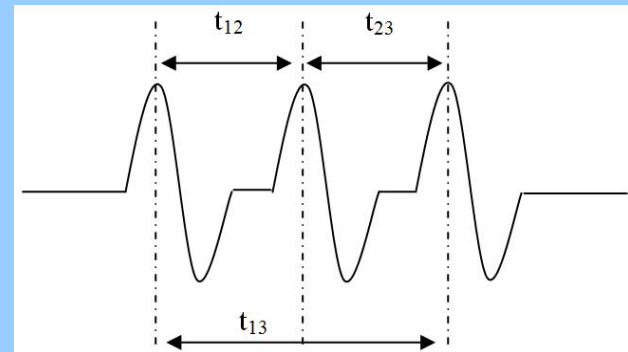
Loaded

Motored Dynamometers

A dynamometer which also has the ability to drive the test engine is called a "Motored dynamometer". This is useful for measuring the friction of an engine. Generally the dynamometer spins the engine (which is not firing) and the torque on the motor is measured.
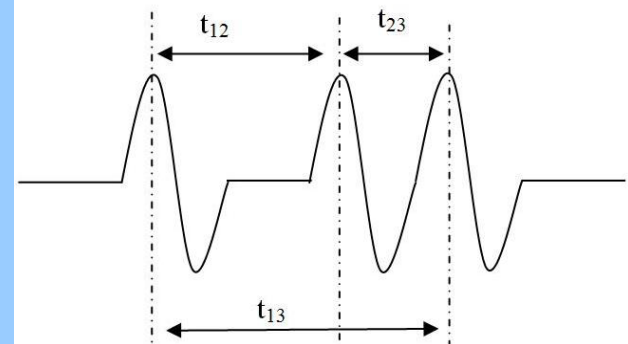
The motor may be integrated with the load device, such as a motor/generator combination which can operate in either absorbing (ie. like a normal dyno) or driving mode (ie. a frictional dyno).

Separate "frictional" dynamometers exist which are solely for the purpose of measuring the frictional load of test engines. These are usually similar to the generator type dynamometers but with a large electric motor instead of a generator.

Motored Dynamometers

This is a 3-Phase electrical motor suspended on bearings, and connected to a load cell. It is used to measure the friction of various engines and components as a function of velocity as well as operating conditions of the components.

Load Cell

Output Shaft

Motor

Comparison of Dyno Designs

Frictional (Break)[*]

Oldest design. Hard to control. Wear on frictional surfaces is a problem.

Hydraulic

Highest power in smallest package (pump).

Generator*

Inexpensive and easy to control. Fairly large for a given power.

Eddy current*

Easiest to control. Low Inertia and bearing losses.

Fan*

Very inexpensive. Needs careful calibration. Less accurate.

Vehicular*

Requires measurement of vehicle mass. Ignores air drag. Good for vehicular studies.

* Indicates that we use this type of Dynamometer in our lab here at USM

Mechanical Details

Engine Dynamometer

Couples directly to the engine

No gearbox or transmission

Engine speed = Dyno speed
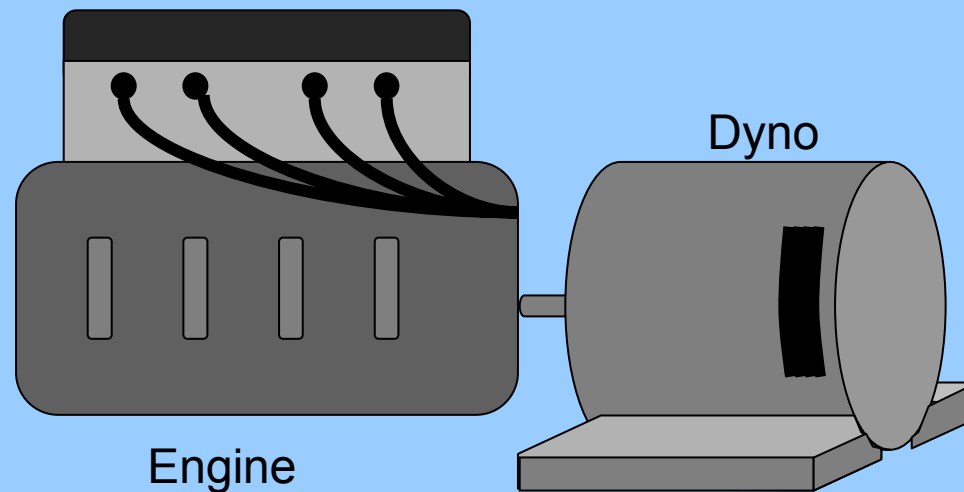
Dyno

Engine

Mechanical Details

A Dynamometer may also be coupled to the output of a transmission or gear box.

Speed and Torque of the engine and dyno are different by the gear ratio (Speed ↓, Torque ↑).

Engine

Transmission
(gear box)
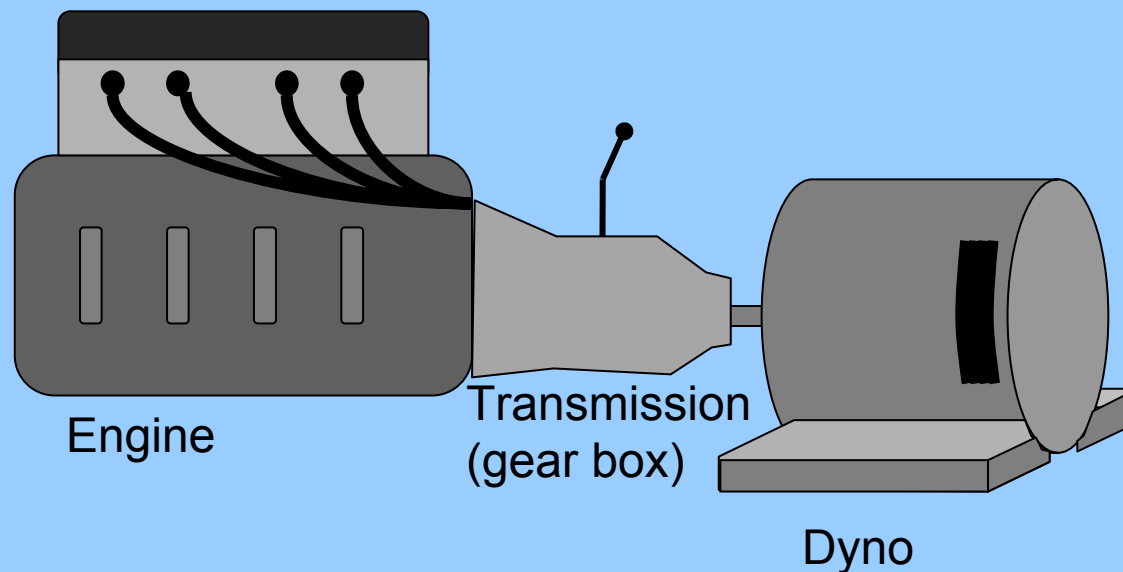
Dyno

Mechanical Details

A Chassis Dyno is driven from the vehicles wheels. The vehicle is mounted so the drive wheels are on a large roller, and locked down so it can not move. The dyno is connected to the roller, either directly or through a transmission of its own.

Driven Wheel

Roller
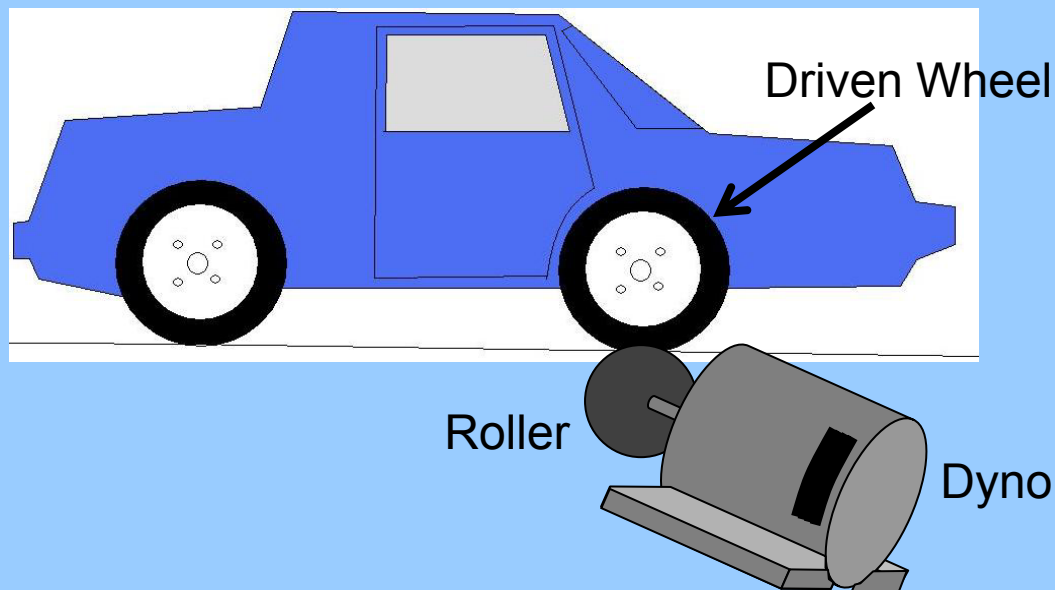
Dyno

Mechanical Details

Chassis dynos are used for testing of in-use vehicles with out requiring disassembly or modification of the vehicle.

Foto: Wikipedia

Mechanical Details: Coupling

A coupler is used to connect spinning shafts to compensate for misalignment.

U (Universal) Joints

"X" shaped bearing configurations at both ends of a shaft. Common on drive shafts of rear-wheel drive vehicles. The 2 ends should be "offset" somewhat to avoid wearing a flat on bearings.

These must be used in pairs (single joint velocity not constant)

Mechanical Details: Coupling

CV (Constant Velocity) Joints

Similar to U-joints but single joints have constant velocities. These are common components on front-wheel drive and 4-wheel drive vehicles.
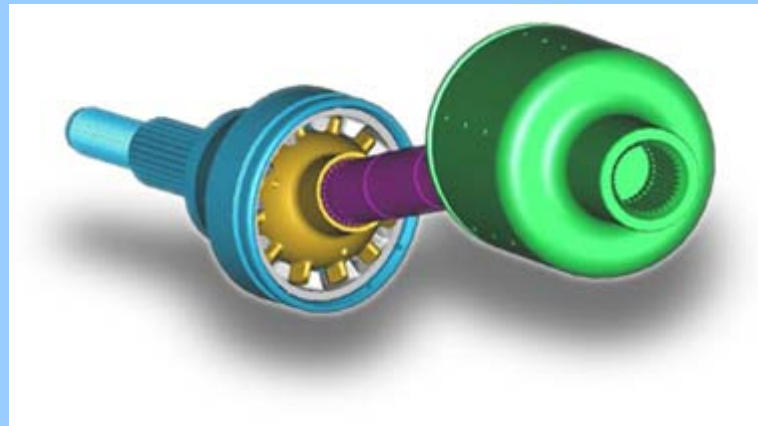
Foto: Torvec.com

Mechanical Details: Coupling

Sprocket

Simple "quick-connect" for existing sprocketed systems (like motorcycles)

Allows misalignment due to "slop" between fingers and sprocket teeth
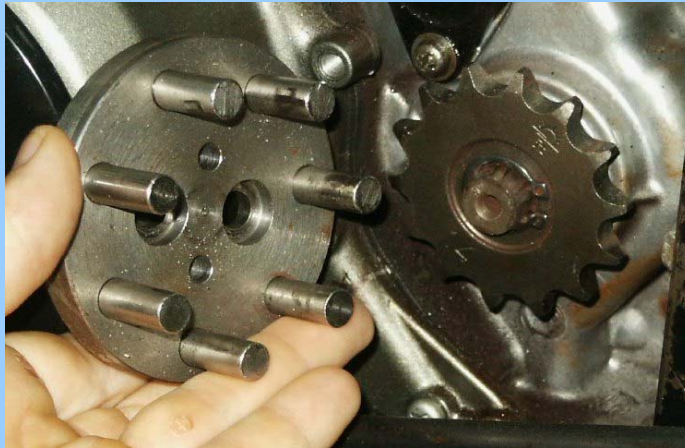
Mechanical Details: Coupling

Belt/Chain

Allows for misalignment and can incorporate a gearing ratio as well

We will use this between the chassis dyno roller and the dyno.
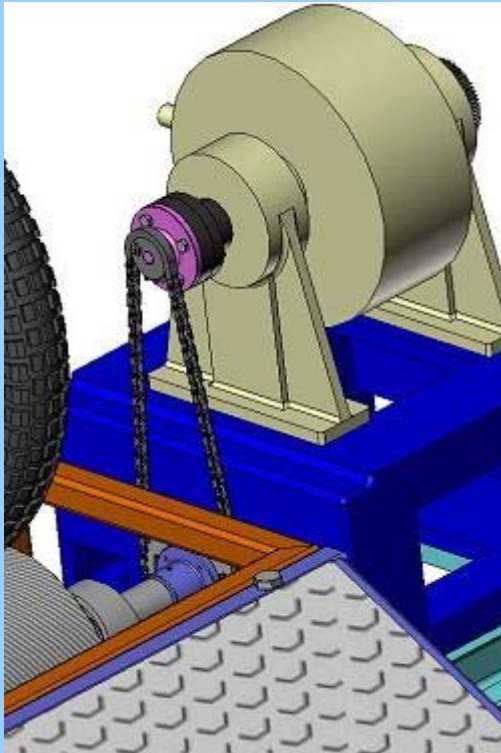
Mechanical Details

Bearings

The body of the dynamometer must be free to rotate, so it is supported on bearings.

Bearings suspending
Generator Housing

Mechanical Details

Load Cell Mounting

The rotation of the dynamometer housing is resisted by a load cell which measures the force. The Load cell should be loaded in only one direction (ie. axially) to avoid biasing the output. Generally the load cell is mounted so the force is perpendicular to the axis of the shaft.

Load Cell mounts via ball-joint ends
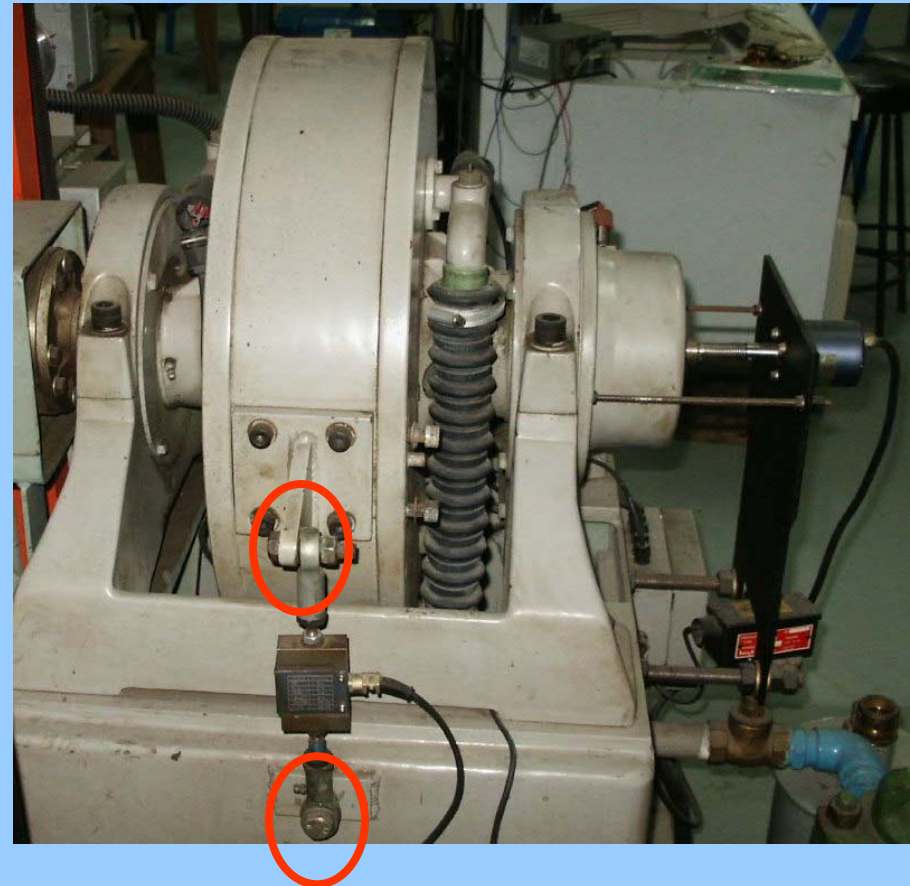
Equations

Torque = F x R

Power = T x w

w = RPM * 2 pi /60

Transmission:

$$T2 = T1 \times Ratio$$

$$w2 = w1 / Ratio$$

Spur gear losses (per stage) ~2%

Tire losses ~ 10%

Chassis or Vehicular Dyno typically reads 15-25% less than engine dyno due to transmission losses.

Dynamometer Test Schematic

Operator Lights

Display

Controller

The controller tries to maintain the dynamometer at the proper speed, while the operator maintains the proper torque, and the Technician runs the data recording devices.

Fuel Meter

Technician

Throttle

Load Cell

Coil Power

Coil

Speed

Dynamometer

Pump

Engine

Cycle Operator

Coolant Reservoir
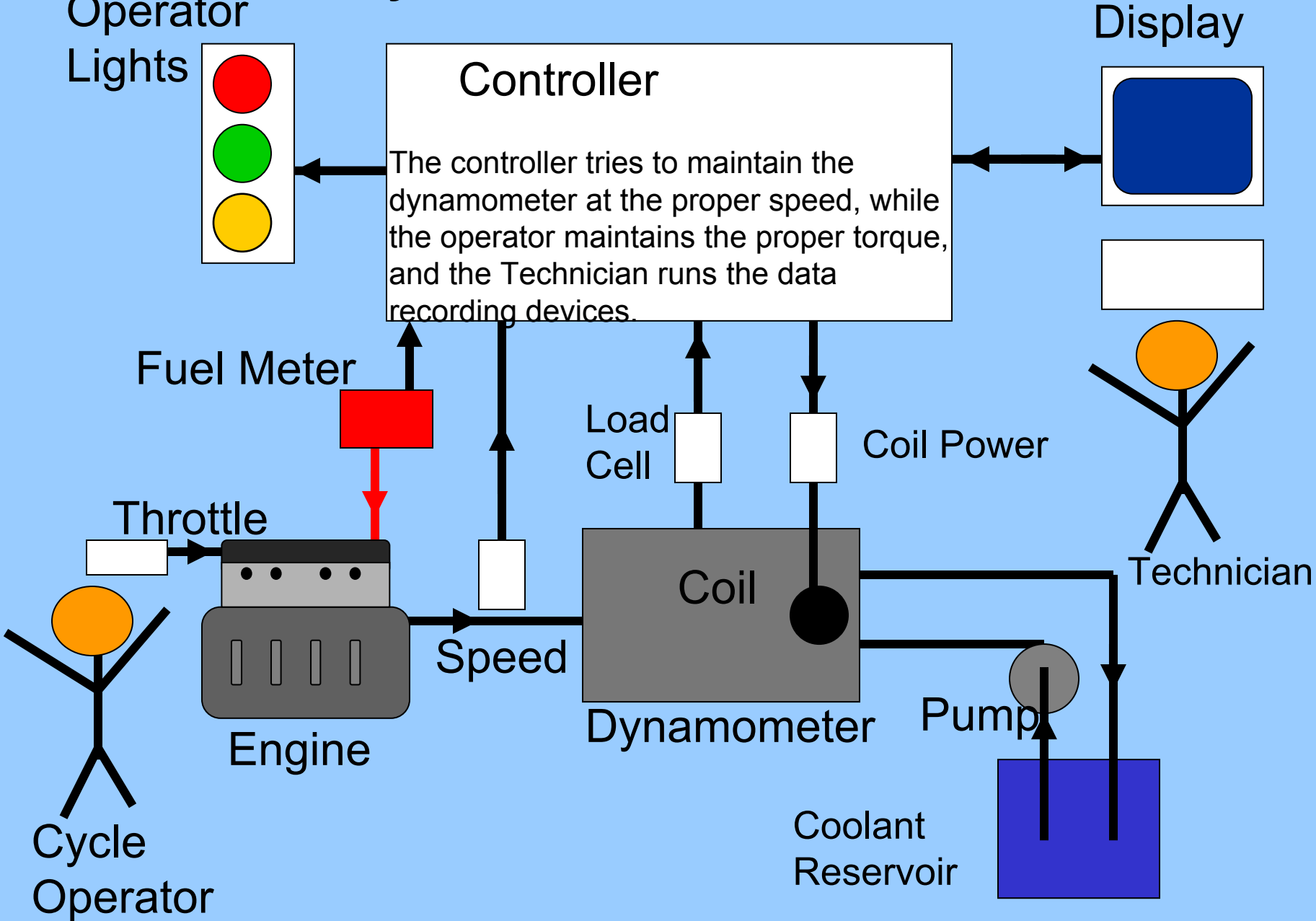
DEMO: Magtrol Dynamometer

In this demo we will demonstrate the measurement of speed and torque, unit conversion and calculation of power.

Part 2: Testing
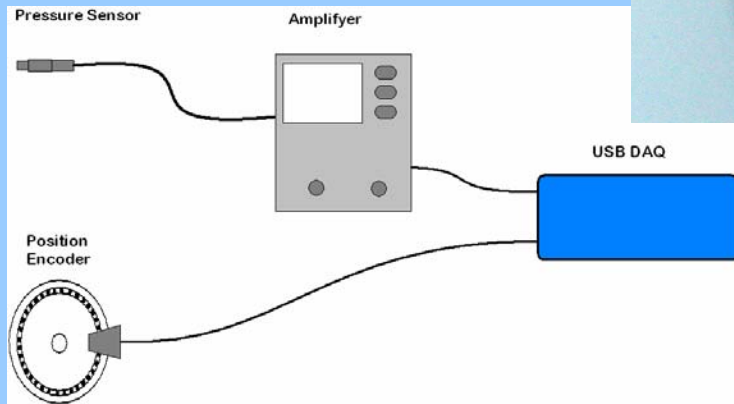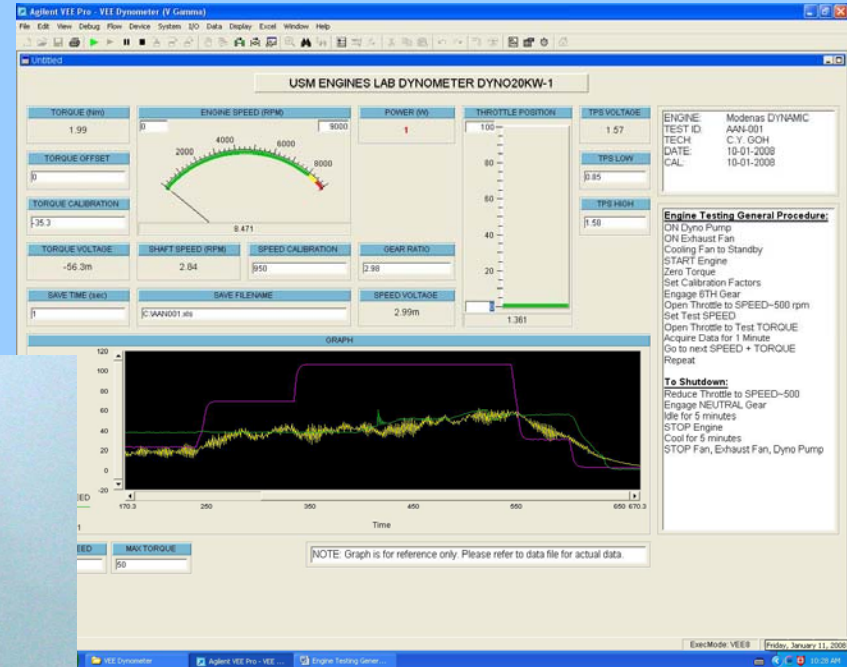
Testing

Commonly Measured Parameters
Torque
Speed
Fuel Consumption
Emissions
Temperatures (Head, Exhaust, coolant)

Occasionally Measured Parameters
Combustion Pressure
Ignition Timing
Dynamics (accelerations, vibrations, stress)
Knock
Intake/Exhaust Pressures
Valve Lift
Acoustics

These parameters can be measured manually or automatically.
We will be focusing exclusively on automatic (computer assisted)
measurements.

Cycle Averaging Data

Typically averaged: Speed, load, throttle, Temps

Some parameters are averaged over several cycles.

Often the signals are "low pass filtered" to remove higher frequency fluctuations.

For example Torque is negative during the compression stroke, and positive during the power stroke. What we're interested in is the *average* torque output of the engine.

This can be done electronically or in code in a data acquisition system.

Electronic Averaging

Electronic averaging (low pass filter):
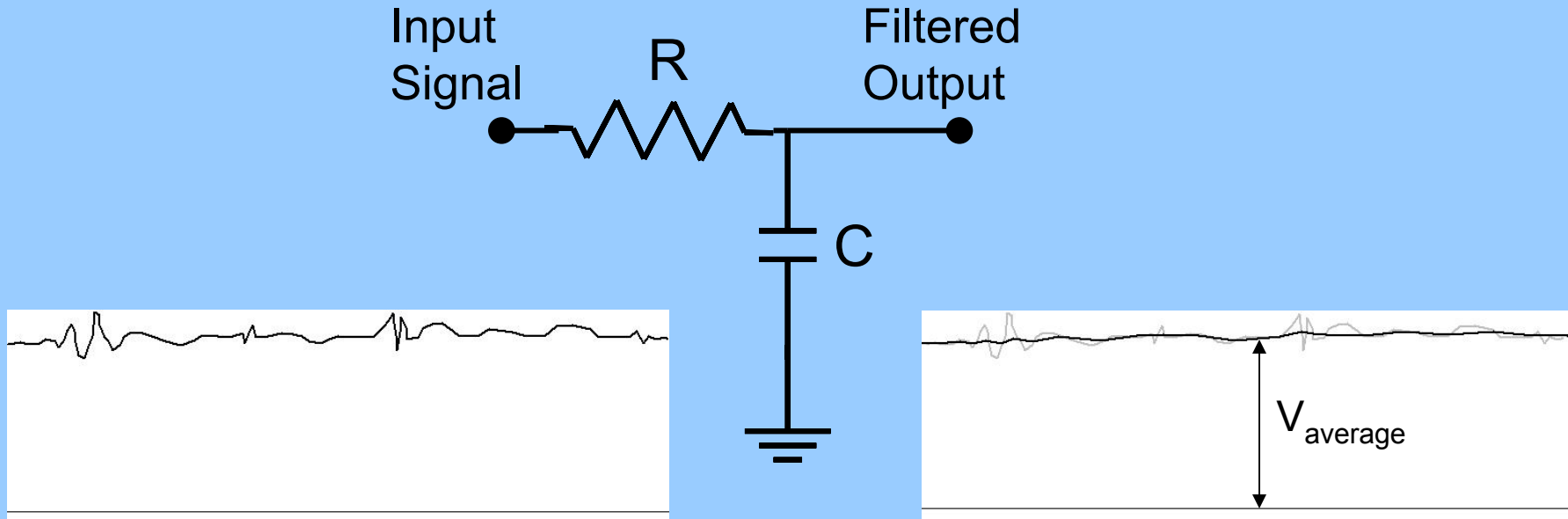
The time constant is 1/RC. For a 6000 rpm signal (100 Hz) we would want to low pass at <10 Hz, so $10 < RC \times 2\pi$, or $RC \sim 1$: R = 10,000 ohm, C = 100 µf

Exponential Averaging Code

Code for an exponential average (60-40 weighting):

Torque = 0.6 * Current_Torque + 0.4 * Previous_Torque

Code segment for exponential averaging in Vee:
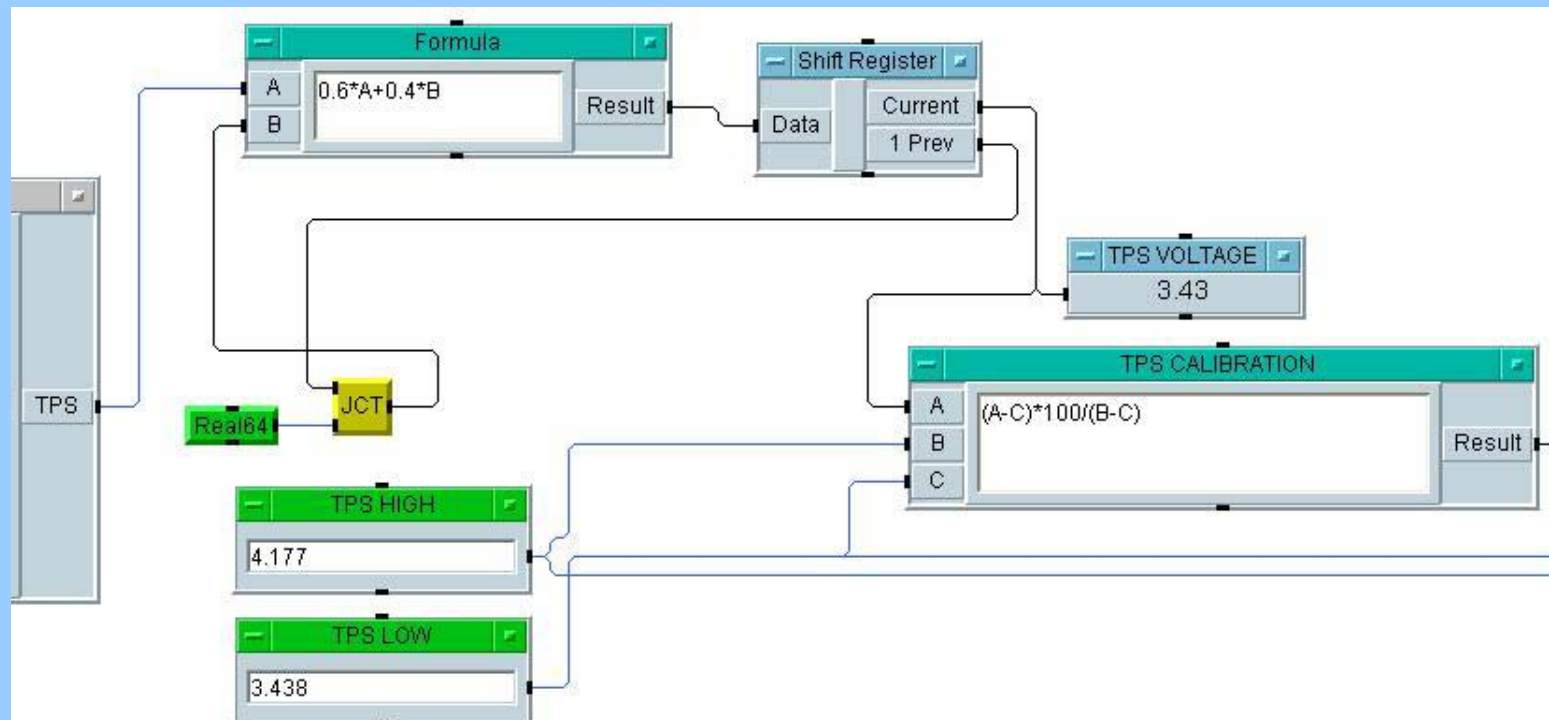
Speed Measurement

Typically comes from an inductive (variable reluctance) sensor reading a number (**n**) of teeth of a rotating gear (directly connected to the dyno's shaft) as they pass.

Sinusoidal output is measured for period. Period is then inverted for frequency, and converted to rpm. 60-tooth gears are common as the frequency (in Hz) is equal to the rpm:

Speed Pickup Signal
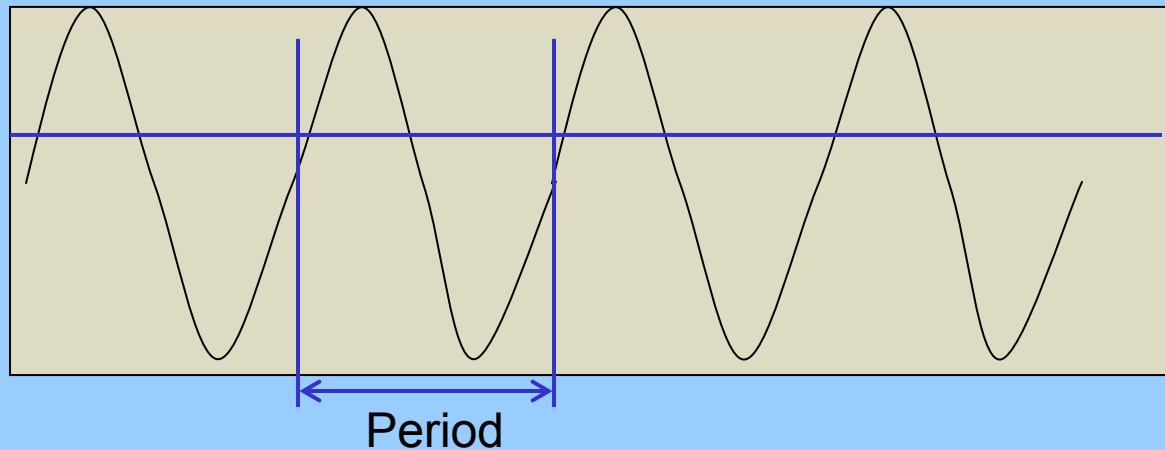
Period

RPM = 60 / (n x Period)

If n = 60:

RPM = 1 / Period

Speed Measurement Demo

Typical Results
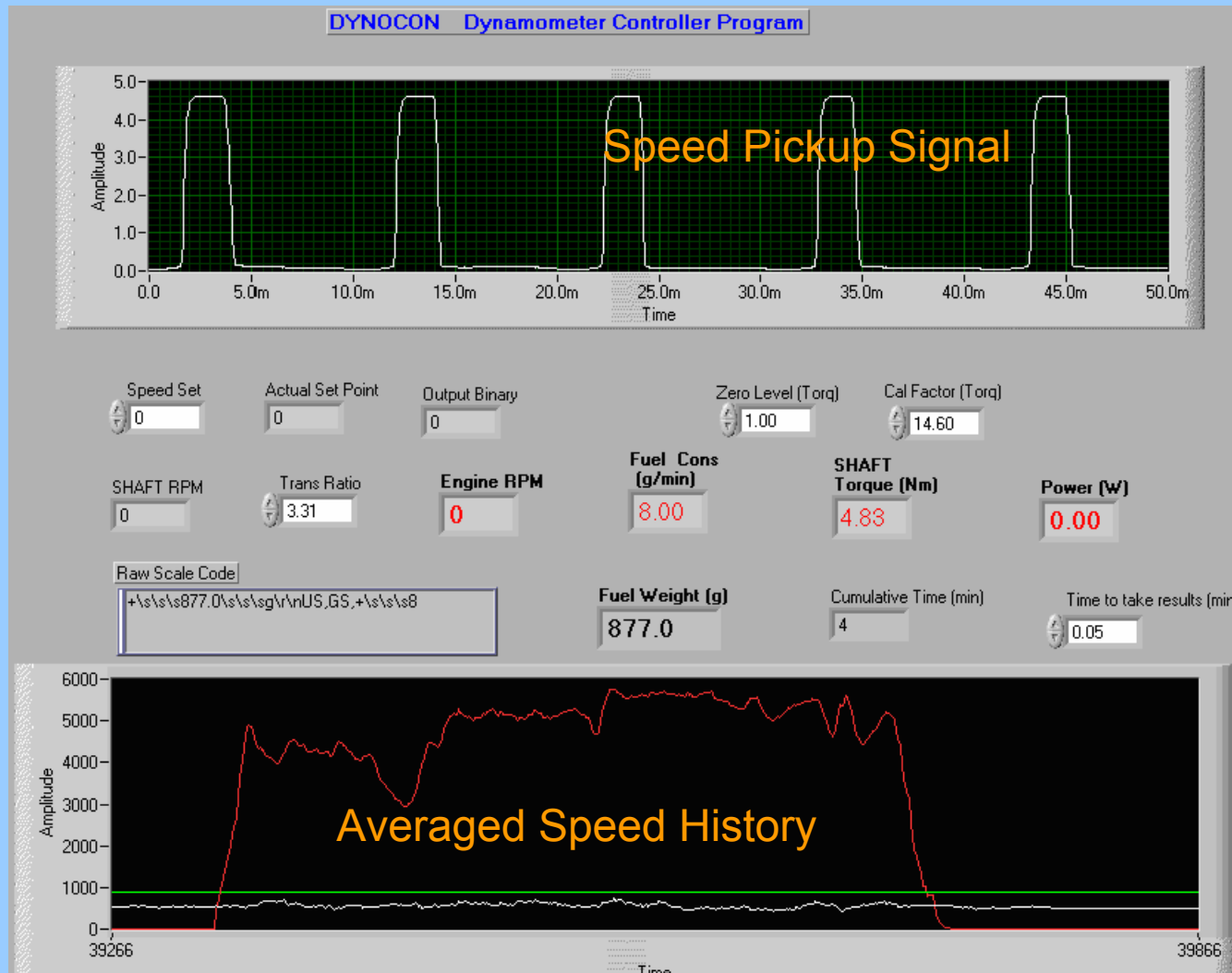
Throttle Position Measurement

Measurement of the throttle position usually comes from a throttle mounted potentiometer (variable resistor) which is connected between 5V and ground. This gives a Throttle Position Signal (TPS) as a voltage directly proportional to the throttle position.

Throttle Cable

Potentiometer

$+$ 5V

V_{TPS}
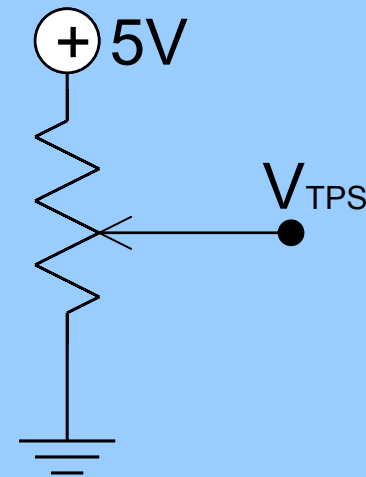
Torque Measurement

Torque is almost always measured with a strain gage instrumented "load cell" or force transducer. This is a mechanical member which undergoes significant strain with an applied force. Semiconductor or wire foil strain gages on the surface are stretched or compressed, changing their resistance. Often several gages are oriented in a "whetstone bridge" giving greater sensitivity and reduced susceptibility to temperature variation effects. Excitation voltage of bridge is usually 5V to 10V.

Load cells almost always require a specific amplifier which can be adjusted to "zero" the load, and adjust the "span" (calibration factor).

$+$ 10V

R_E R_C

ΔV

R_C R_E 2 gages are placed in compression (R_c) and 2 are in tension (R_e)
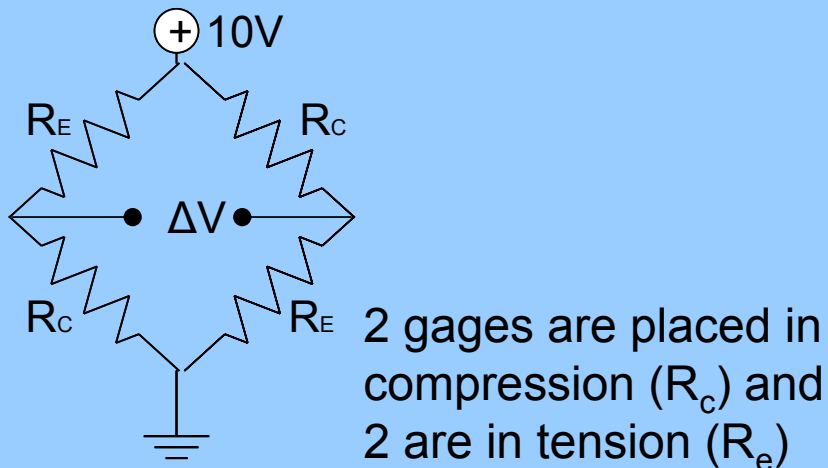
Load Cell

Emissions Measurements

The most common tool is a 5-gas analyzer measuring CO, HC, CO2 with a non-dispersive Inferred sensor. There is a separate sensor for O2 and NOx. These units are fairly inexpensive (<30k RM) and reasonably accurate.

For other Diesel applications separate SOx sensors are available, as well as "smoke" analyzers. The common Smoke analyzers are based on exhaust gas opacity.

For further identification of exhaust components FTIR (Fourier Transform Inferred Spectroscopy) is common. Gas Chromatography (GC) is another useful device useful for identifying various exhaust components.

Most measurements are taken directly from the exhaust tract. Water is usually condensed out, yielding "dry" exhaust gas numbers (ie. Excluding water from the exhaust gasses).

Occasionally exhaust gas samples are bagged for "off line" analysis.

Fuel Consumption

Fuel consumption is usually measured gravimetrically. The engine is operated at a constant speed and load for 1 to 10 minutes. Fuel weight is measured once (**Wt1**), and re-measured again (**Wt2**) after a time **t**. Fuel consumption is then calculated by:

FC = (Wt1 – Wt2) / t

Typical units are grams per second or grams per minute. This value is an average fuel consumption for the duration **t**.

Inexpensive and accurate digital scales can often be interfaced to computerized data acquisition systems via a serial port connection, allowing automated measurements to be made easily. It may alternatively be measured volumetrically.

Fuel Consumption

For comparison purposes it is common to calculate the **Break Specific Fuel Consumption** (BSFC). This is the Fuel consumption divided by the power output during the FC measurement:

BSFC = FC / Break Power

Typical Units are gm/kWh (grams of fuel per kilo-Watt hour)

BSFC obviously depends on your operating speed and torque. BSFC is used to compare the relative efficiencies of different engines or engine designs. Lower BSFC means better Efficiency.

Typical best automotive BSFC ~ 300 gm/kWh

Good Diesel DI BSFC ~ 200 gm/kWh

Carbureted Two-stroke BSFC ~ 400 gm/kWh

Temperature Measurements

Thermocouples are fairly linear, compact and have a wide temperature range, so they typically are the sensor of choice for temperature measurements in engines.

Unfortunately their output is very small (mV) so they require a special amplifier.

Some data acquisition units have special front ends and can read Thermocouples directly.

Crank Angle Resolved Data

Some parameters are measured as a function of crank position. These are "high speed" parameters that are a function of crank position.
Such parameters include:

      Ignition Timing
      Combustion Pressure
      Knock
      Valve Lift

Although Engine Speed is generally measured as a cycle-averaged value the engine speed does change significantly over each cycle. During the compression stroke it slows, and then speeds up again during the exhaust stroke.

To compensate for this data must be synchronized to crank-shaft position. This is generally done by reading a shaft encoder connected directly to the crank shaft.

Shaft Position Encoders

"Missing tooth" encoders (60 – 2)

"60 – 2" wheels with 58 teeth on 1/60th rev spacing's

Missing teeth indicate Index (eg. TDC)

Index

Index + Timing channel

256, 512, or 1024 pulse per revolution timing channels plus
a separate index pulse (set for TDC or BDC) used to synchronize

Absolute position Encoder

Typically 8, 9 or 10 bits are used.
Usually encoded as "grey code"
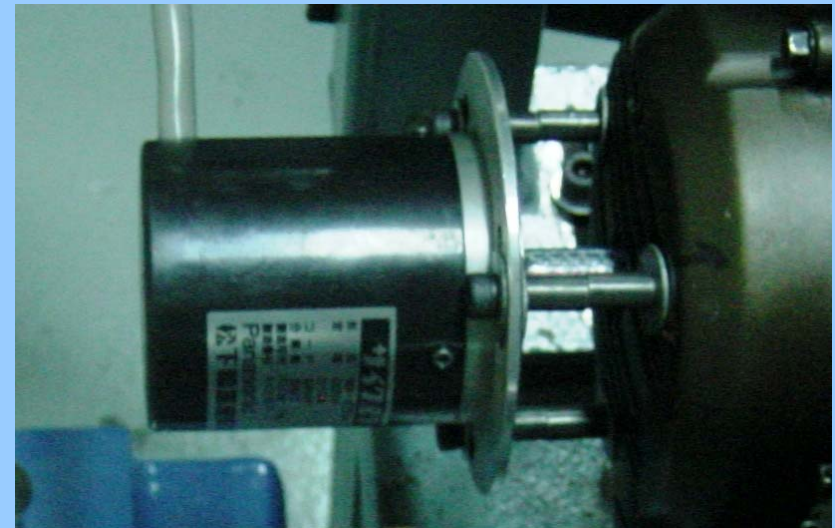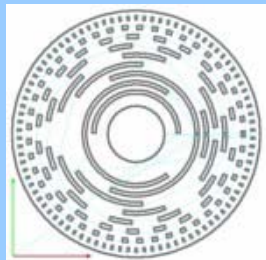
Crank Angle Resolved Data

Individual data points can be read triggered by the encoder channel, or data from several channels can be streamed in along with the encoder channel, and resynchronized to crank position:
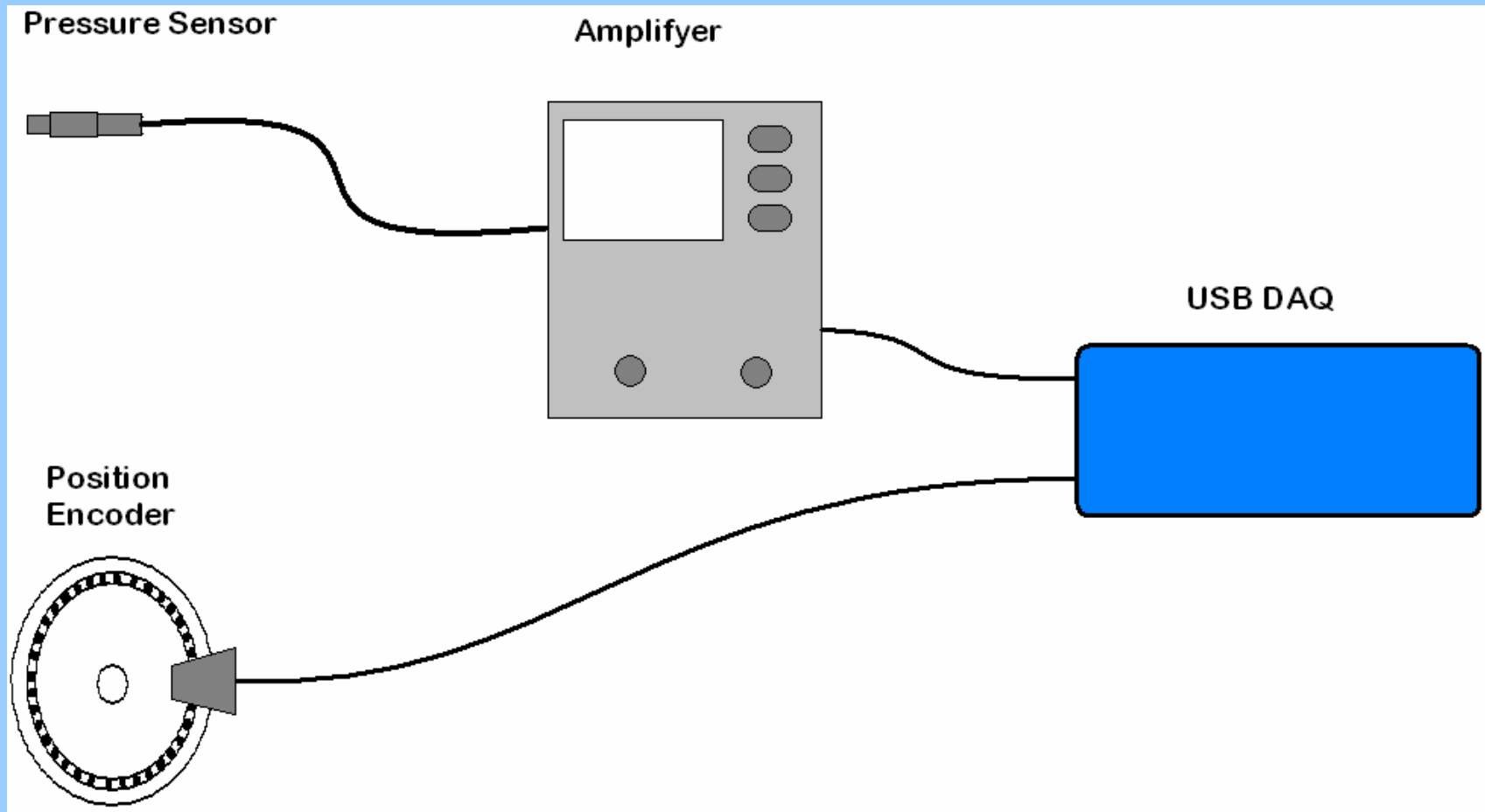
Crank Angle Resolved Data

At each LSB transition (ie. timing signal) the pressure is read into an array.
The array index is set to zero (TDC) at the MSB (Index) transition.

Re-Indexing Pressure Data from Time base to Crank Shaft Angle
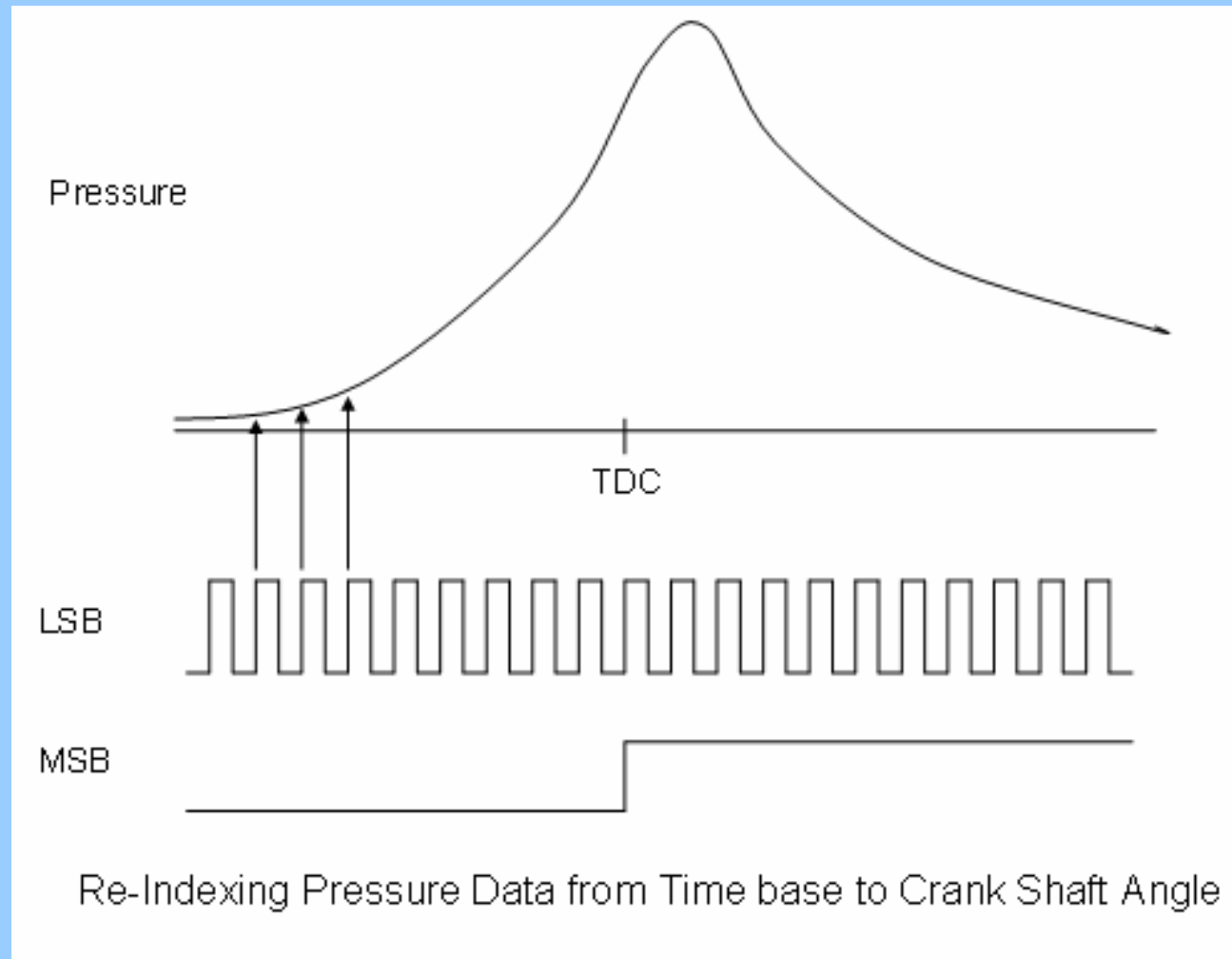
Crank Angle Resolved Data

Here is a sample of VEE code for re-synchronizing the data to a timing channel (LSB) starting from a known position of the index channel (LSB):
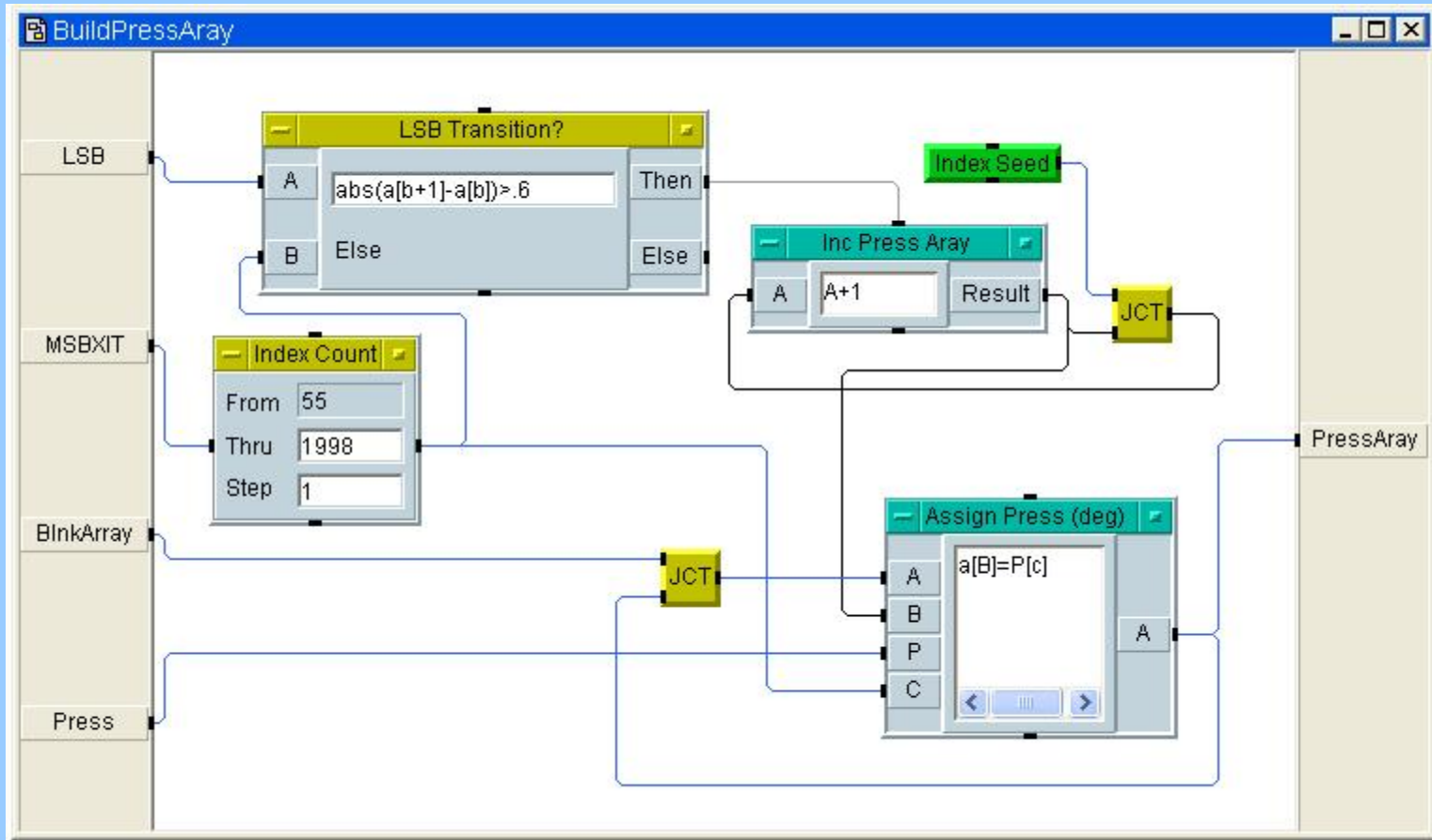
Pressure Sensors

Cylinder Pressure

Requires a special Piezo-Electric transducer and amplifier. These expensive units must be precision-mounted to combustion chamber. Various designs are available including very small (~4mm) sensors and some with integrated water cooling.

Kistler Pressure Sensor
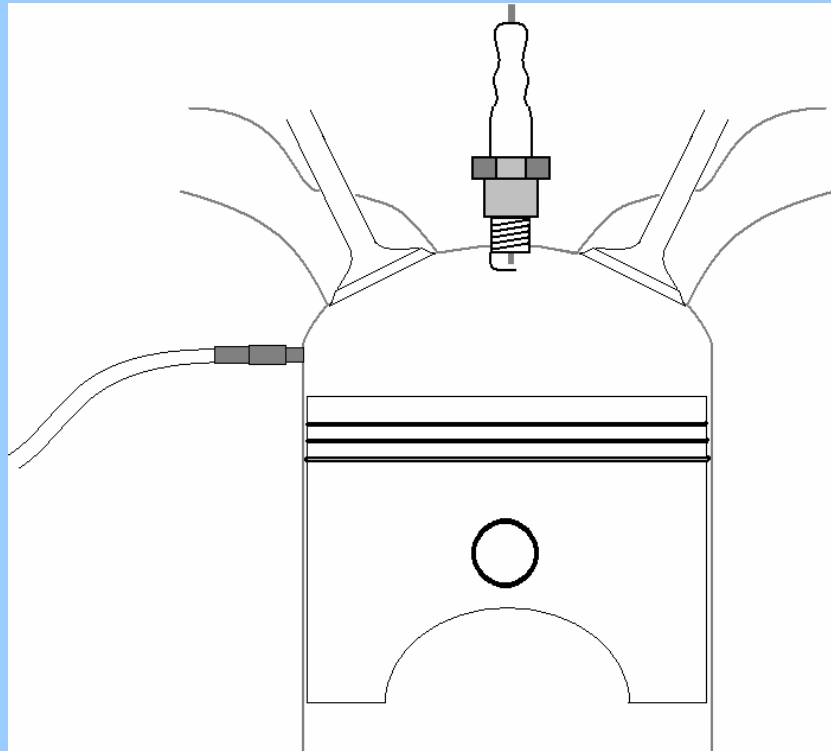
Pressure Sensor Mounting

Pressure Sensors

For intake and exhaust pressure low-cost MEMS devices are widely available which can measure fractions of a bar to tens of bar.
Both differential and absolute pressure sensors are common.

These are inexpensive and easy to wire up and use.

MEMS Atmospheric
Pressure Sensor

Pressure Data

Combustion Analysis can highlight problems with ignition stability, timing, air/fuel mixing… Addition of exhaust and intake pressure sensors can give details of the gas exchange process including backwash and back pressure.

Notice the irregularity of the peak pressure.
This indicates an ignition stability problem caused, in this case, by retarded timing.
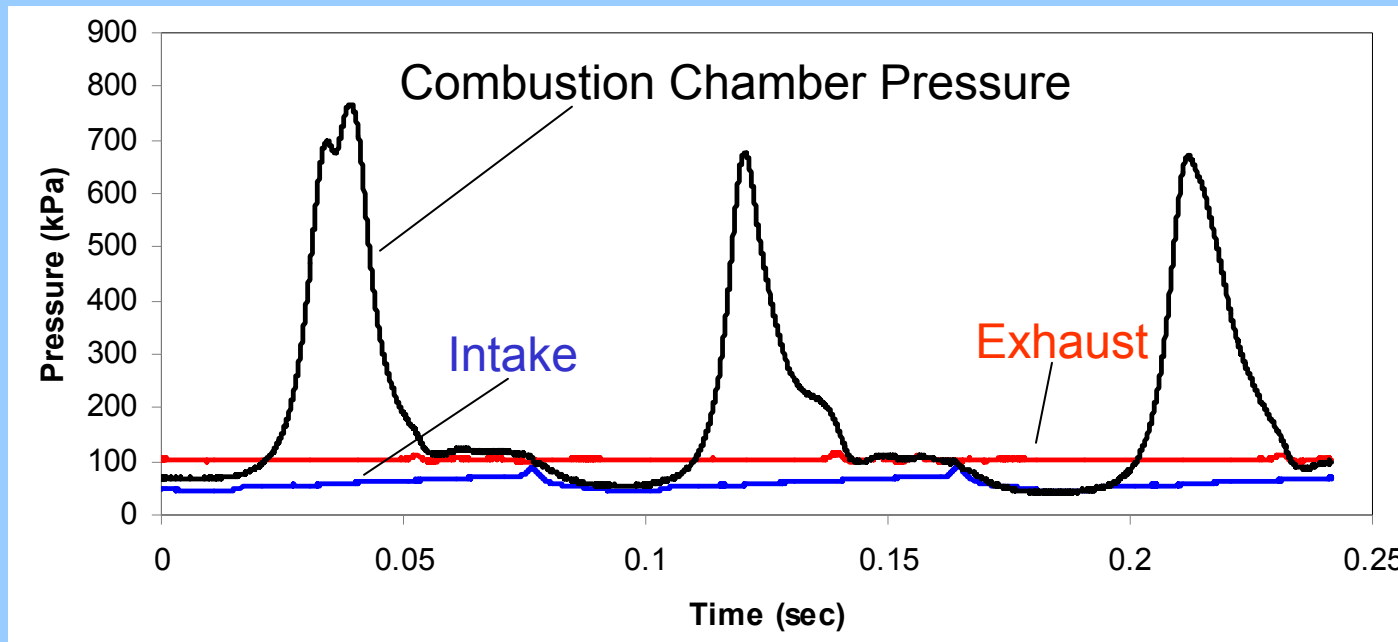
Pressure Data

Here we can see how the combustion chamber and exhaust pressure "ring" after blow down (Exhaust Valve Open). There is a spike in the intake pressure during valve overlap when Exhaust pressure washes back into intake.
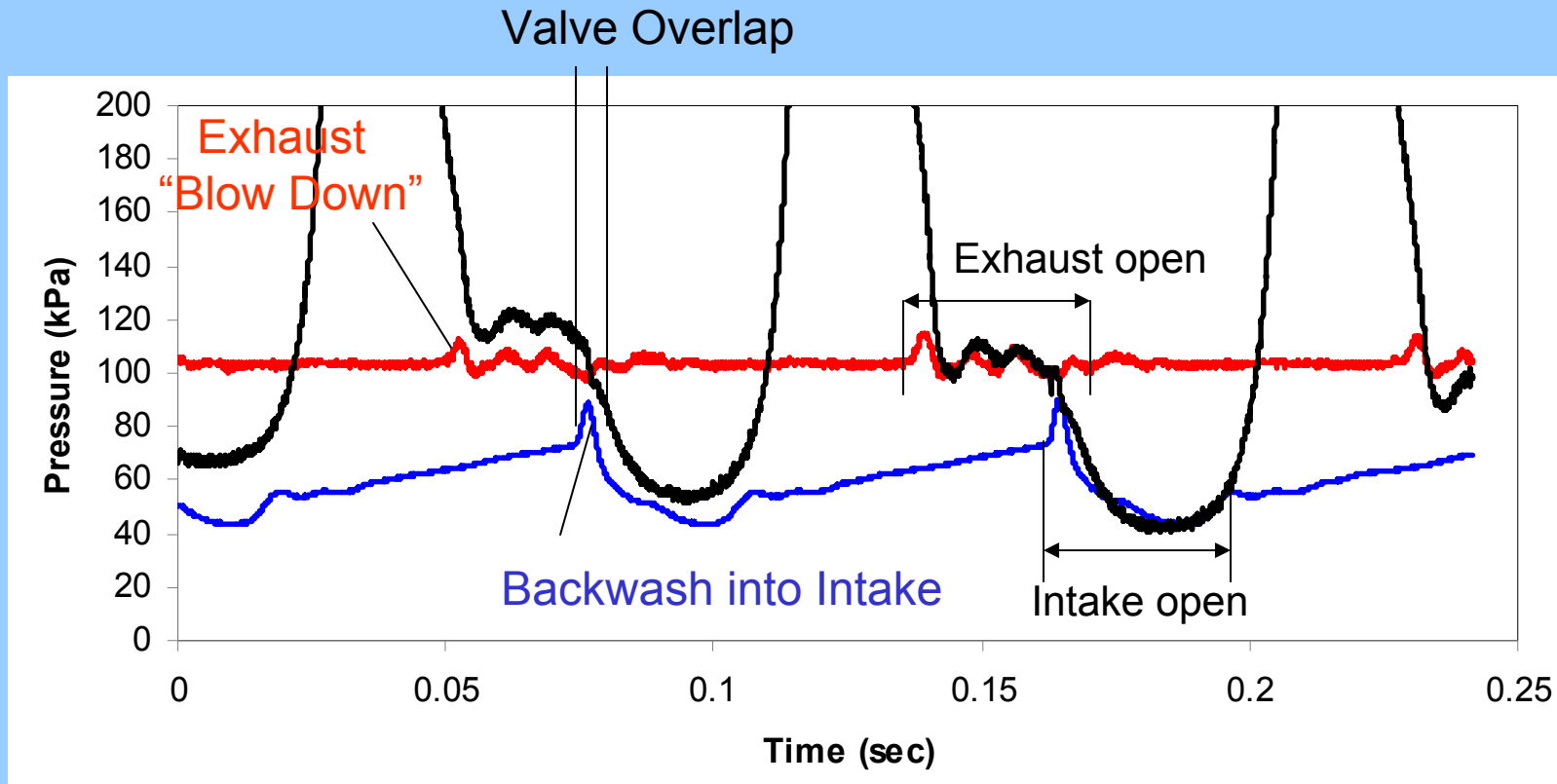
Steady State Testing

Constant speed, load, throttle

Time required for accurate measurement of:

      Fuel Consumption

      Emissions

Usually 1+ minute per point.

Test Points – Several speed/load points weighted to simulate a given drive cycle (explained further below) eg.:

Point	RPM	Torque	Power	Weighting
1	1000	0	Idle	10%
2	2500	1.5	Low power	35%
3	3000	3	Cruising	50%
4	5000	6	High power	5%

This 4-point test is weighted to assume the vehicle is used mostly for cruising and low-power driving (85% of the time), idling 10% of the time, and accelerating hard only 5% of the time.

Steady State Testing

Dyno Throttling

Slowly changing the dyno load (dyno throttle) at constant Engine Throttle allows tracing out the Motor Torque curve.

A common test is to measure the "Wide Open Throttle" Power and Torque curve for an engine.

Engine Throttling

Slowly changing the engine throttle at constant Dyno Throttle allows tracing out the Dyno's torque curve

Torque Curve of a 4-stroke Motorcycle Engine
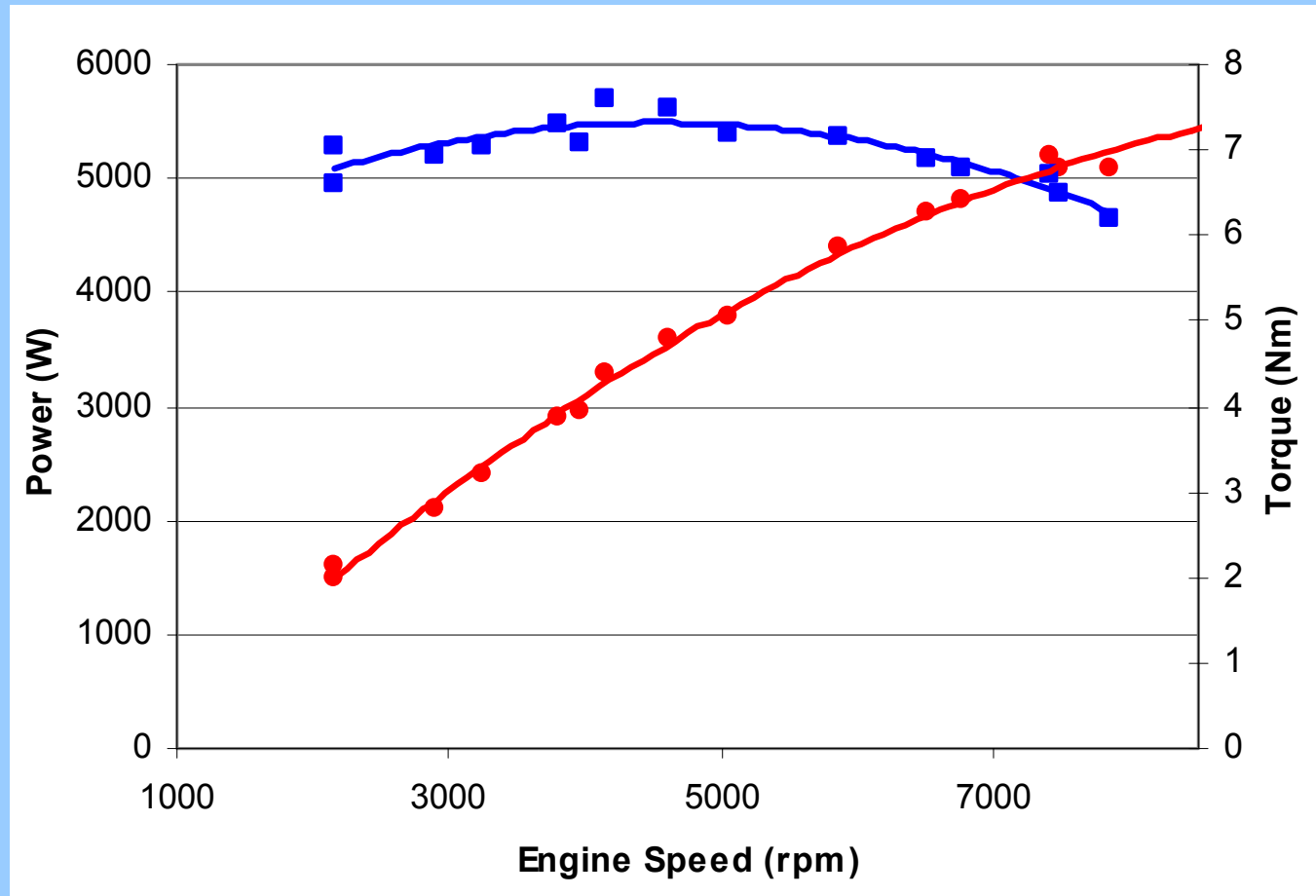
The motor's torque varies as a function of engine speed and throttle. Spark ignited engines usually have a peak torque at a medium-high speed, while Diesel engines have a relatively flat curve. Electric motors can have ascending, descending or flat torque curves.

Torque Curve Demo

We will now demonstrate the torque curves as a function of speed for a motor and the dynamometer on a small electric motor dynamometer demonstration unit.
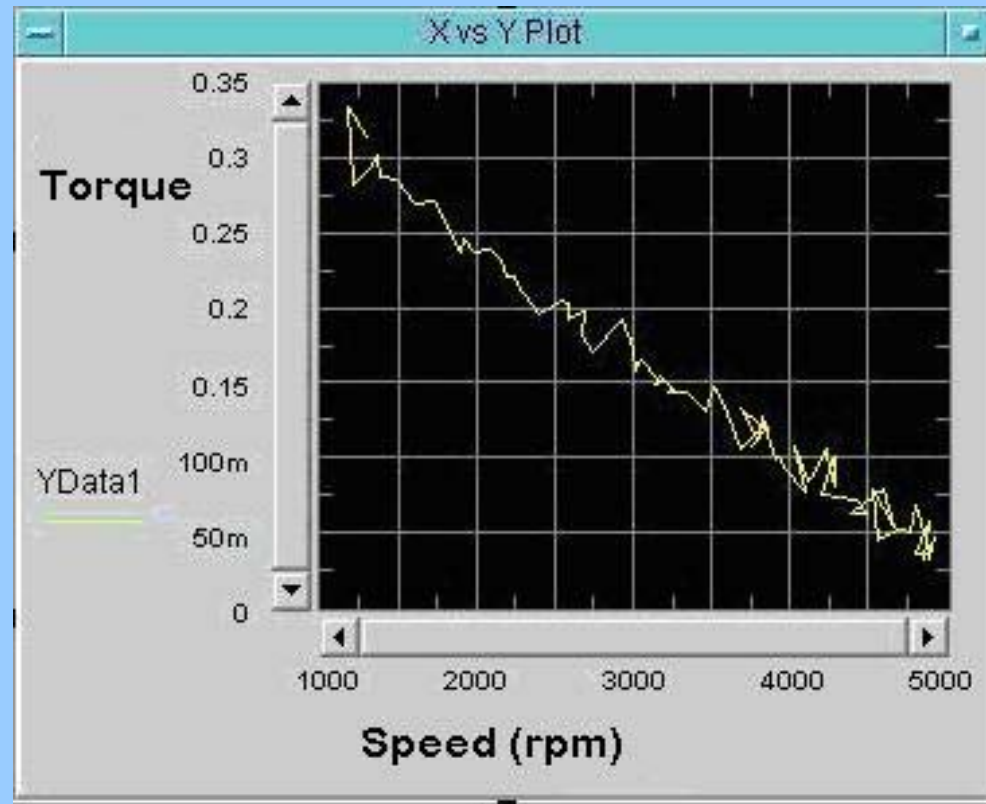
Dynamometer Controllers

The Controller controls the load (Dyno throttle). The set point can be electronically generated, or manually. They are usually set up to operate in 1 of 3 modes:

DIY Dyno Controller

20 kW Dyno Controller

Open Loop

This allows manual setting of load. It will vary as speed of the system varies.

Speed Control

The controller adjusts the load to maintain a constant speed.

Torque Control

The controller adjusts the load to maintain a constant torque.

Dynamometer Controllers

Speed Control Mode
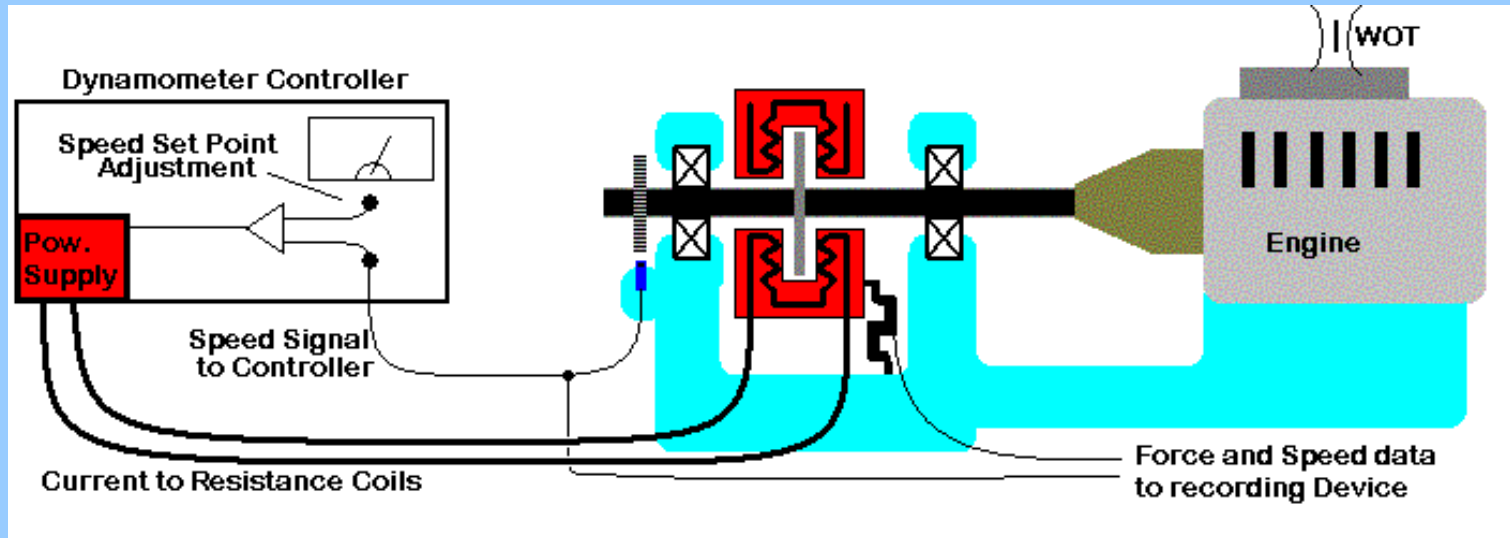
The Controller continuously measures the S**peed** and adjusts load to maintain speed at desired set point.

It is generally a full PID controller and must be tuned for the appropriate engine-dyno combination.
It can either be a stand-alone controller or integrated with the data acquisitions system.

Dynamometer Controllers

Torque Control Mode
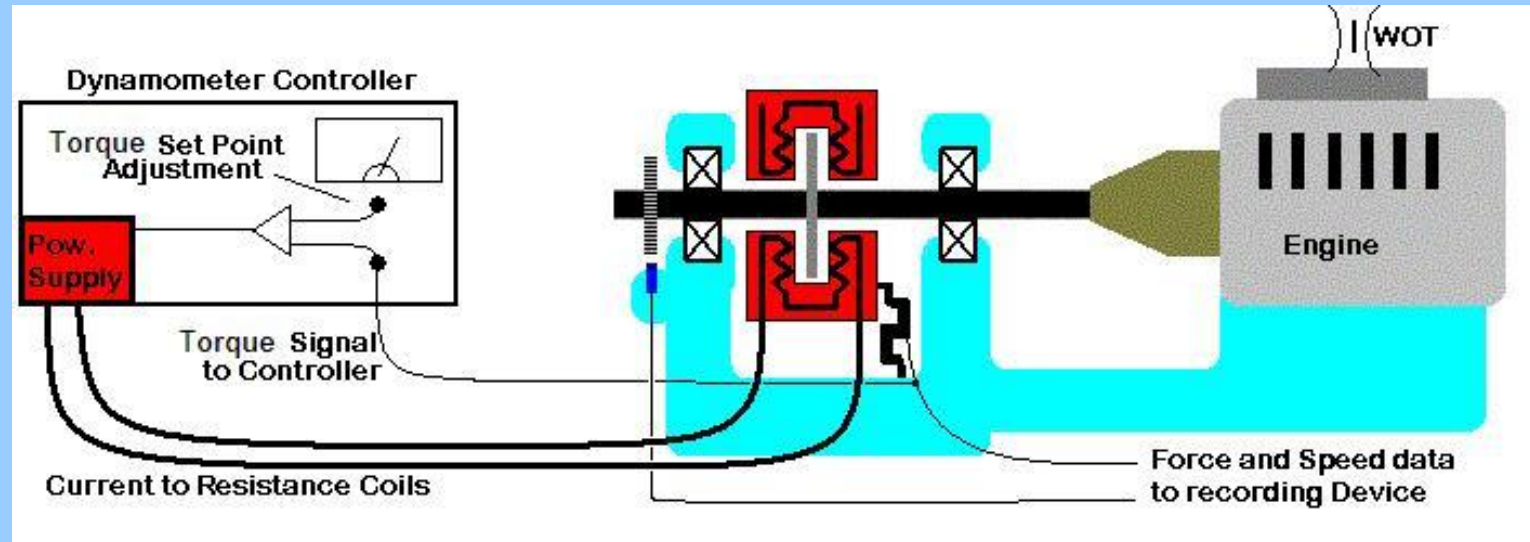
Same as the Speed mode, but now controller maintains constant Torque.

The Controller continuously measures the **Torque** and adjusts load to maintain Torque at desired set point.

Dynamometer Controllers

Various techniques are used in controllers depending on the system under test. Simple set-point control won't generally work due to inertia in the system as it leads to overshoot and instability.

Proportional Pulse Width Modulation of control signal is common with Generator and Eddy Current type dynos. Their Torque response is almost instantaneous, but again, inertial loads will cause dynamic problems.

The most common control schemes involve PID (Proportional, Integral, Differential) controllers. They must be tuned for appropriate response from the full system.

Hydraulics dynos respond slower as they have a mechanical valve that must opened or closed. Also as their torque curve is very non-linear, they are more difficult to control. PID controllers are still common, but some times Fuzzy Logic must be used.

Often Mathematical models of the system are useful in developing control systems.

Dynamometer Control: PWM

Pulse Width Modulation (PWM) is a common technique for controlling the load of a eddy current and generator type dynamometers. The control current going to the coils is pulsed on and off at a high frequency (typically 10 kHz to 300 kHz). In the "high" state the full current is applied to the coils, in the "low" state the coils are off. The resulting load is therefore proportional to the duty cycle of the pulses.

This allows for the use of an inexpensive digital controller running an efficient switching unit such as a transistor (BJT) , field effect transistor (FET) or IGBT.

Control Signal

Low Load — 5% — High / Low

Half Load — 50%

High Load — 95%
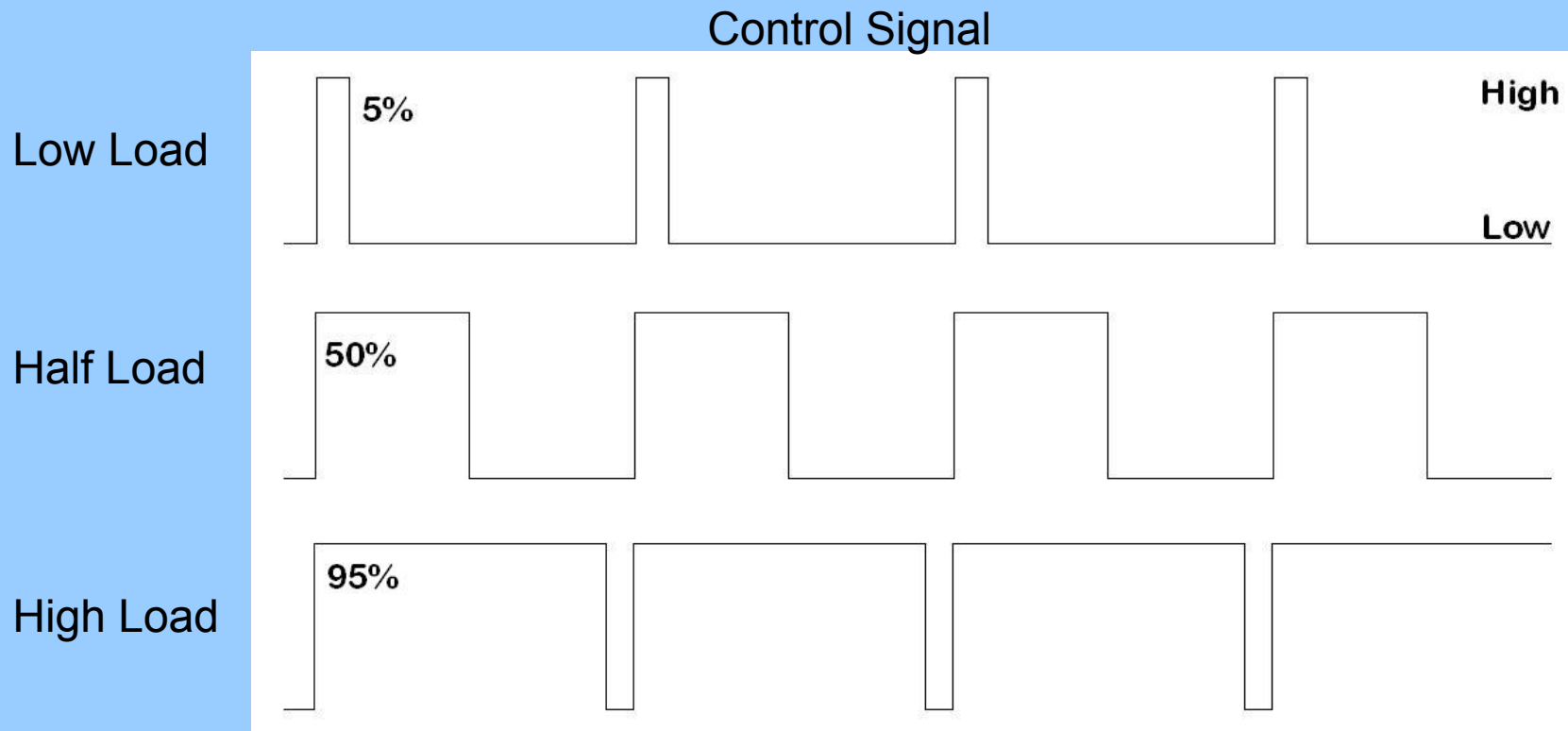
Transient Testing

Sometimes we want to measure various parameters during throttle transient, or engine acceleration-deceleration. This is important for investigation of:

      Air/fuel ratio changes due to fuel "hang up"

      Accelerator pump action / Transient enrichment

      Knock

      …

This is referred to as "***Transient Testing***" as the dyno is no longer being held to a single operating point.

For Transient Testing we need fractional cycle resolution in our data, so data acquisition must occur at 10kHz+.

Transient Testing

How can we perform transient testing on a dyno?
Two methods are common:

Inertia only
We add a large rotating mass to the dyno to simulate the effective "inertia" of the vehicle. This is easy to fabricate, as you just add inertia to dyno shaft, but less realistic.

Inertia + Load
Inertia may be added to improve system stability, but we also use a Computer controlling the dyno to simulate actual road load (Inertia, Rolling resistance, air drag) based on a model of load versus speed for the vehicle.

Dynamometer Controller Dynamics

Velocity of Dynamometer during controlled step with various differential gains
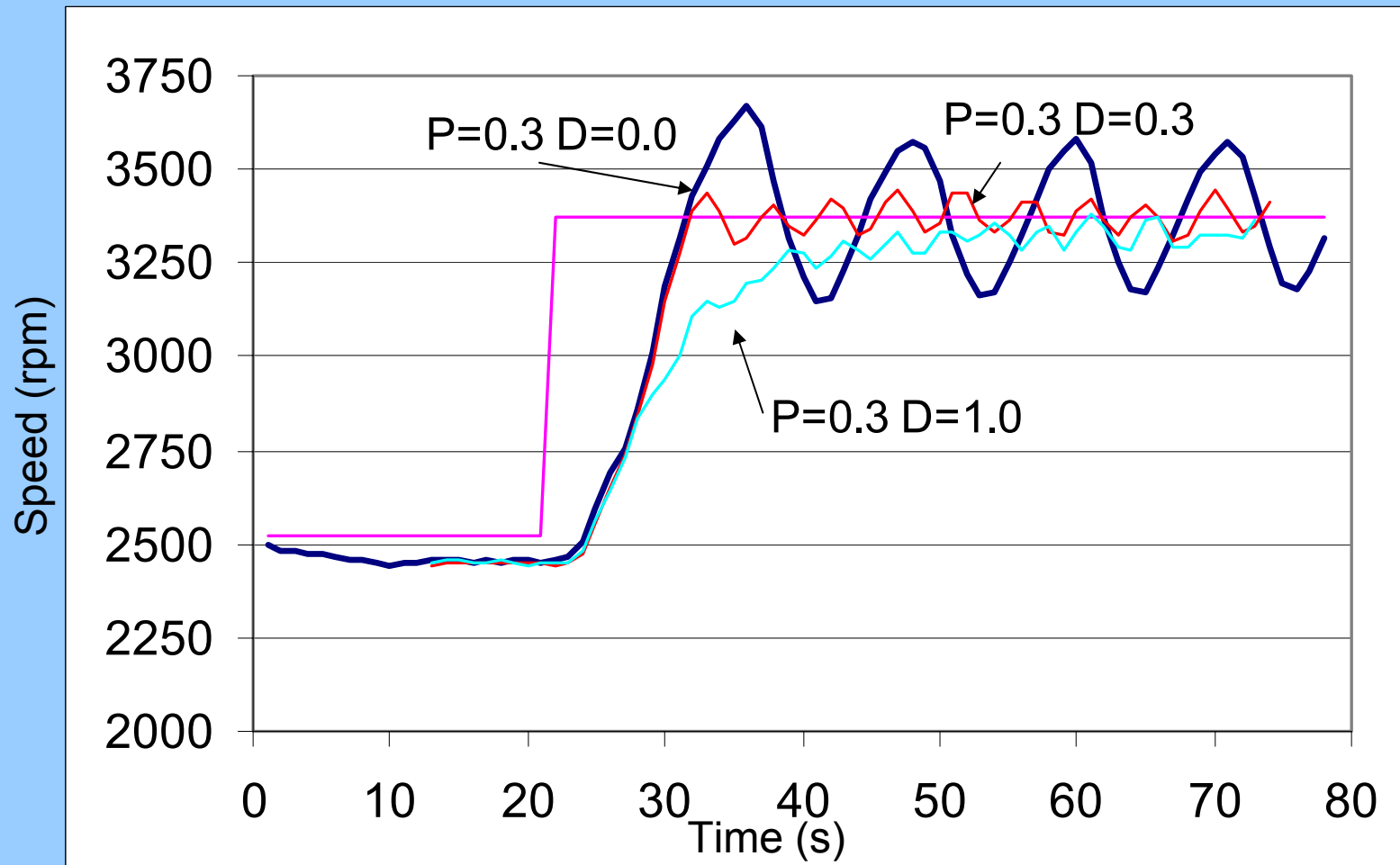
The controller needs differential control to avoid Overshoot but too much differential gain gives a long "settling" time. This hydraulic dynamometer has a large inertia and responds very slowly.

Dynamometer Controller

One final control method is "road load" simulation control. This requires a computer which has a "model" of the vehicle (weight, rolling resistance, aerodynamic resistance). As the vehicle speed is increased, the load is increased to simulate the actual load when driving on the road.

Chassis Dyno should hold engine to "max speed" at engine's peak power. This should be adjustable based on dyno settings (ie. should be able to stall out engine at lower speed by adding more load)
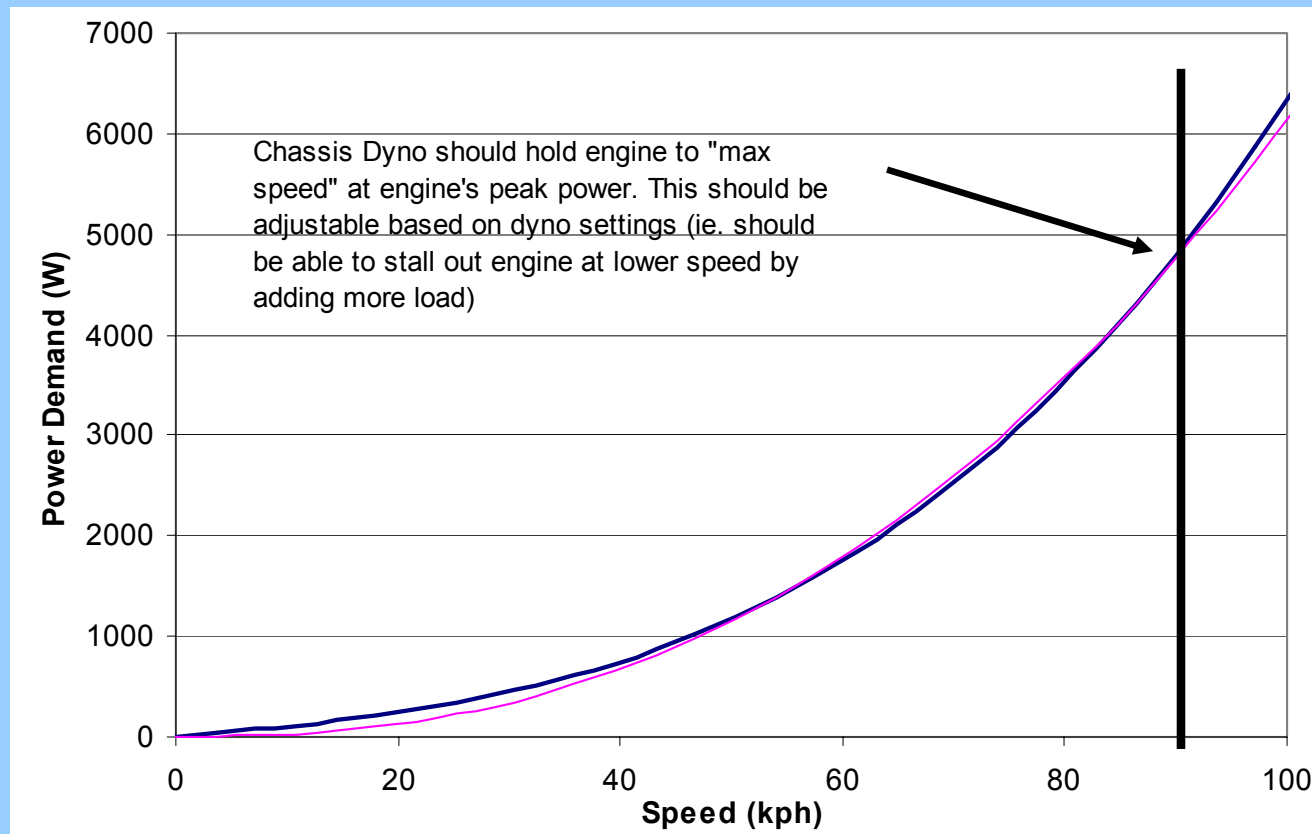
Modeled load vs. Speed for a typical small motorcycle and rider
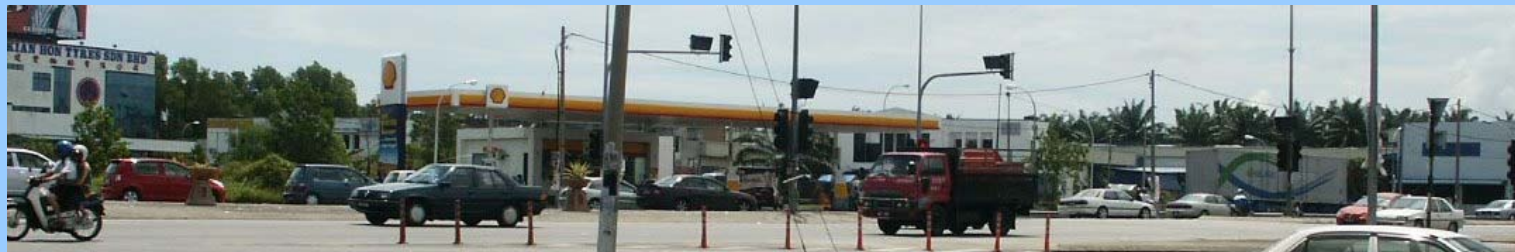
Drive Cycle Determination

What speeds and loads should we test at?
What speed and load does the engine normally experience when it is being used?

To determine this we must know *how* the vehicle will be used.
Will it be driven on the highway, or just around town?
Heavily loaded, or with a single passenger?

This information is collectively known as the ***Drive Cycle***.

An example of a drive cycle could be a "commuter" cycle from a suburb to a city center 30 km away, (ie. from Parit Buntar to George Town).

Typical drive cycles are:
Highway
City
Commuter (suburb to city center)
Country Side
Delivery Run

Drive Cycle Determination

It is common for regulatory agencies to specify drive cycles very carefully. For example the US Environmental Protection Agency (EPA) defines the Highway drive cycle as:
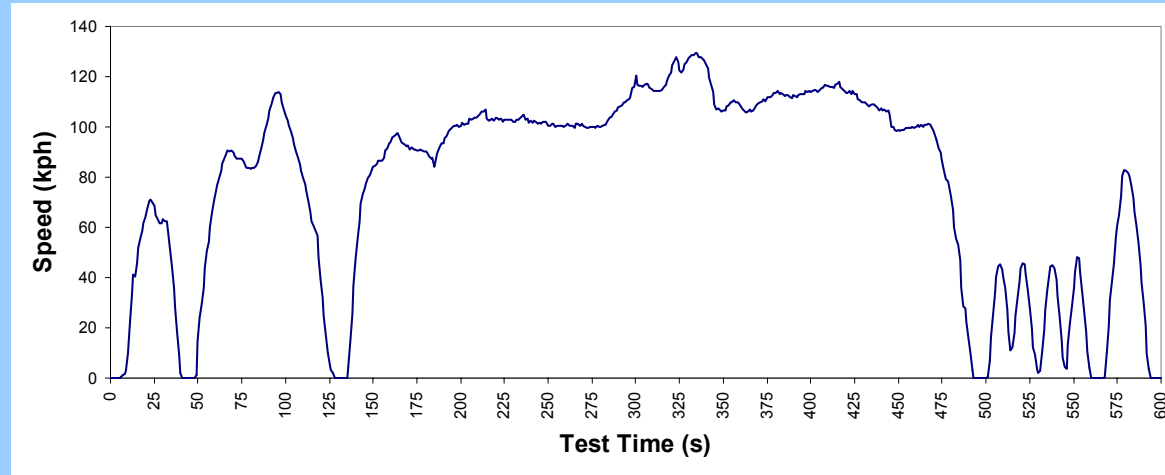
The older "Federal Test Procedure" was designed in the early 1970's and only updated in 2006. The newest drive cycle features peak speeds of 130 kph and cruising at 110 kph.

We need to ask our selves, do these US drive cycles really reflect how vehicles are used here? What about motorcycle and other "light" vehicles?

Drive Cycle Determination
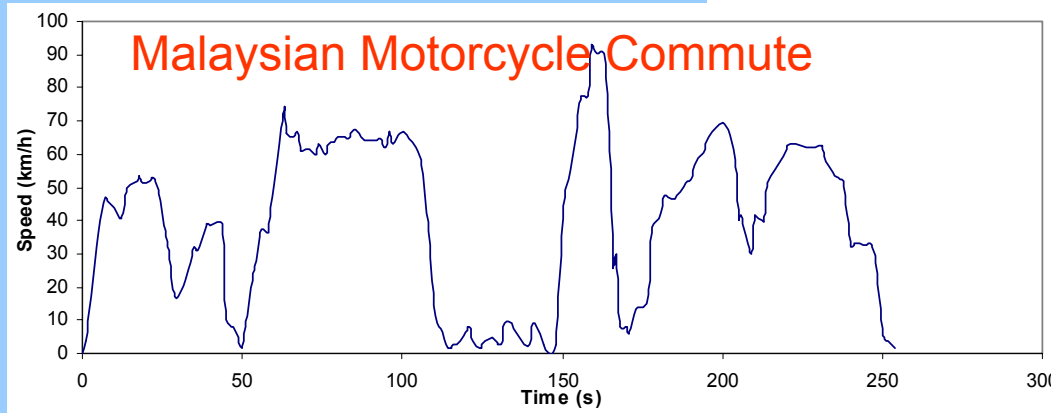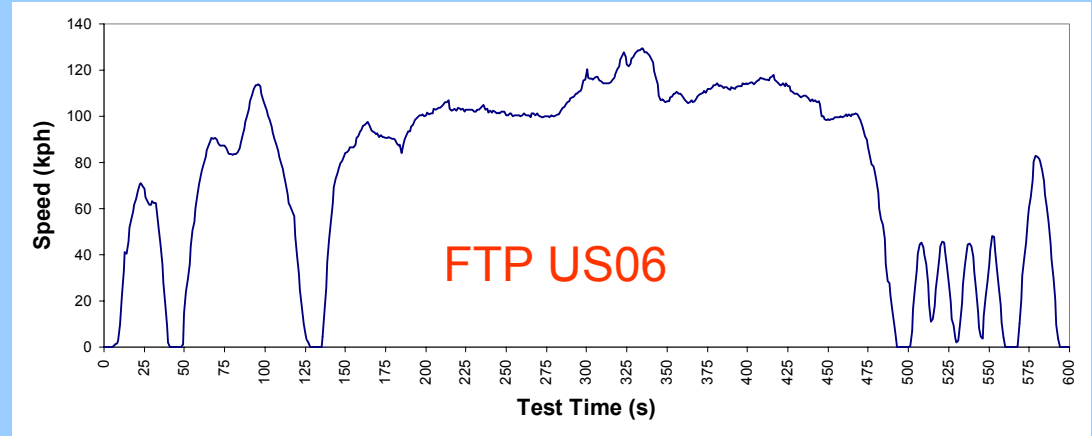
The answer is: The US Drive Cycles do *not* reflect how vehicles are used here.

This is why we need to define our own "Malaysian" drive cycles.

Drive Cycle to Test Point Conversion
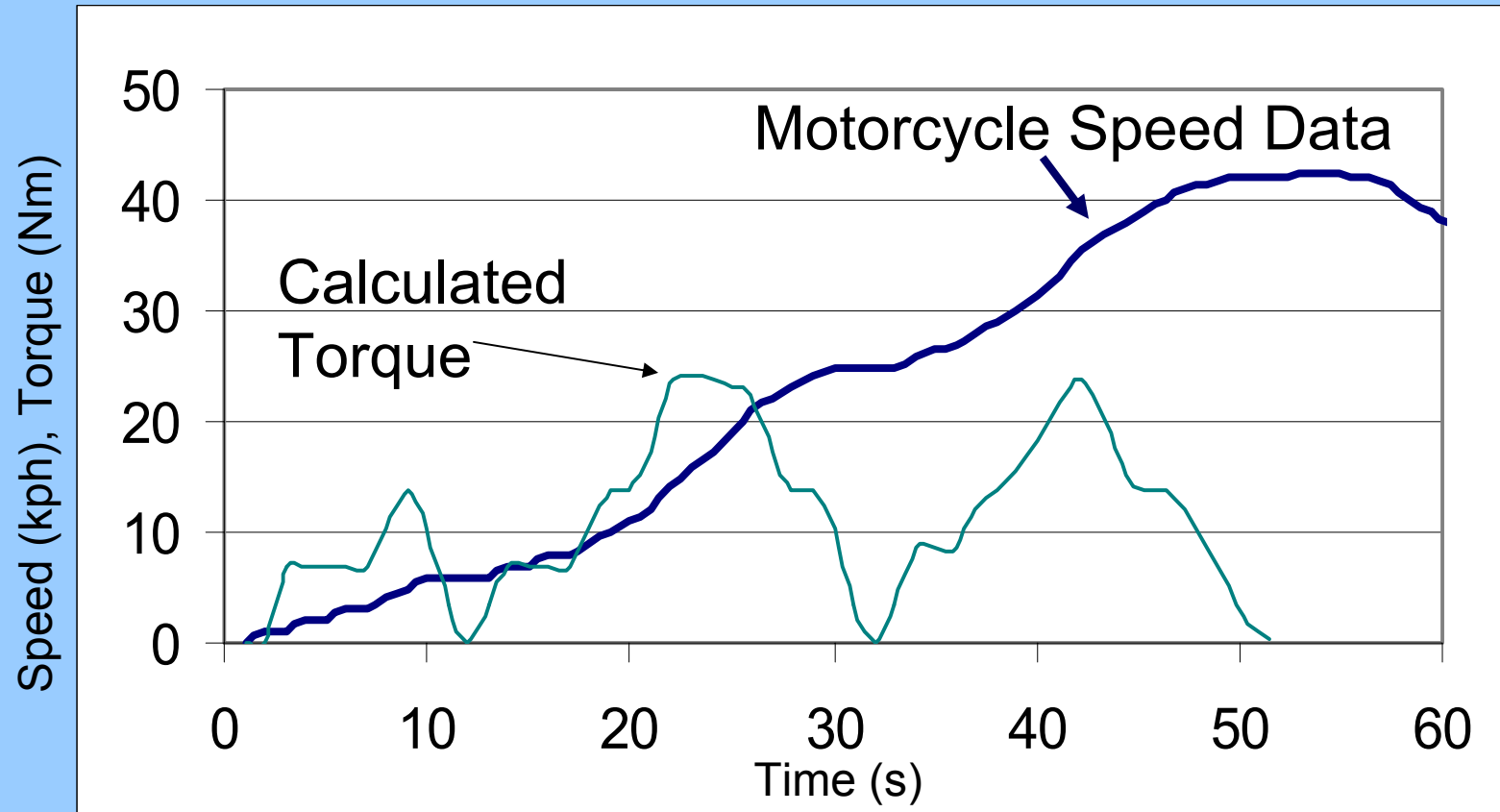
The engine operates at some torque loads more than others. We need to test at the most common torques and speeds experienced by the bike

Drive Cycle to Test Point Conversion
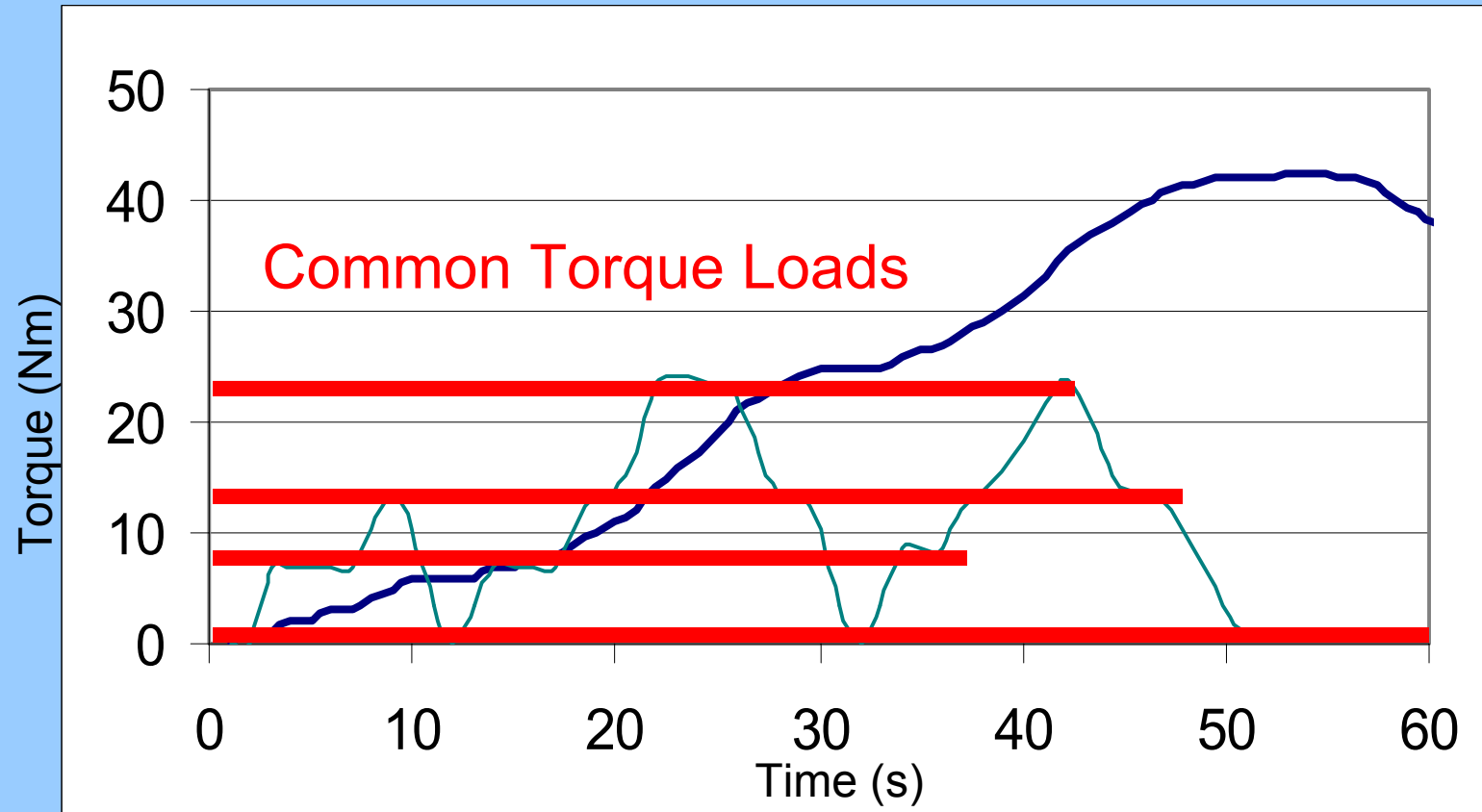
Common Torque (given at Chassis Dyno) loads on this bike are:

0 Nm (idle, or coasting)

7 Nm, 14 Nm, and 22 Nm

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

Drive Cycle to Test Point Conversion
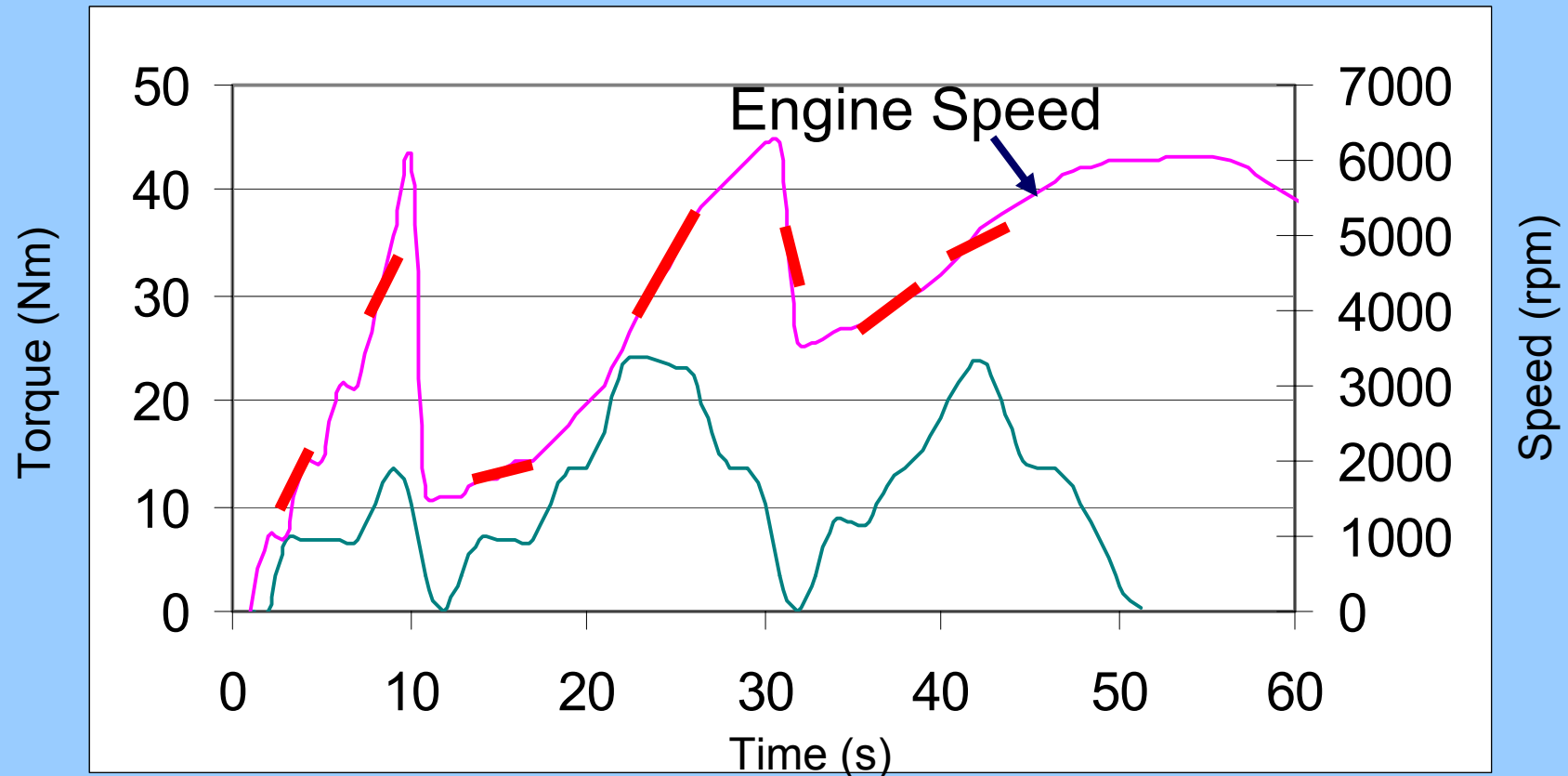
We need to determine the most common speed/torque points to test at
RED lines indicate common speeds for some common torques:
7 Nm at 1800 rpm, 14 Nm at 4750 rpm, 24 Nm at 5000 rpm

Drive Cycle to Test Point Conversion

Once we have identified the various test points, we need to determine the approximate weight of each point, based on a typical drive cycle:

Test Point	Load (Nm)	Engine Speed	Vehicle Speed	Weight
1	Idle	1200	0 kph	10%
2	7	1800	15	40%
3	14	4750	30	30%
4	24	5000	45	20%

The average FC (gm/min) is calculated from each test point as:

$$FC_{AV} = 0.1\ FC_1 + 0.4\ FC_2 + 0.3\ FC_3 + 0.2\ FC_4 \qquad (FC_1 \text{ is the FC for point 1})$$

Average Velocity (kph) is:
$$V_{av} = 0.1\ V_1 + 0.4\ V_2 + 0.3\ V_3 + 0.2\ V_4$$

Field fuel mileage (km/l) is now:
$$FM_{field} = V_{av} / (\ FC_{av} \times 60_{min/hr} / 720_{gm/liter}\ )$$

Drive Cycle to Test Point Conversion

For example, if we get the following data:

Test Point	Load (Nm)	Engine Speed	Vehicle Speed	Weight	Measured FC (gm/min)
1	Idle	1200	0 kph	10%	2
2	7	1800	15	40%	5
3	14	4750	30	30%	12
4	24	5000	45	20%	18

FC_{AV} = 0.1 (2) + 0.4 (5) + 0.3 (12) + 0.2 (18) = 9.4 gm/min

V_{av} = 0.1 (0) + 0.4 (15) + 0.3 (30) + 0.2 (45) = 24 kph

Field fuel mileage (km/l) is now:
FM_{field} = 24 / (9.4 x 60 / 720) = **30.6 km/l**

With careful selection and weighting of test points the predicted mileage should agree to within ~10% of the actual field mileage for a wide range of vehicles.

Drive Cycle to Test Point Conversion

Many "real world" vehicles and drivers must be measured and analyzed. Wind load and Rolling Resistance estimates may be introduced in to calculations to improve the accuracy of the torque load estimates.

Eventually the most common Speed + Torque combinations are selected as test points, and weighed according to their probability.

Some drive cycles have been divided into as many as 50+ test points!

Obviously there is a limit to the number of test points that can be run practically. The goal is to simplify testing, and reduce the cost and complexity, while maintaining a fair basis for evaluating changes (in FC, emissions or etc.)

In the end 5+ points may be sufficient to simulate a given drive cycle.

In our work in the Philippians we defined a 6-point test and had better than 10% agreement between our Fuel Consumption test results and the actual field FC numbers.

Part 4: Dynamometry Case Studies
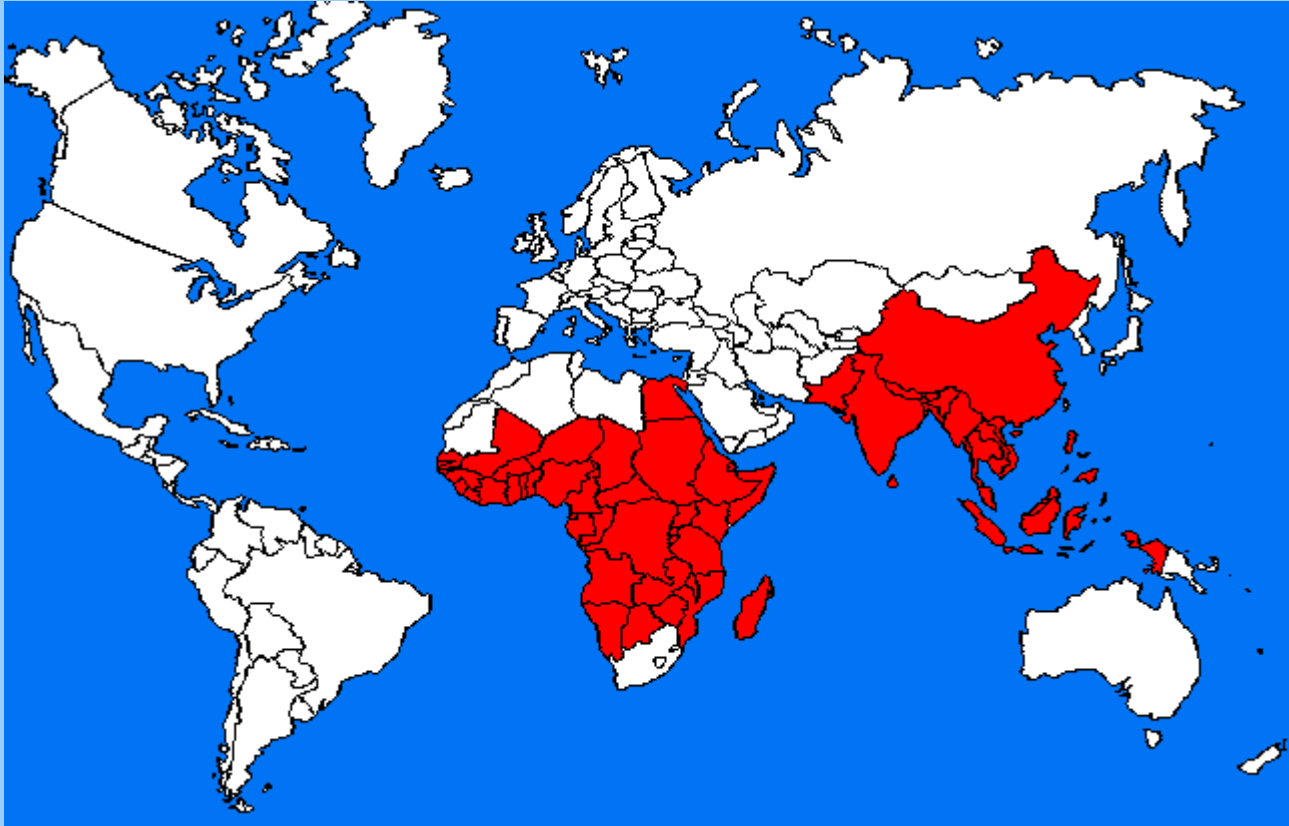
Case Study: Colorado State GDI Work

Eddy Current Dyno with loose plates – Had to be rebuilt
Used for GDI development as well as CPDI
Controller: "old-school" hardware PWM. Burned out– Had to be rebuilt

Cooling Shroud

Dynamometer

Exhaust Duct

Revo-Power Hub Motor

Engine
Speed Pickup
Dynamometer Controller
Drive shaft
Coils
Crankshaft Speed Wheel
Induction Disk
Strain gage
Rotation
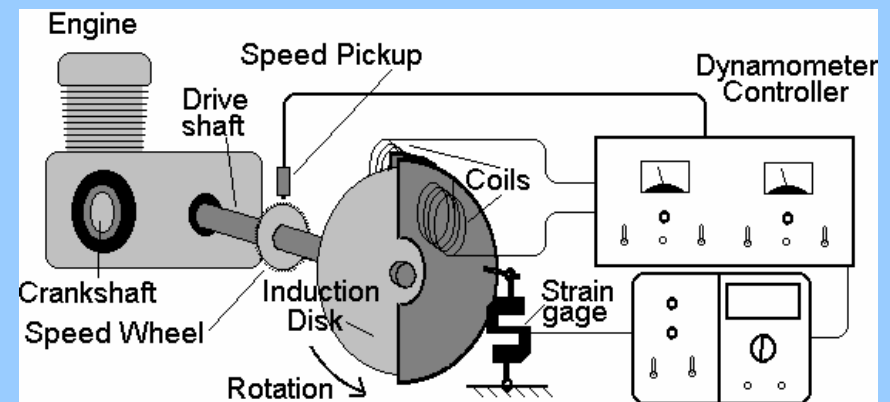
Case Study: Colorado State Univ.

Dyno re-used as Revo-Power chassis dyno for Bicycle "hub motor" (motor rotates with wheel)

Chassis Dyno Roller
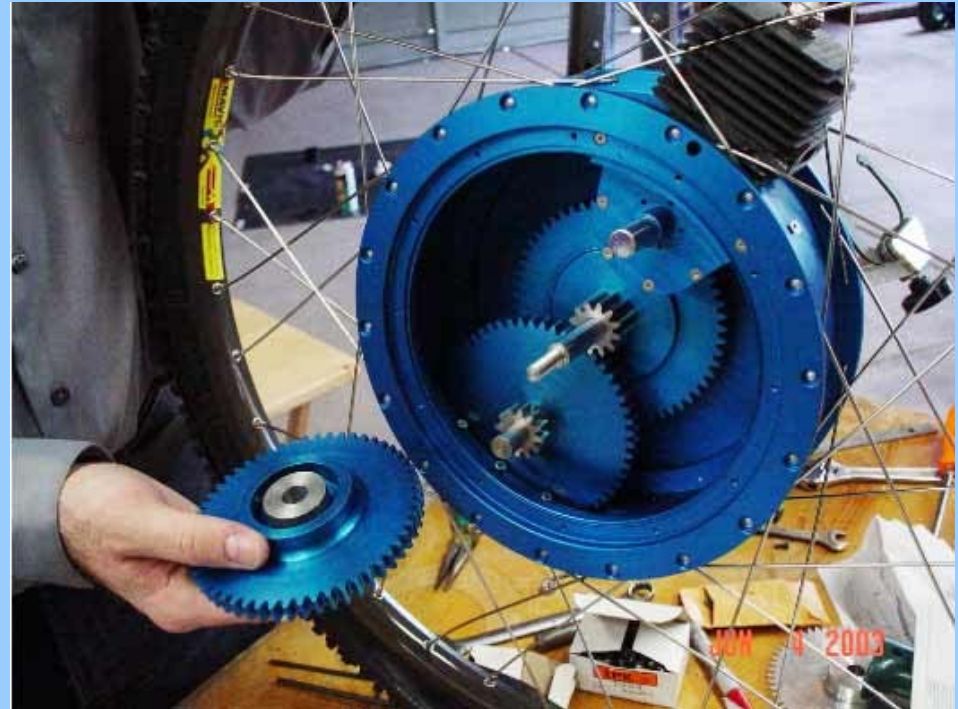
Revo-Power Hub Motor

Case Study: GDI Testing in Manila

Old Diesel Engine Hydraulic Dyno, rebuilt as chassis dyno for motorbike testing. Extremely slow ~500 rpm max! Hydraulic valve "spool" time was 13sec stop to stop! Speed was from DC motor directly driven from roller. Roller–Dyno coupled via U-joint. Had to build a special controller with PD and fuzzy logic. Data acquisition system was a 4-channel Serial Port DAQ. Controller-DAQ was all computer controlled.

Water Lines

Hydraulic Dyno

Load Cell

Control Lines

Throttle Valve Motor

Shaft
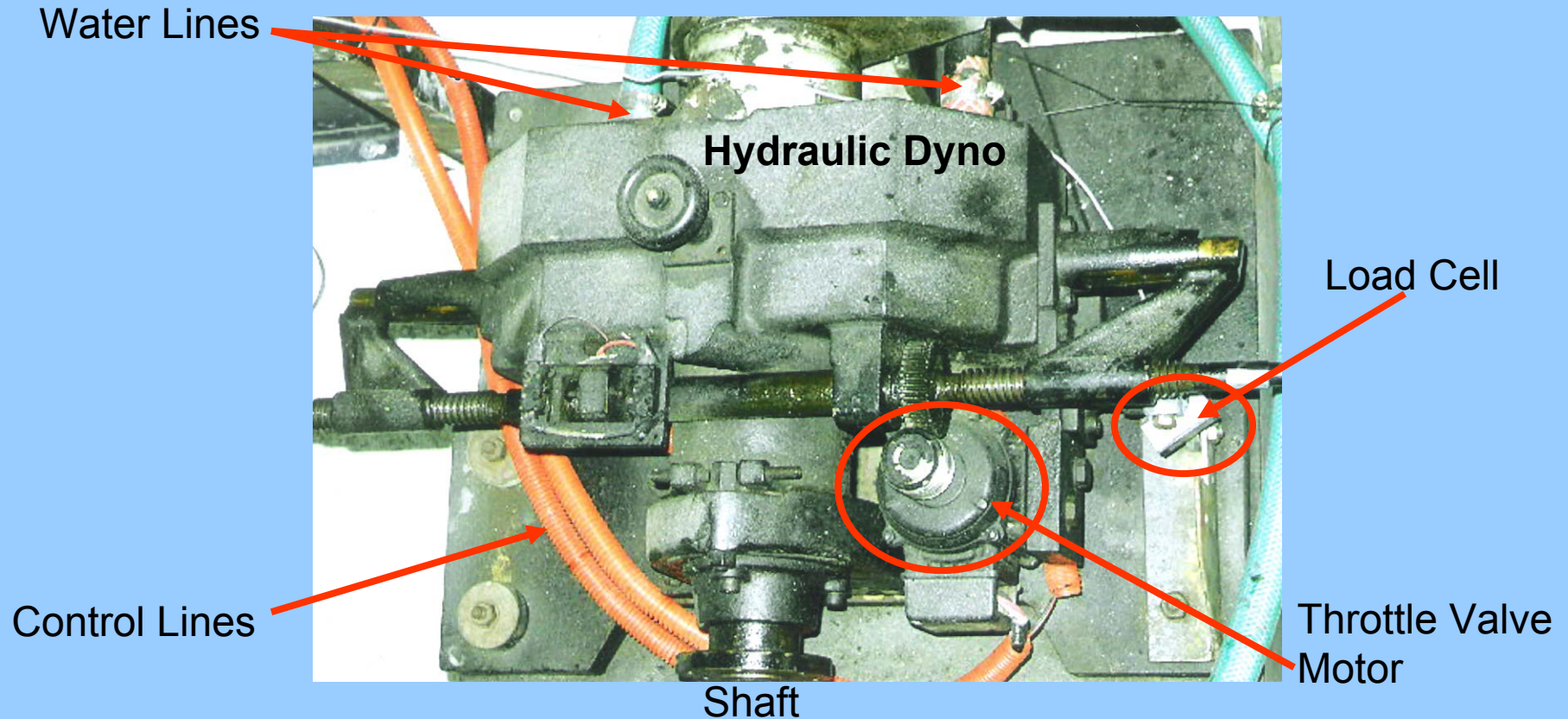
Case Study: GDI Testing in Manila

During transitions from one test point to another the controller used "Fuzzy" rules to adjust the Hydraulic Valve. When the speed came within range of the target value, a PD controller algorithm was used. Fuzzy logic was still used to determine when the system had achieved stability, and started data taking automatically.

```
'Controll Calculation ================================
        a = (rpm - rlast) / (TIMER - told)
        told = TIMER
        a = .5 * a + .5 * aold                    'Average Acelleration to smooth
        aold = a
        rpmerr = rpm - tp(it)                     'Error in RPM
        rpmerr = rpmerr - 20                      'hystorisis
        IF ABS(rpmerr) < 20 THEN rpmerr = 0       'Hyst
'        rpmerr = rpm - tp(it)                    'Error in RPM
        tmod = .2                                 'When Torq hi/speed low
        IF sign(-rpmerr) = sign(vload - tl(it)) THEN tmod = 1
        aj = pf * (rpmerr) + df * a
        aj = aj * tmod
        idig = ioff
        IF it = 0 THEN aj = 0                     'No actuation on Test0

        LOCATE 6, 34:  PRINT "Dyno ";
        LOCATE 2, 20: PRINT "Fuel: "; fuel;
        LOCATE 2, 50: PRINT "REC: "; rec
        d$ = "  ----  "
        IF aj > ajmax / 2 THEN idig = ileft: d$ = " <<<<  "
        IF aj < -ajmax / 2 THEN idig = irite: d$ = " >>>>  "
'oooooooooooooooo Fuzzy Dampening: ooooooooooooooooooooooooo
        IF ABS(rpmerr) < Fsp AND ABS(a) < Fac THEN d$ = " oooo  ": idig = ioff

'On Target Cryterion for Load (Stability detector):
        'INPUT a$
        IF ABS(vload - tl(it)) < .05 * tl(it) AND ABS(vold - vload) < .5 THEN
            IF d$ = " oooo  " OR d$ = " ----  " THEN
                dur = dur + 1                     'Duration of stability
                IF stab = 0 AND dur > 3 THEN      'Min Stability Time 3 readings
                  stab = 1
                  ttest = TIMER + 30
                END IF
            ELSE dur = 0
            END IF
        ELSE dur = 0
        END IF
        IF stab = 1 THEN d$ = "ST:" + STR$(INT(TIMER - ttest)) + " "
        vold = vload

        IF stab = 1 AND fuel = 1 AND TIMER - ttest >= 0 THEN
            IF ftest = 0 THEN
                ftest = 1                         'On fuel test
                ftime = TIMER                     'Take first point
                PRINT #4, CHR$(27); "P"
                CALL pse(.1)
                p$ = ""
                WHILE NOT EOF(4)
                    p$ = p$ + INPUT$(LOC(4), #4)
                WEND
                f1 = VAL(p$)
                LOCATE 12, 7 * (it + 2) - 4
                PRINT USING "  I####"; f1
            ELSE                                  'Take end measurement
                IF TIMER - ftime >= 60 AND ftest = 1 THEN 'Take end measurement
                    ftest = 2                     'Take off test
                    ft2 = TIMER                   'Time of 2nd measurement
                    PRINT #4, CHR$(27); "P"       'Get fuel weight
                    CALL pse(.1)
                    p$ = ""
```

Case Study: GDI Testing in Manila

In 2007 it was regeared using automotive transmission – much more responsive!

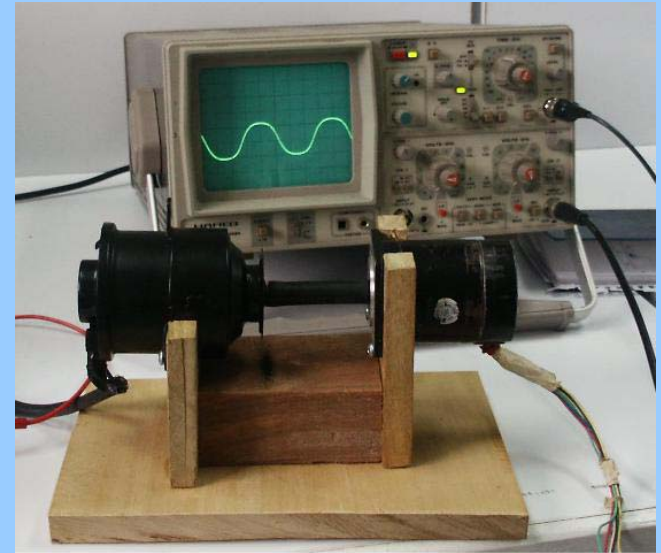Typical Data from 125cc 2-stroke "Tricycles" looked like this:

Test Point	**Direct Fuel Injection** HC	CO	AFR	**Carbureted** HC	CO	AFR
Idle	500	0.2	25+	6000	3	13
1	600	0.5	25+	4000	3	13
2	500	1.5	25	3000	3	14
3	800	3	15	3000	3	14
4	1200	4	14.5	2500	3	14
5	1500	4	14.5	3000	7	14

Case Study: Wind Turbine Controller

This Electric motor – Generator dynamometer was designed specifically to simulate a wind turbine output.

It was used in the design of power conversion circuits for alternative energy systems.

It is being replaced by an actual 1 kW wind turbine to be online by the end of 2008

Simulated Wind

Variable DC Power Supply

Computer

A-D Board

DC Motor

AC Generator

Input Voltage Divider

Input Current

Controller

Output Voltage Divider

Output Current

Load
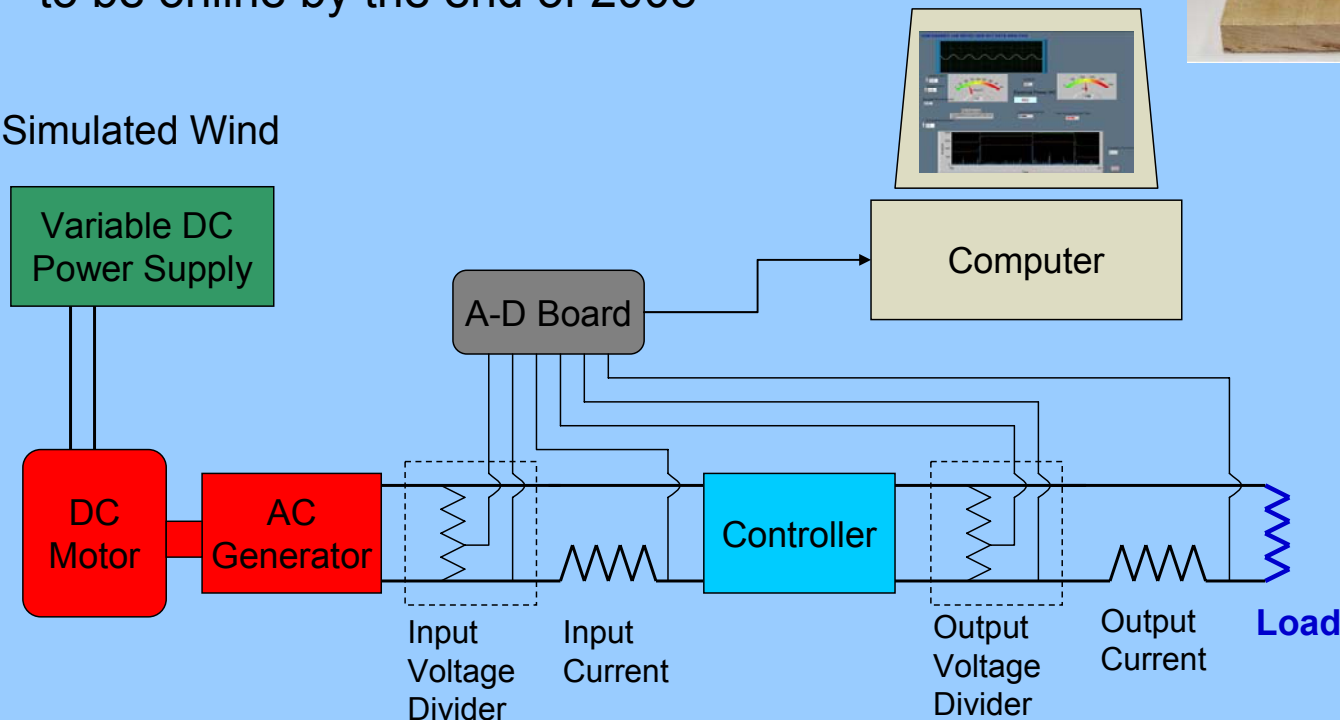
Case Study: 10 kW Diesel Genset

Only Speed, Electrical Power output and FC are measured.

Overall Break-Thermal Efficiency can be directly calculated

Has been used for Fuel Additives Studies
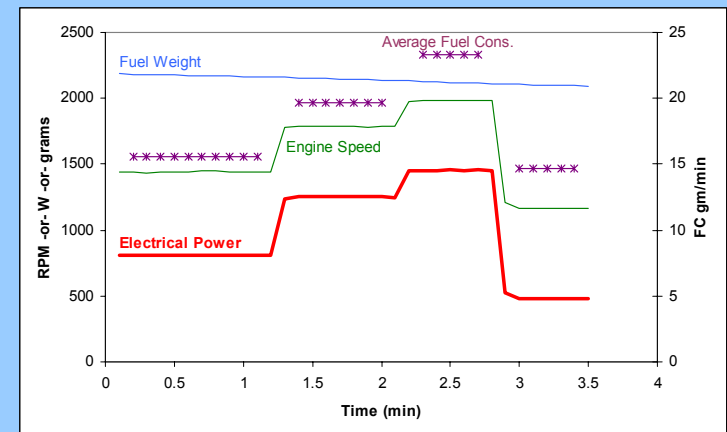
Case Study: USM Automotive Dyno

150 kW U-joint coupled Automotive Engine, a relic of the "Tronoh Days".

Required minor rehabilitation to return to full effectiveness.

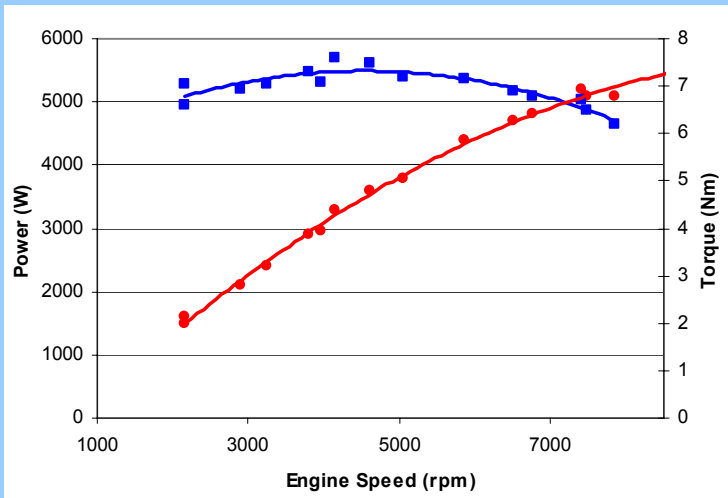Has subsequently been used in Fuel Additive testing (Note: Fuel additive gave no significant improvement in FC).

It is scheduled to be refurbished with new controller and DAQ system later this year.
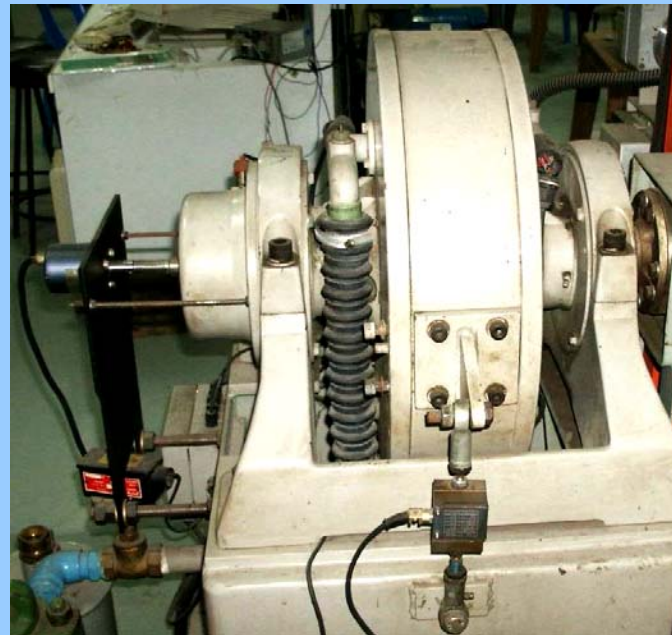
Case Study: DIY Dyno Development

5kW generator suspended by bearings in frame. Coupled to motorcycle engine via drive sprocket. Electrical power is dumped to water heater.

This dyno has been used extensively in industrial and academic research.

Mechanical Power

Speed		Torque		Power Outpt
1000	rpm	10	Nm	1047 W
x 2 PI / 60				(Torque x Speed rad/sec)
104.7	rad/sec			

Power Input

| Fuel Consumption	Chemical Energy	Power Input
6 gm/min	44,000 J/gm	4400 W
/ 60		(Chem Energy x FC gm/sec)
0.1 gm/sec		

Break Thermal Efficiency
Pout/Pin 23.8%

Case Study: 20kW Tranny Dyno

Eddy Current sprocket coupled dynamometer and controller.

We added instrumentation including combustion analysis.

This has been used extensively in the development of a two-stroke Direct Injection system for Gaseous Fuels
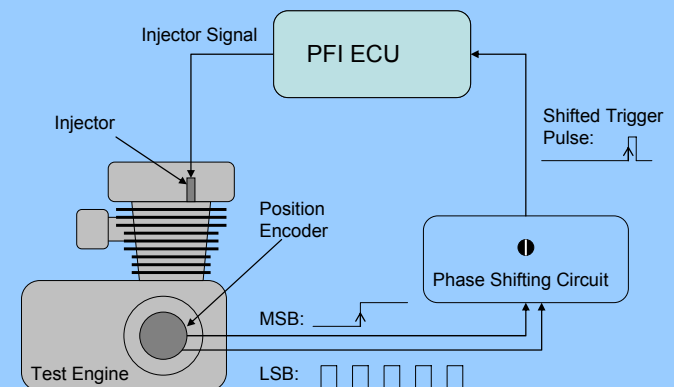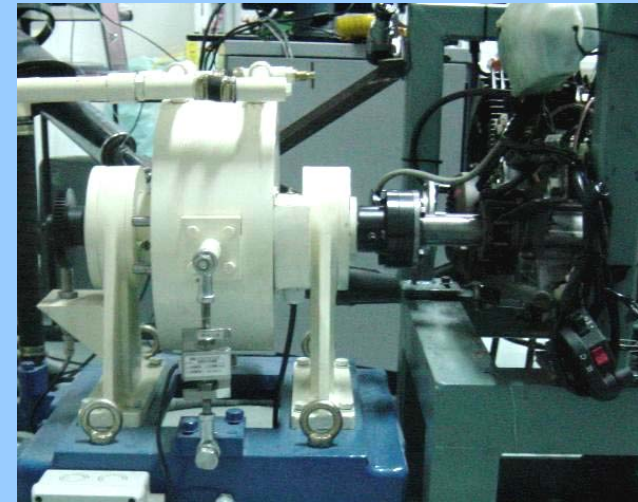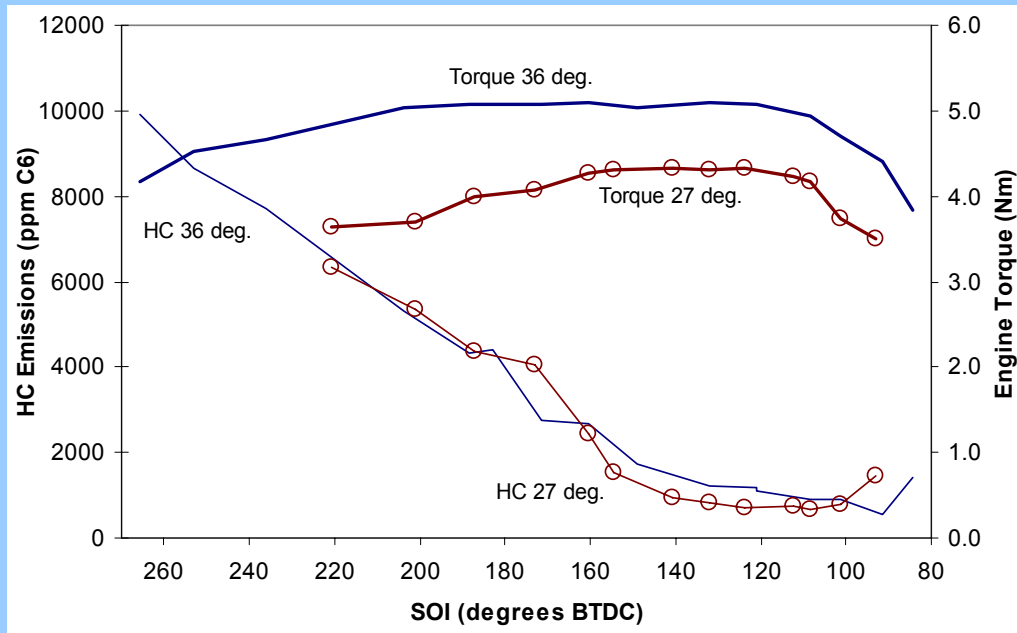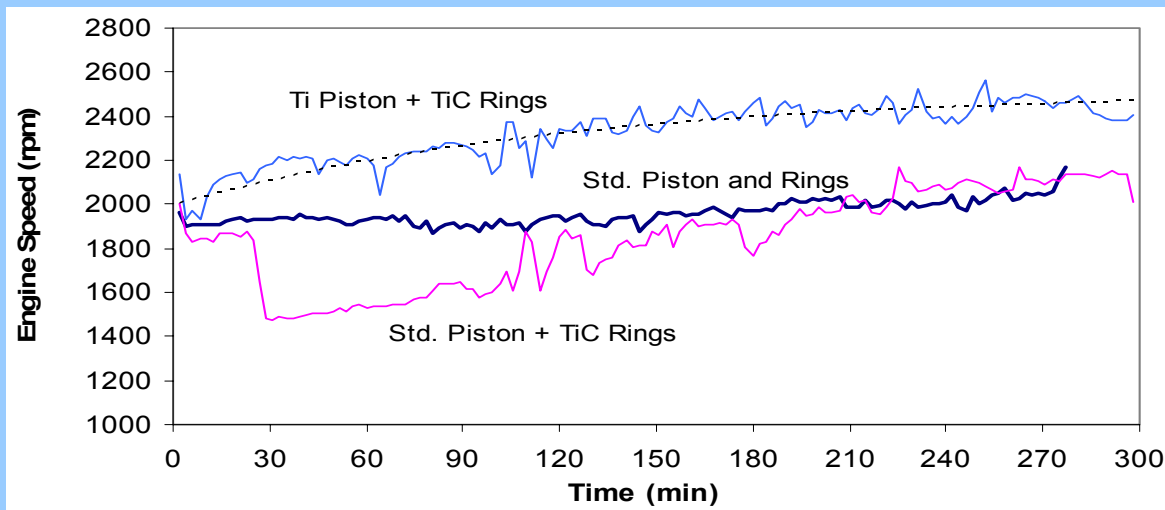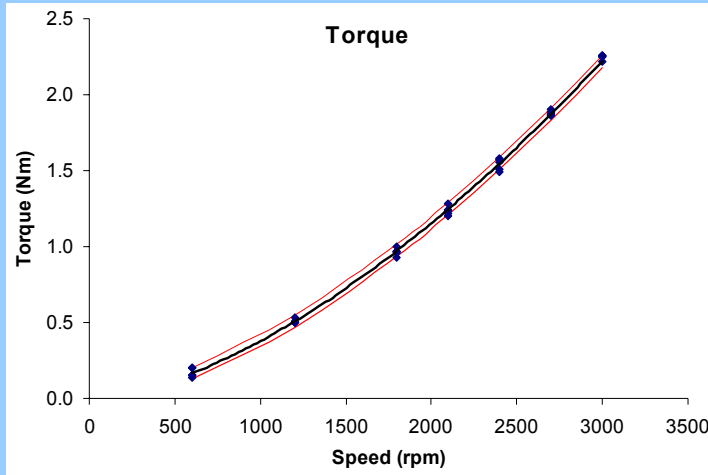
Case Study: Fan Dynamometer

Automotive aftermarket radiator fan directly coupled to small engine's crank shaft. Inexpensive (10 RM) and reasonably repeatable (5 different fans shown in calibration curve).
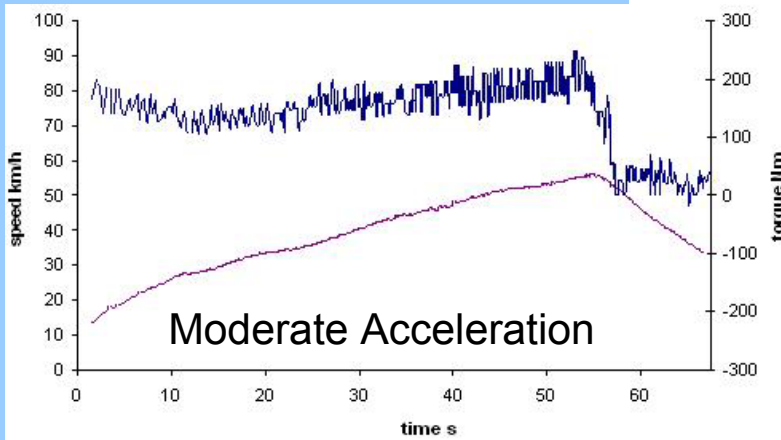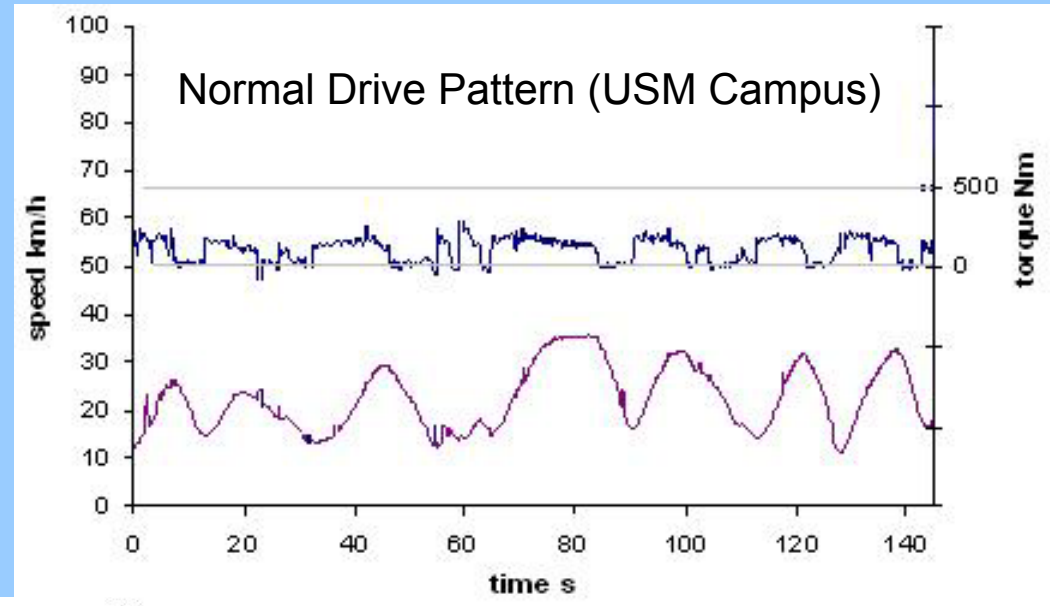
Speed was measured from the Back EMF on Kill Switch.

Case Study: Torque Sprocket

Measures speed and torque on vehicle
Will be used extensively starting Fall 2008 for Drive Cycle Studies

Normal Drive Pattern (USM Campus)

Moderate Acceleration

Case Study: 20 kW Eddy Current Chassis Dyno

We are developing a motorcycle chassis Dyno for FC and Emissions measurements to generate statistics on various designs of in-use vehicles for economic analysis. Scheduled to be online by late 2008
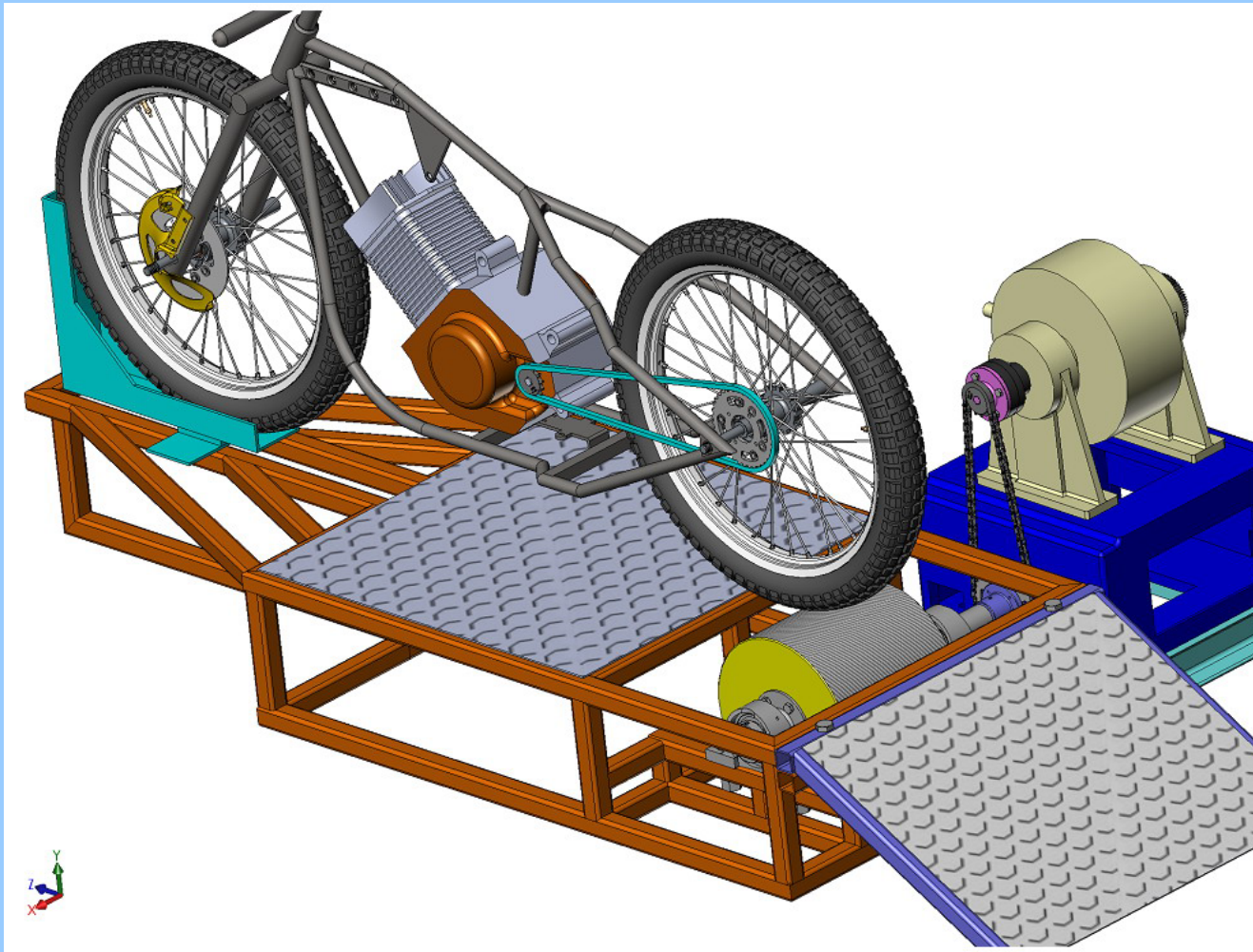
Questions?

Please be sure to fill out the survey forms.

If you have any questions in the future, or would like additional help in this are feel free to contact me:

Dr. Horizon Gitano-Briggs
+ (6016) 484-6524
HorizonUSM@yahoo.com