Diesel Dynatronix™

Diesel Dynamometer/Mechatronics Educational Trainer

Curriculum/Lab Manual

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Chapter 1: Internal Combustion Engine

The internal combustion engine (IC) is the most common power-producing device on earth and predominantly uses a piston-cylinder configuration. It is a heat engine that receives heat at a high temperature because of combustion (burning) of fuel inside the engine. The fuel is usually a hydrocarbon type fuel such as gasoline, kerosene or diesel fuel. Other forms of fuel such as LP Gas and methane are also used as alternative fuels.

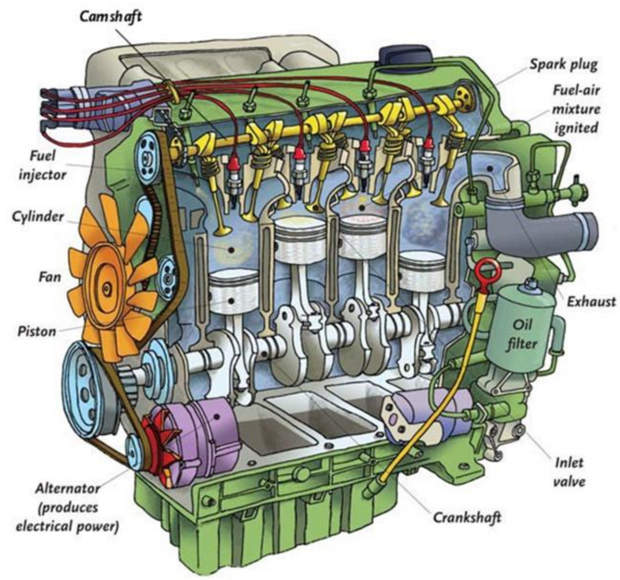


Figure 1-1: Internal Combustion Engine Cut-Away

The fuel usually mixes with air inside the engine and burns rapidly, with the resulting exhaust gases being high temperature and pressure. This process is a release of chemical energy which provides the high-temperature, high-pressure gases inside the engine. The hot gases are expanded in the engine which causes work to be done (produces power). The gases are then released from the engine after reaching a low temperature and pressure.

The Otto and Diesel Cycles are the two primary thermodynamic piston-cylinder cycles that have been used to characterize the IC engine.

Otto Cycle

The Otto Cycle is named after Nikolaus Otto, a German engineer who in 1861 developed the successful compressed charge internal combustion engine which ran on petroleum gas and led to the modern internal combustion engine.

Figure 1-2: Nikolaus Otto

The ideal Otto cycle is defined as the following set of processes:

1-2 Adiabatic* Compression
2-3 Constant Volume Heat Addition
3-4 Adiabatic* Expansion
4-1 Constant-Volume Heat Rejection

**Heat does not enter or leave the system*

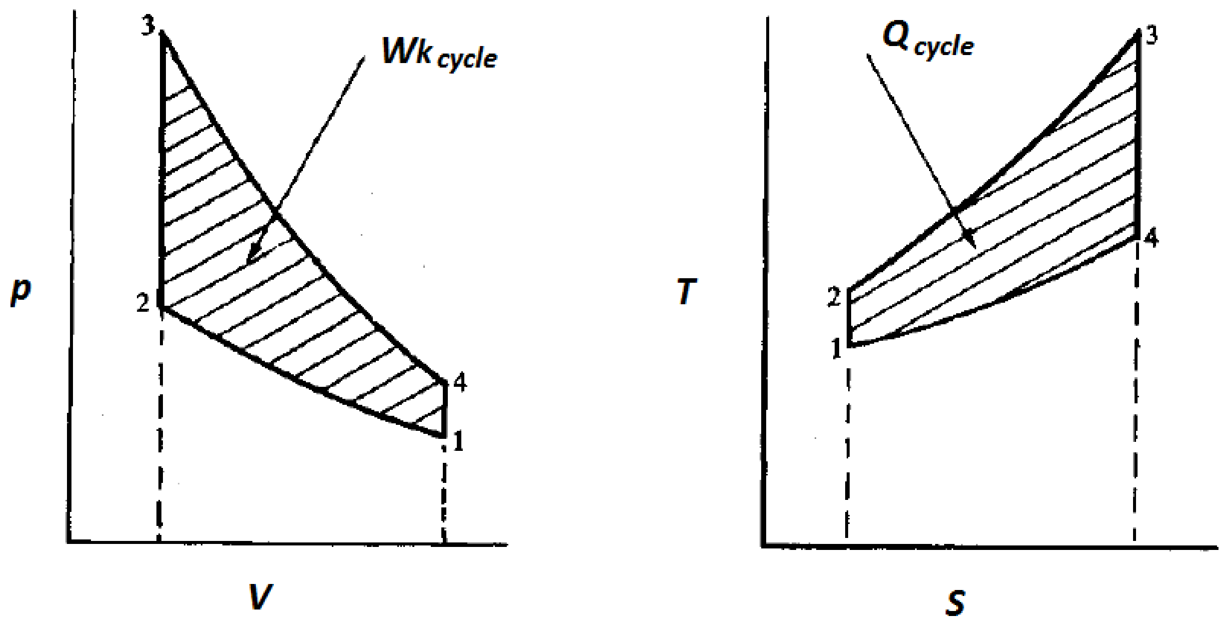


Figure 1-3: Property Diagrams for the ideal Otto Cycle.

These processes are shown in figure 1-3, where p-V and T-S diagrams are used to describe the Otto Cycle. Ideally, these processes can be considered as reversible, which allows us to identify the closed area in the p-V (pressure-volume) diagram as the net work of the cycle (Wk_{cycle}) and the enclosed area in the T-S (temperature-entropy) diagram as the net heat added (Q_{cycle}).

To gain an understanding how these four processes are descriptive of a real machine in operation, let us look at how a piston-cylinder arrangement can be used with the Otto Cycle. Figure 1-3 shows the sequence of motions of a piston corresponding to those four processes. Since this is an ideal cycle with pistons reciprocating in a continuous operation, it would be evident that processes 2-3 and 4-1 must be performed at a zero time period because there is no motion (study those diagrams closely). In actuality, this really can't happen in an actual case, but is presented to demonstrate the basic cycle and will be expanded upon later.

Reference: Thermodynamics and Heat Power, Sixth Edition, Dr. Kurt Rolle

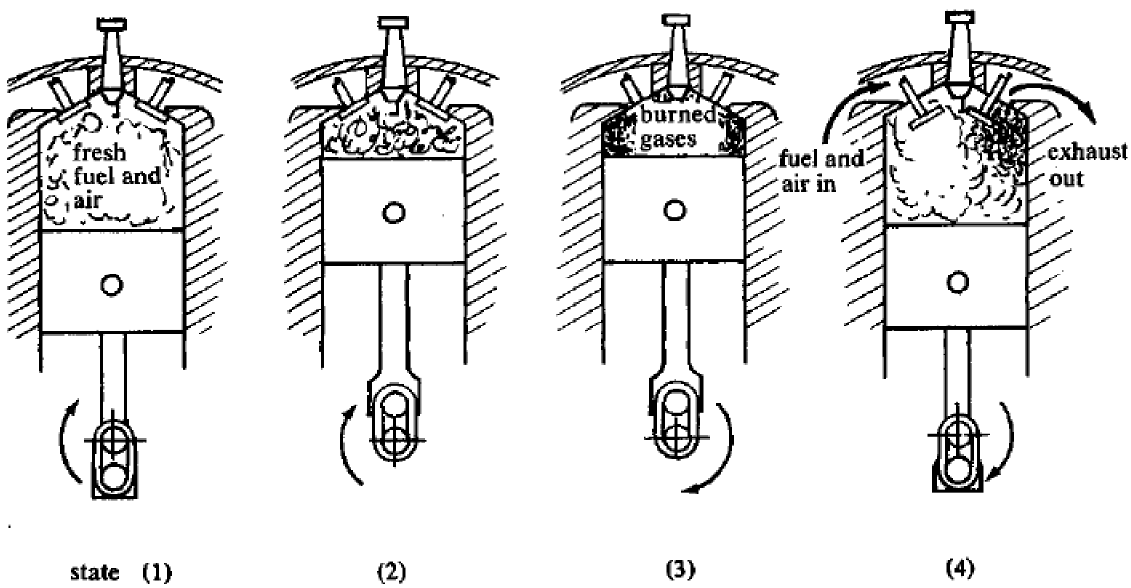


Figure 1-4: The Otto Cycle application in a piston-cylinder device

In Figure 1-4 above, process 1-2 is a compression of a charge of air and unburned fuel. The fuel is frequently added to the air by means of fuel injection near the end of the compression process 1-2. Fuel injection is usually accomplished by a pump that delivers fuel at a high pressure to a nozzle that sprays the fuel into the combustion chamber. When state 2 is reached, the spark plug fires, starting a chemical reaction between the fuel and air. This "internal combustion" defines IC engines and releases energy from the fuel in the form of heat to the piston-cylinder, producing a high-temperature, high pressure gas that drives the piston through an expansion process to state 4. This is typically known as spark ignition and the engine will be called an internal combustion spark-ignition (ICSI) engine.

Heat is then removed by opening the exhaust and intake valves, discharging the burned exhaust gases and quickly replacing this volume with a fresh charge of air and unburned fuel to allow the cycle to repeat. This transferring of gases provides power produced on each cycle is called a two-stroke cycle or two stroke engine. It is called this because it takes two strokes (up-down) of the piston to complete the cycle.

Expelling the exhaust gases while importing fresh fuel and air on the same stroke requires innovative valve configuration and still does not provide a good exchange of fresh charge for exhaust, thus wasting fuel in discharging the exhaust gases.

Because this two-stroke version of the Otto Cycler is inefficient, the cycle is changed to add one more revolution to clear out the exhaust gases and add fresh charges more effectively. This variation is known as the four-stroke cycle and is characterized by the opening of the exhaust valve only when the piston-cylinder gets to state 4.   This valve remains open through process 1-5, shown in Figures 1-5 and 1-6, during which time all the exhaust is pushed out of the piston. At state 5, the exhaust valve closes and the intake valve opens. The fresh fuel-air mixture is then taken in by the retreating piston until state 1 is reached, the intake valve closes, and the normal Otto cycle can proceed.

The four-stroke cycle is more commonly used because it allows for better control of the gases than the two stroke cycle, even though there is only one power stroke for every two revolutions, thus the term four stroke.

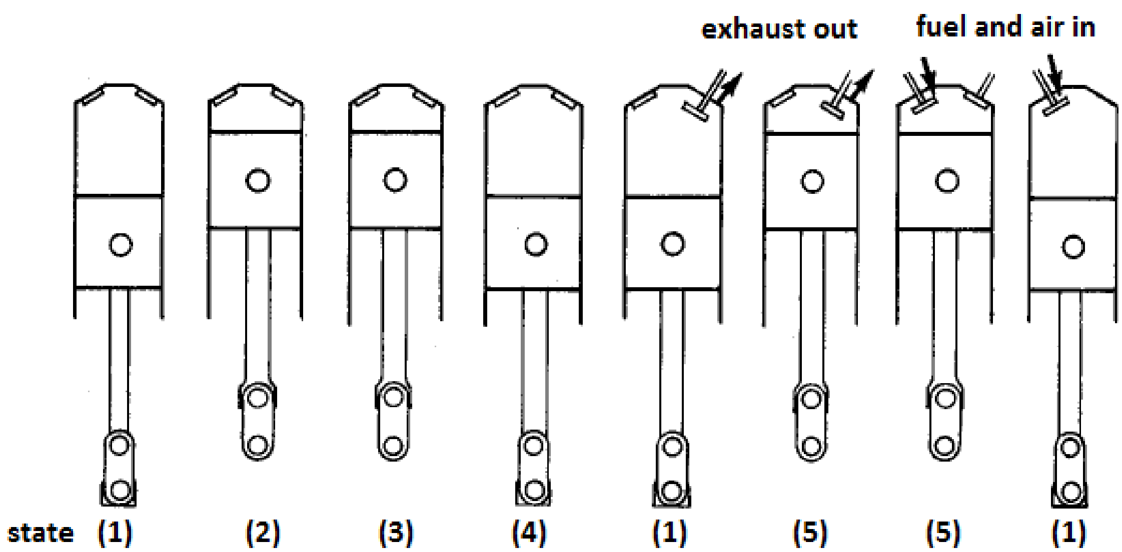


Figure 1-5: Four-stroke Otto Cycle

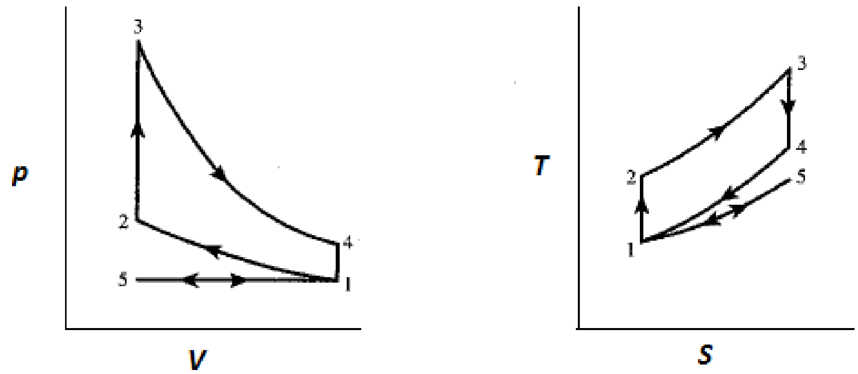


Figure 1-6: Property diagrams for the four-stroke Otto cycle

Theoretically, the four-stroke engine needs to rotate twice as fast as the two-stroke engine to achieve the same power. In practice, this is not generally the case due to additional issues which tend to degrade the attractiveness of the two-stroke cycle.

In Table 1-1, intake and exhaust valve operational positions are compared between Four-Stroke Cycle and Two-Stroke Cycle.

	Four-Stroke Cycle		Two-Stroke Cycle	
Process	**Intake Valve**	**Exhaust Valve**	**Intake Valve**	**Exhaust Valve**
1 to 2	Closed	Closed	Closed	Closed
2 to 3	Closed	Closed	Closed	Closed
3 to 4	Closed	Closed	Closed	Closed
4 to 1	Closed	Open	Open	Open
1 to 5	Closed	Open		
5 to 1	Open	Closed		

Table 1-1: Valve positions of the Otto Engine

Figure 1-7 depicts a typical cutaway view of an internal combustion engine that operates on a cycle that approximates the Otto cycle. This figure shows the major components and external characteristics of the typical water-cooled IC engine with water cooling. The Otto cycle is characterized by heat transfer during constant volume, but the real engine is continually experiencing heat transfers. Because of this, water is generally directed through cavities in the engine block to keep the cylinder and piston from reaching high temperatures. Air-cooled engines are also effective when properly designed and operated. Air is forced around the cylinder block to provide heat transfer to keep engine cool.

Fuel is typically gasoline, which has a low viscosity, high flash point and is formulated for spark ignition in an ICSI engine.

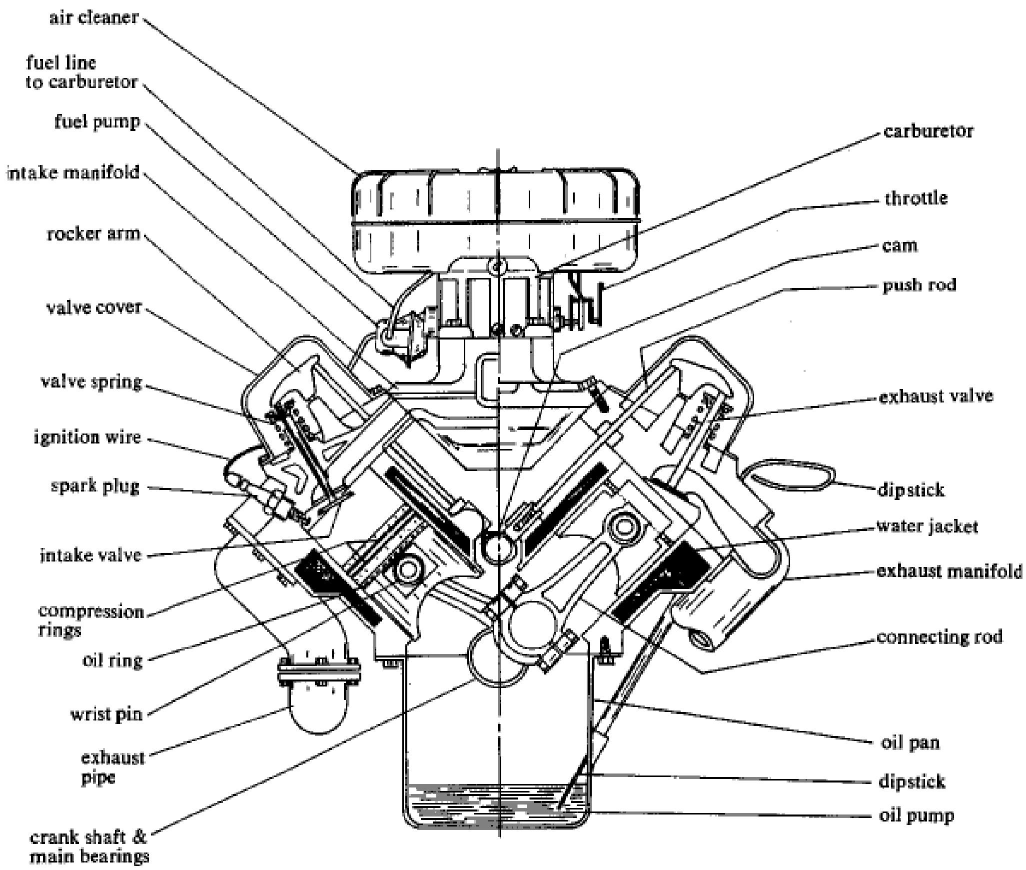


Figure 1-7: Typical internal combustion, spark-ignited engine, V configuration (cross-sectional view)

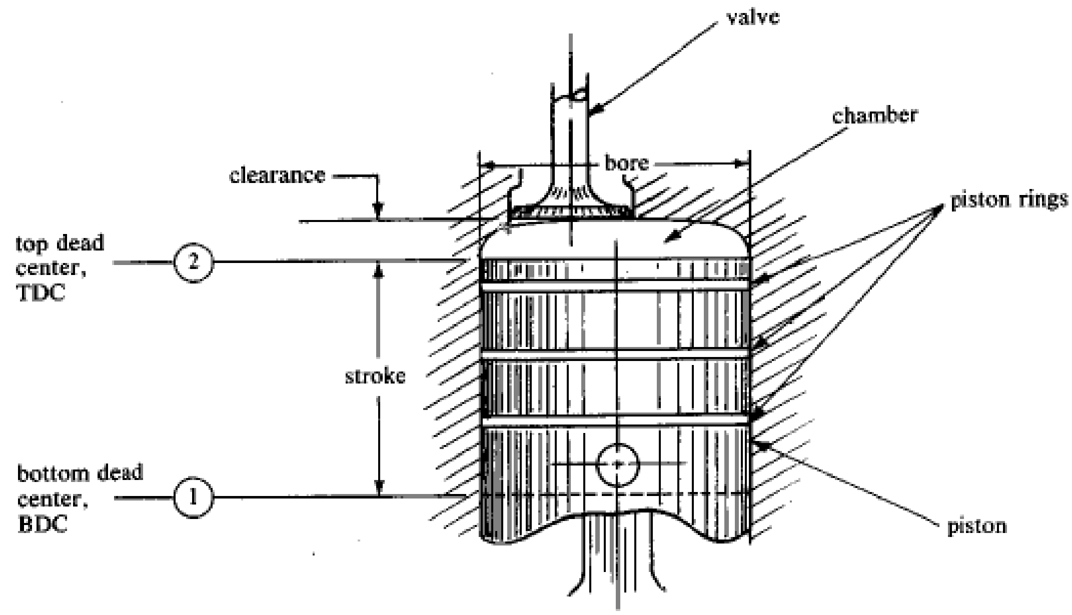


Figure 1-8: Common IC engine parameters

Certain terms are used often and have precise meanings in IC engine analysis. Referring to Figure 1-8; the **bore** refers to the diameter of the cylinder, the **piston** has a slightly smaller diameter than the bore so that it can slide freely in the cylinder. **Piston rings** provide the sealing between the piston and the cylinder so that the gases remain in the **chamber**. The **stroke** is the distance traveled by the piston from **top dead center** (TDC), when the piston is all the way in the cylinder, to the **bottom dead center** (BDC), when the piston is retracted as far out as possible. The **clearance** is the minimum distance between the piston and the end of the cylinder and the **clearance volume** is just that volume. If we denote the clearance volume as V_2 and the volume of the chamber when the piston is at BDC as V1, then;

Compression Ratio = V1/V2

Cylinder Displacement = V1-V2

For multiple-piston engines, engine displacement is the cylinder displacement times the number of cylinders. If the engine displacement is given, the displacement for each cylinder would be the total displacement divided by the number of cylinders.

Example Calculation

An internal combustion, spark-ignited (ICSI) four-cylinder engine has a bore (piston diameter) of 3.0 in, a stroke or piston travel of 3.0 in, and a clearance of 0.4 in. Determine the compression ratio and the engine displacement.

The Diesel Engine

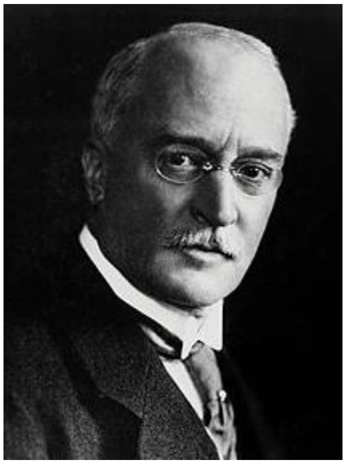


Figure 1-9 Rudolph Diesel

The concept for the Diesel engine was invented by German Rudolph Diesel in the late 1800's.

The diesel engine is an internal combustion engine, similar to the Otto engine, but operating at higher compression ratios, which ignites the fuel-air mixture by the compression process rather than spark ignition from a spark plug. The heat addition is accomplished during a longer time period. The fuel used is called diesel fuel and is denser with a lower flash point than gasoline. It is formulated to operate in the diesel cycle.

The ideal diesel engine operates on the ideal diesel cycle, defined as follows;

1-2 Adiabatic Compression
2-3 Constant-pressure heat addition
3-4 Adiabatic expansion
4-1 Constant-volume heat rejection

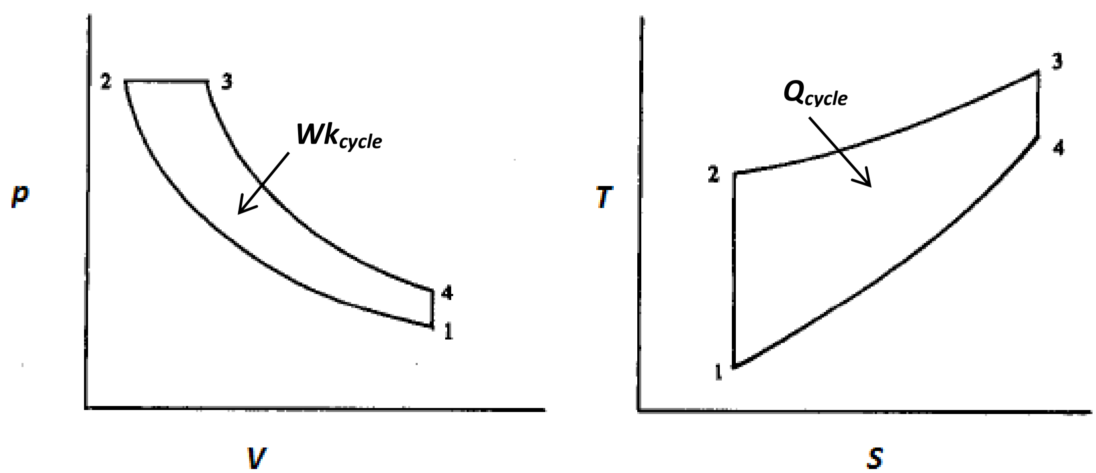


Figure 1-10: Property diagrams for ideal diesel cycle

Figure 1-10 shows the diagrams illustrating the paths of these processes on the p-V and T-S coordinates, comparable to the Otto cycle. The enclosed area on the p-V diagram is the work of the cycle and area of the T-S diagram is the net heat added. The areas must be equal. The mechanism normally used to carry out these processes is the piston-cylinder device as depicted in Figure 1-8 and has the same basic configuration and operation as that depicted in the earlier Figure 1-4, except that no spark plug is used.

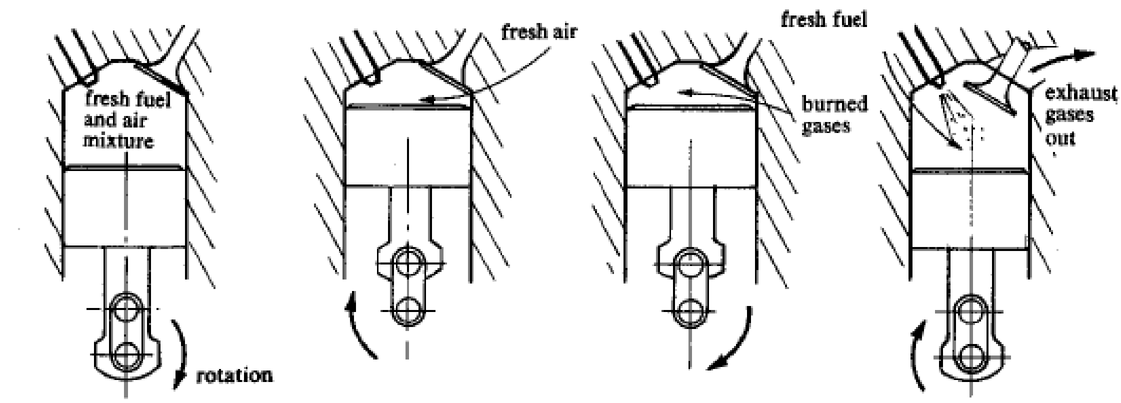


Figure 1-11: Physical Operations of the Diesel Engine

The piston-cylinder operation shown above in Figure 1-11 is very similar in configuration and operation to the Otto Cycle shown earlier in Figure 1-4. The main exception is there is no spark plug present in the diesel cycle. Fuel is introduced by a fuel injector, which is a nozzle that sprays fuel into the combustion chamber.

Continuing with Figure 1-11, process 1-2 is a compression of a fresh charge of air and fuel. Reaching state 2, the gases combust spontaneously due to the high pressure and, and the process continues at constant pressure to state 3. Most of the time, only air is introduced and compressed in process 1-2, with the fuel being injected at a pressure near that of state 2. Process 2-4 classifies the diesel engine as an internal combustion, compression-ignition engine (IC-CI engine).

Process 3-4 is an expansion of the exhaust gases until the piston reaches Bottom Dead Center (BDC) at state 4. Then the exhaust is rejected into the atmosphere in process 4-1. Simultaneously, air and fuel (or just fresh air) is injected into the chamber to be ready for a new cycle. This constitutes the two-stroke diesel cycle with the exhaust and and intake strokes of the piston together taking one revolution of the engine.

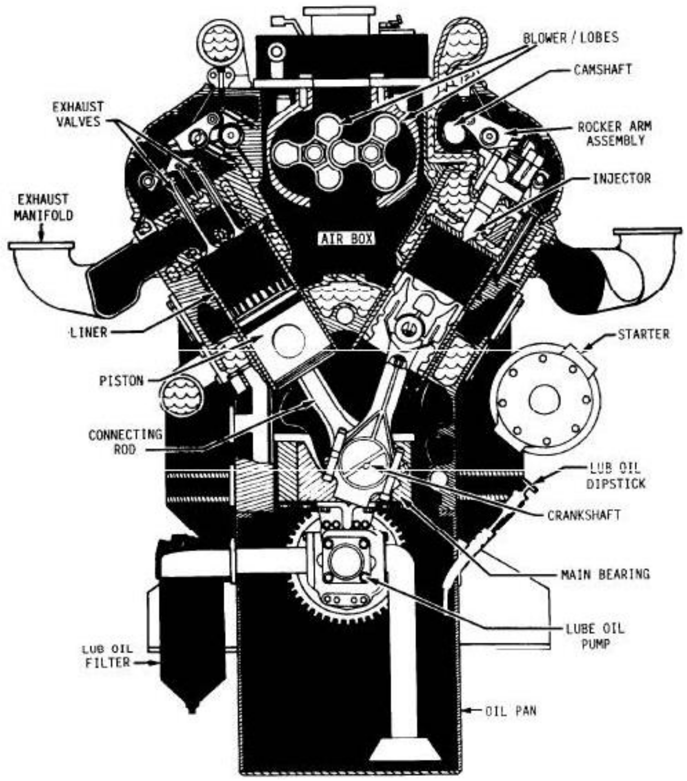


Figure 1-12: Cross-sectional view of typical V Configuration two-stroke-cycle diesel engine

Figure 1-12 details the critical parts that convert thermal energy to work through the piston-cylinder device. This view shows the manner of operation of the intake of air and fuel and the exhausting of the spent gases. At the top center of the figure, are shown two three-lobed rotors which pump air into the center cavity where it is introduced into the cylinder through the peripherial openings in the cylinder walls when the piston is at the bottom of its travel. The exhaust valves are actuated through a linkage system by the camshaft to allow the exhaust gases to escape from the cylinder at an appropriate time during the cycle. Fuel is introduced into the cylinder through the injector while fresh air is introduced seperately through openings in the cylinder walls.

Two and Four Stroke Engines

It should be noted that smaller engines like the one we are working with in the lab are four stroke engines. Larger systems such as those used in marine applications are two stroke engines.

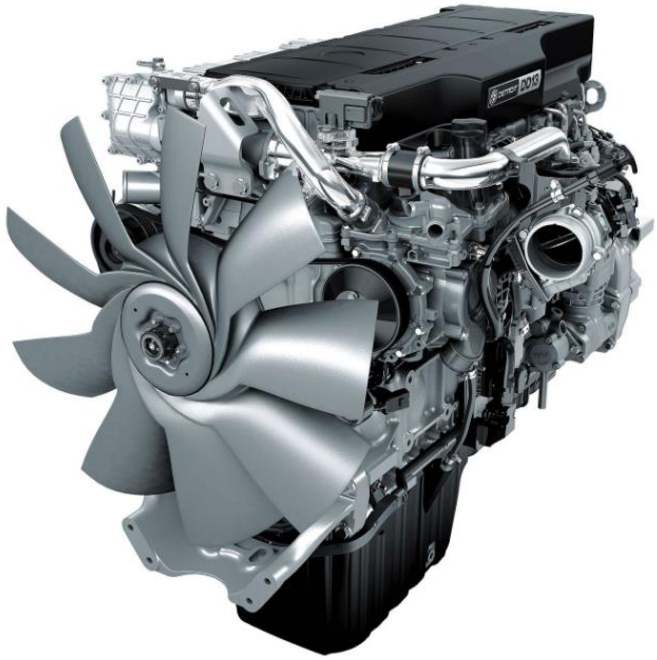


Figure 1-13: Commercial Diesel Engine (Detroit Diesel Model DD13)

Figure 1-13 shows an external view of a typical commercial diesel engine. The large nine-bladed fan is needed to draw air past the a radiator (not shown) to cool the engine when running.

Even though the diesel engine is commonly used in heavy applications such as trucks, tractors and stationary power plants, lighter versions are used as alteratives to the gasoline-powered engines used in automotive applications.

Cut-Off Ratio

One important distinction of the Diesel Cycle is what is known as cut-off ratio.
In a Diesel engine the fuel is continually injected during the initial part of the Expansion Stroke. Hence the first part of the expansion stroke up to when the fuel is added and the piston is getting pushed at a constant pressure is the heat addition at constant pressure. The point at which fuel addition is stopped is called cut-off point and the ratio of this fraction of the expansion stroke to the full stroke is called cut-off ratio and only the remaining length of the expansion stroke is actually utilized for the adiabatic expansion or the significant work output.

By contrast in a gasoline engine; the fuel-air mixture is taken in the suction stroke and is compressed. The heat addition takes place at constant volume via instantaneous combustion via spark plug ignition when the piston is at the top most position. The majority of the expansion stroke is responsible for the adiabatic expansion and the work output.

Chapter 2: Dynamometer

A dynamometer, or "dyno" for short, is a device used to measure force, moment of force (torque) or mechanical power output of a rotating machine such as a diesel engine. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm).

Power is defined as the rate of doing work. Common units of power are horsepower and kilowatt, where 1 horsepower (HP) = 33.000 ft-lb/min = 0.746 killowatt (kW).

Figure 2-1: Industrial Diesel Dynamometer

The power output to a rotating machine in hp or W is $P = 2\pi nT/k$, where;

n = revolutions/minute of the shaft

T = torque, measured in lbf-ft (N-m)

K = constant = 33,000 ft-lbf.hp-min [60 N-m/(W)(min)]

The same equation applies to the power output of the of an engine or motor, where n and T refer to the output shaft.

Engine Dynamometers are considered the industry standard for acurate power measurement as they are connected directly to the engine (hence the name "engine dynamometer"). We will focus on these types of dynamometers.

Chassis dynamometers are less accurate, smaller scale dynamometers that utilize the drive wheels of the subject machine to spin two rollers tied to resistance loading a measuring devices. We will briefly cover these types of dynamometers but will not focus on them.

There are typically of two different types of engine dynamometers;

- those absorbing power and dissipating it as heat (brake dynamometers)
- those transmitting the measured power (transmission dynamometers)

As indicated in the power equation, two measurements are involved; shaft speed and torque. Speed is typically measured by a tachometer and torque is usually measured by balancing against weights applied to a fixed lever arm, among other methods.

Brake Dynamometers-Absorbing Power and Dissipating as Heat

A brake dynamometer is a dynamometer type that measures horsepower at the engine's output shaft. All dynamometers are used to measure the performance of something. It is difficult to state the primary context for dynamometer use in precise terms; their application ranges from the measurement of force exerted by a human hand as well as the measurement of combustion engine horsepower.

Brake dynamometers are most widely used in the measurement of the forces generated by motors/engines. In that context, brake dynamometers can be considered variations of engine dynamometers or motor testers. They take their name from the method by which they produce measurements of force generation in an engine.

A brake is a utility that inhibits motion in a machine. When a brake is applied to a motor, it resists the movement that results from the force generated by that motor. The amount of force necessary to inhibit motion can be measured, and the expression of that measurement and its appearance on a display is the fulfillment of a brake dynamometer's purpose.

There are several kinds of brake absorption style dynamometers;

Prony Brake

One of the first ever brake dynamometers was the Prony brake, invented by Gaspard de Prony in 1821. The Prony Brake is a mechanical friction brake that applies a friction load to the output shaft by means of wood blocks, flexible band, or other friction type surface. Measurement can take place by attaching a pair of spring balances to the brake (Figure 2-2). While the shaft is rotating, one balance will show an increase in tension and the other will show a decrease in tension. Adding weights to a torque arm to apply measured resistance to a shaft/fly wheel is shown in Figure 2-2.

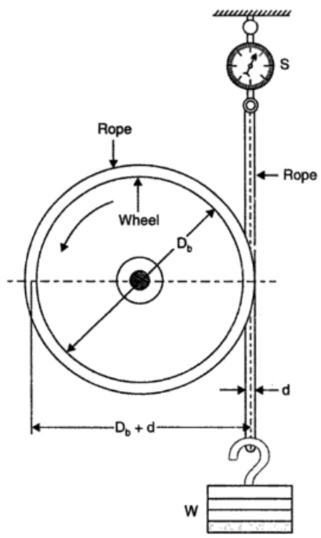


Figure 2-2: Prony Brake (Rope with balance springs)

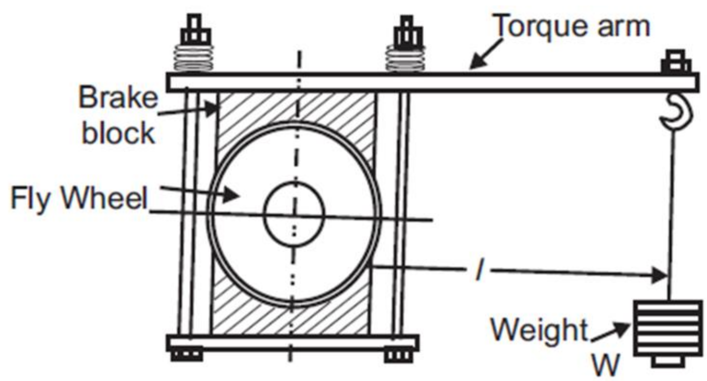


Figure 2-3: Prony Brake (Torque Arm)

Water Brake

Water brake dynamometers, also called hydraulic dynamometers, are very popular for engine testing because they have a high power capability while remaining inexpensive to operate. The Water Brake acts as an inefficient centrifugal pump which converts mechanical energy into heat. The pump casing (stator) is mounted on anti-friction bearings so that the developed turning moment developed by the rotor can be measured. Figure 2-4 shows how this works.

The rotor is attached to the shaft output of the motor being measured. Water is added to the dynamometer until the engine is held at a steady RPM. The water is then kept at that level and replaced by constant draining and refilling that carries away the heat created by absorbing the horsepower. The rotor slings (pumps) the water, which transfers this pumping force to the stator. This causes the stator to rotate the torque arm attached to it. The arm transfers that rotational force to a scale, which measures this force (and restricts the stator from spinning on its axis). The transferred force changes as motor speed changes. The force multiplied by the length of the torque arm yields the torque value of the shaft output. Water is used as the resistive fluid and is also continuously replaced to remove heat build-up from the process.

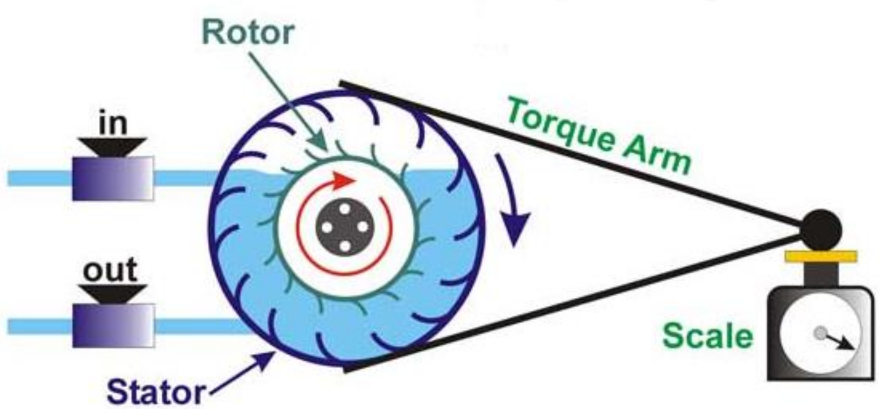


Figure 2-4: Water Brake Dynamometer Schematic

Eddy-Current Brake

In the Eddy-Current Brake (magnetic drag), rotation of a metal disk in a magnetic field induces eddy currents in the disk which cause a restrictive resistance which is dissipated as heat. The field assembly case is mounted on bearings in order to measure torque (similar to the Water Brake stator).

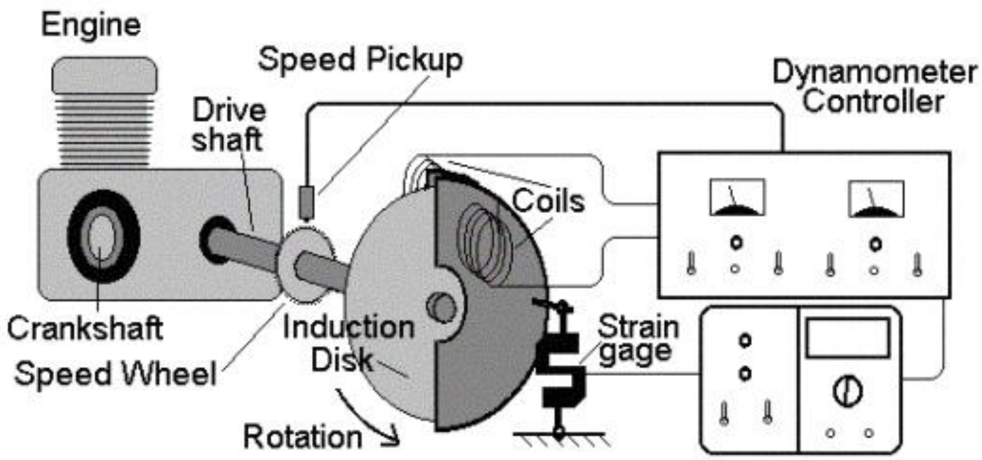


Figure 2-5: Eddy-Current Brake Dynamometer Schematic

Transmission Dynamometers

Transmission dynamometers are also called torque meters. They mostly consist of a set of strain-gauges fixed on the rotating shaft and the torque is measured by the angular deformation of the shaft which is indicated as strain of the strain gauge. A four arm bridge is used to reduce the effect of temperature and the gauges are arranged in pairs such that the effect of axial or transverse load on the strain gauges is avoided. We are not covering this type of dynamometer.

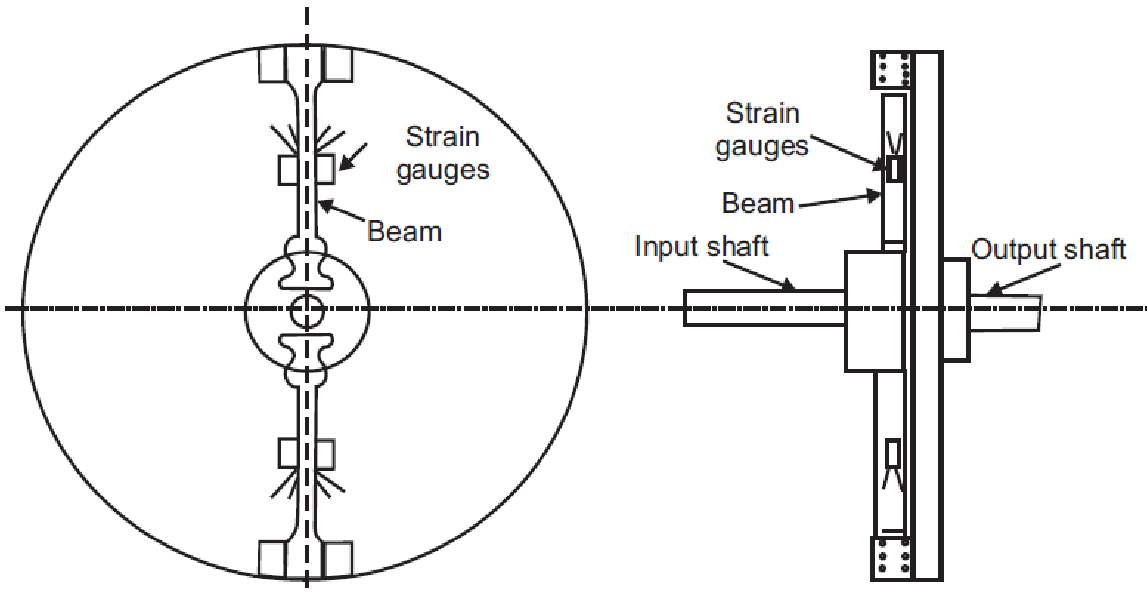


Figure 2-6: Transmission Dynamometer

Figure 2-6 shows the transmission dynamometer which employs beams and strain-gauges for a sensing torque. Transmission dynamometers measures brake power very accurately and are used where continuous transmission of load is necessary. These are mainly used in automotive units.

Chassis Dynamometers

As mentioned earlier, another common dynamometer configuration that can be found in smaller automotive and sport vehicle performance shops is the chassis dynamometer, which has the drive wheels of an engine-equipped vehicle/machine spinning rollers with various load inducers and sensors. We are not covering this less-accurate dynamometer system.

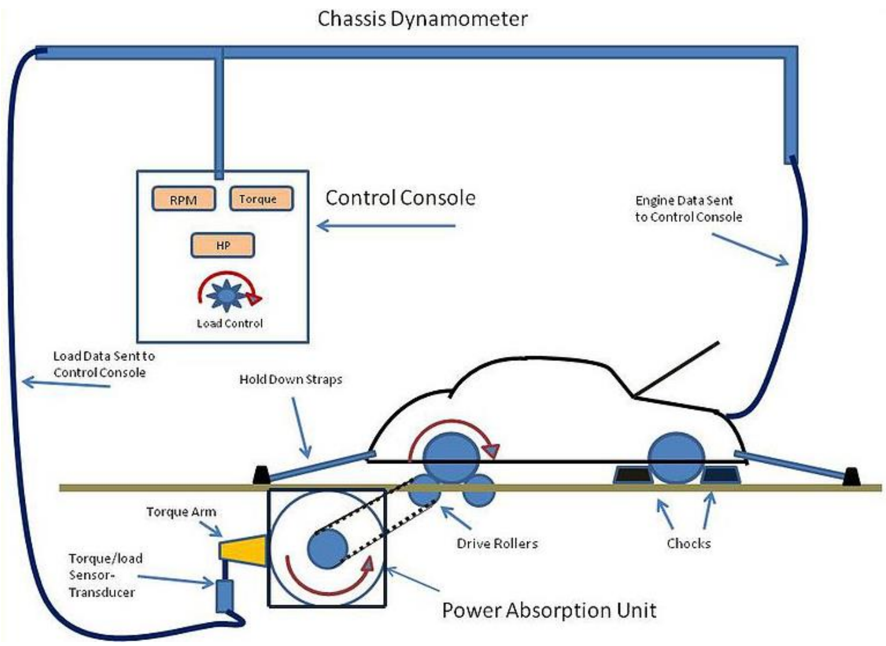


Figure 2-7: Chassis Dynamometer Configuration

Chapter 3: Diesel Dynatronix™ System

Overview

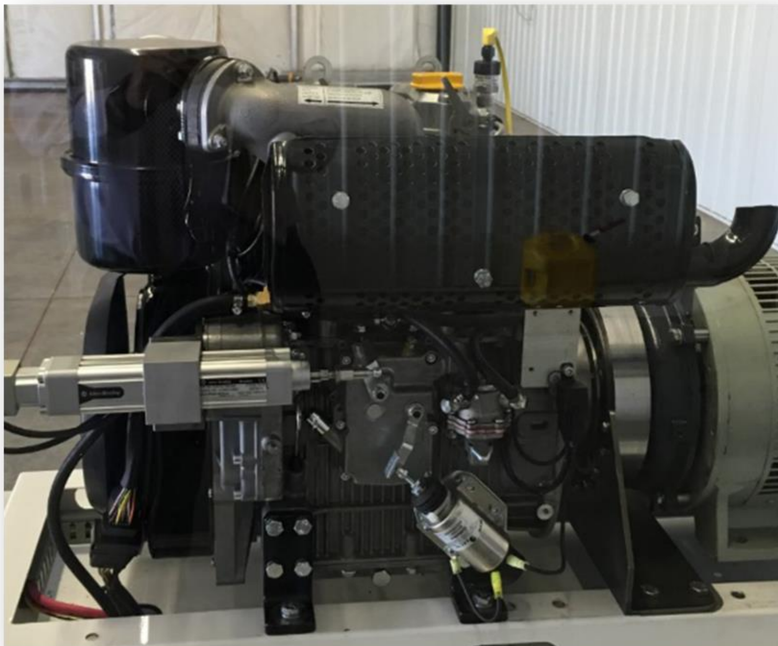
Diesel Dynatronix™ is a portable diesel engine performance analysis system comprised of a two-cylinder industrial diesel engine driving an air-cooled eddy-current brake absorption style dynamometer. The eddy-current dynamometer is induction-loaded through a 48 volt DC variable-excitation system. A built-in torque arm (1 foot in length) mounted to the outer case (stator) actuates a load cell (calibrated to read in lbs) to provide a direct torque readout in ft-lbs.

Diesel Dynatronix System

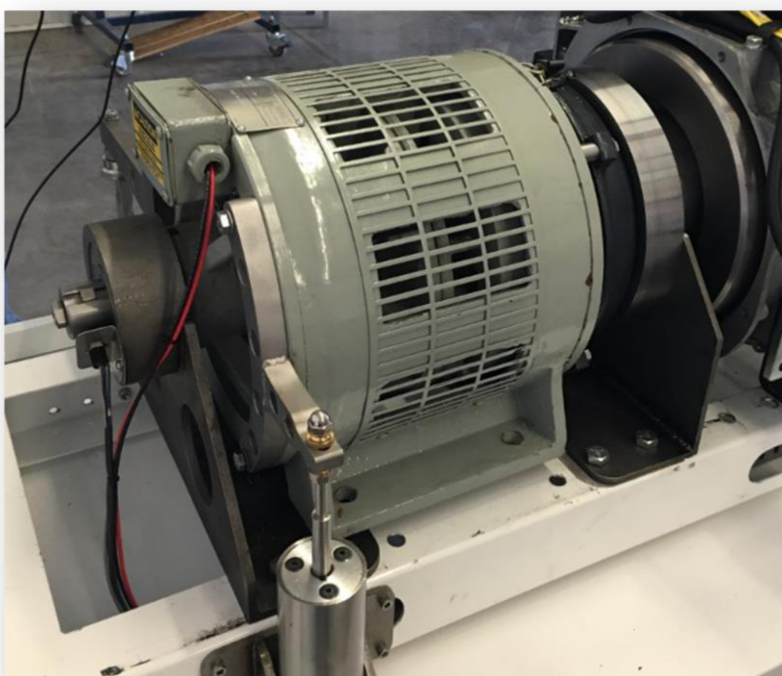
The total system is controlled by an integrated Industrial Human-Machine Interface (HMI) built-into the systems' front view shield. The HMI communicates with an Allen Bradley Programmable Automation Controller (PAC) to control engine start/stop and servo drive throttle position, as well as dyno loading. The PAC will enable PID feedback control to automatically adjust engine speed based on loading, among other capabilities

Full automation software is on-board which will allow students to program different engine/dyno operational scenarios as well as reprogram the HMI interface to provide a customized look and tactical operation for those scenarios.

Engine and Dynamometer

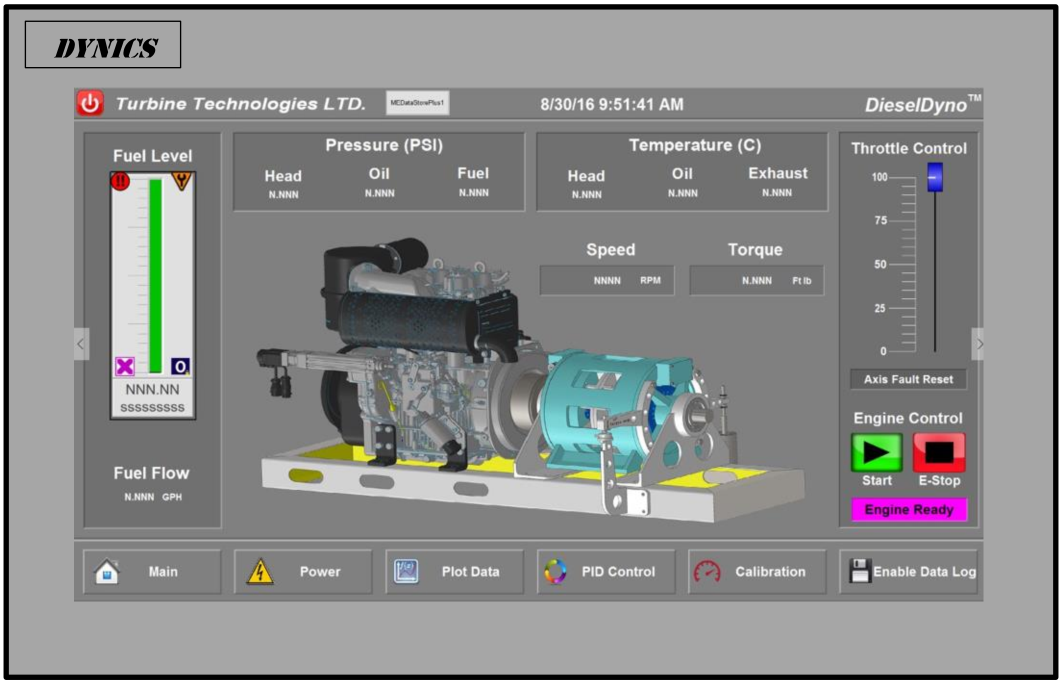


Lamborghini/Kohler™ KD-625-2 Engine



DSI Dynamatic™ AS-704 Eddy Current Brake Dynamometer

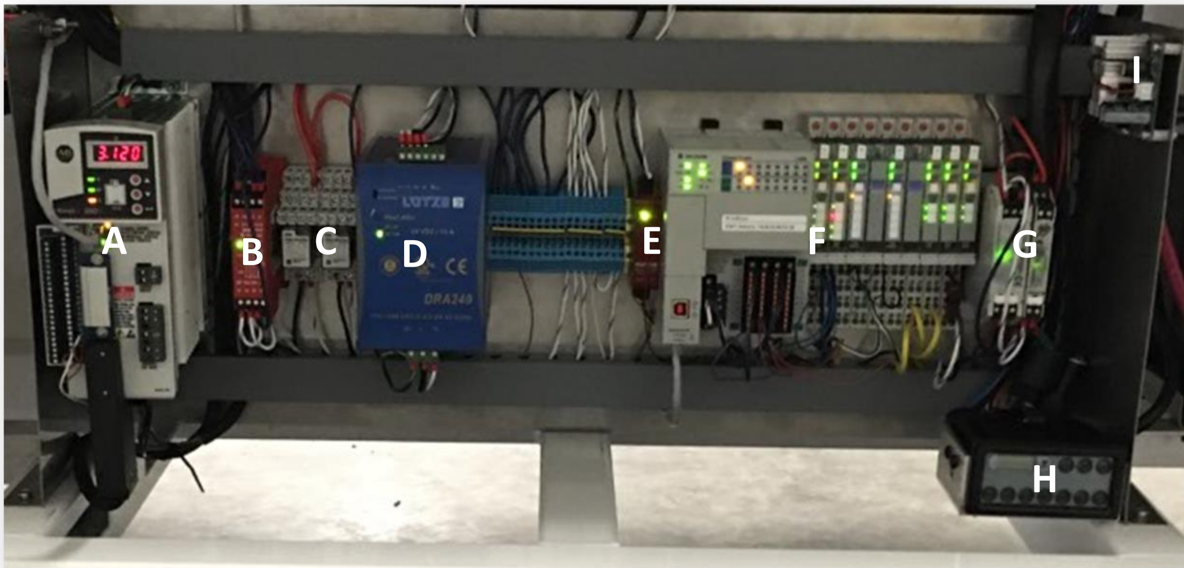
Automation Suite



Dynics™ Human Machine Interface (HMI) with **Allen Bradley Studio 5000™ and FactoryTalk™** Automation Programming Software Loaded

Ethernet Communications with Wireless Capabilities

Automation Suite Continued…



A: Engine Throttle Servo Drive

B: Throttle Disarm Safety Relay

C: Engine Starter/Shutoff Relays

D: 24 VDC Automation System Power Supply

E: Torque Arm Load Cell Signal Conditioner (Voltage to 4-20 mA signal)

F: Allen Bradley L18ERM Programmable Automation Controller (PAC)

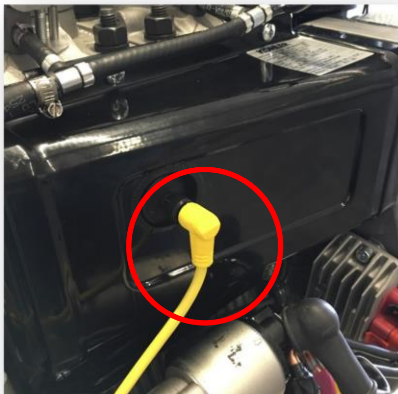
G: Dynamometer Signal Conditioners (Voltage and Current)

H: Kohler Engine Operational Computer

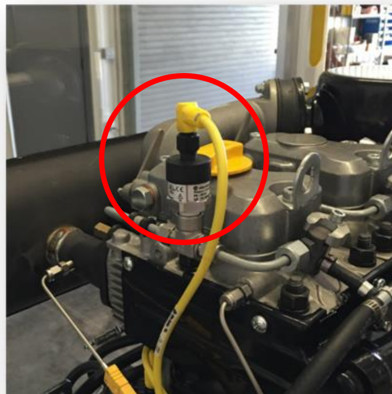
I: Dynamometer Excitation Controller (Pulse Width Modulation)

Diesel Dynatronix will measure and display the following system operational conditions;

Engine Pressure Measurements



Engine Head Pressure

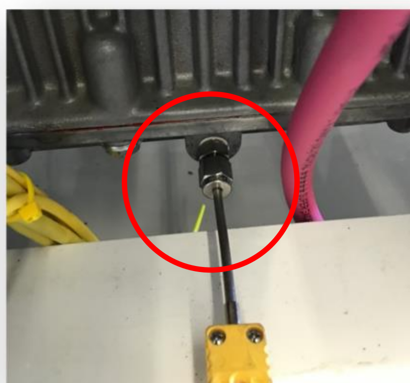


Engine Fuel Pressure

Engine Oil Pressure

Engine Temperature Measurements

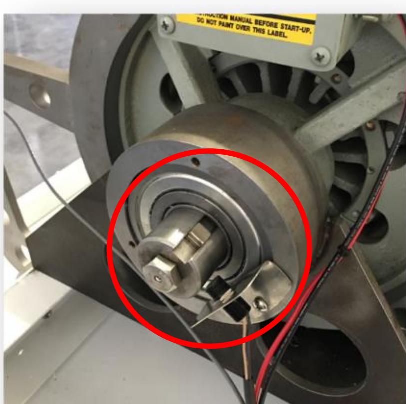
Engine Head Temperature



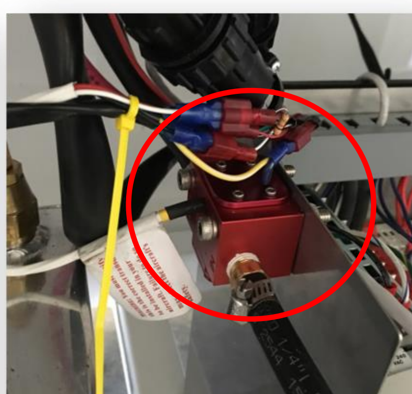
Engine Oil Temperature

Engine Exhaust Gas Temperature

Engine Performance Measurements



Engine RPM



Engine Fuel Flow

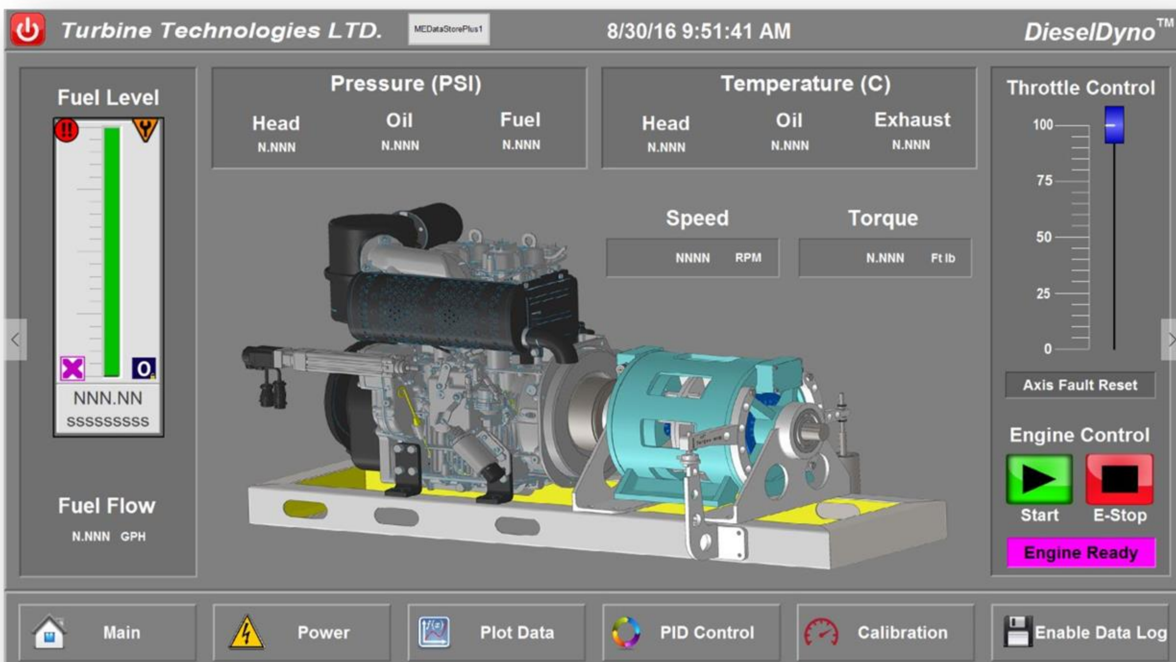
Engine Torque

Dynamometer Excitation Loading Measurements

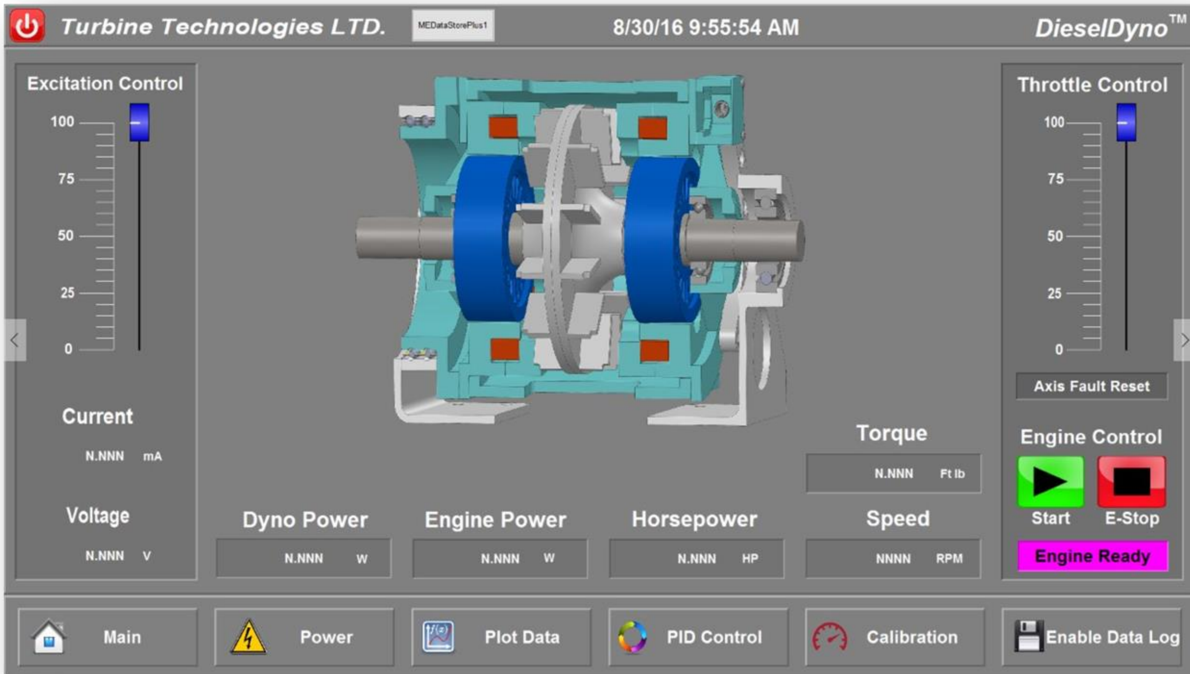
48 VDC Dyno Voltage Source

Dyno Excitation Voltage Control

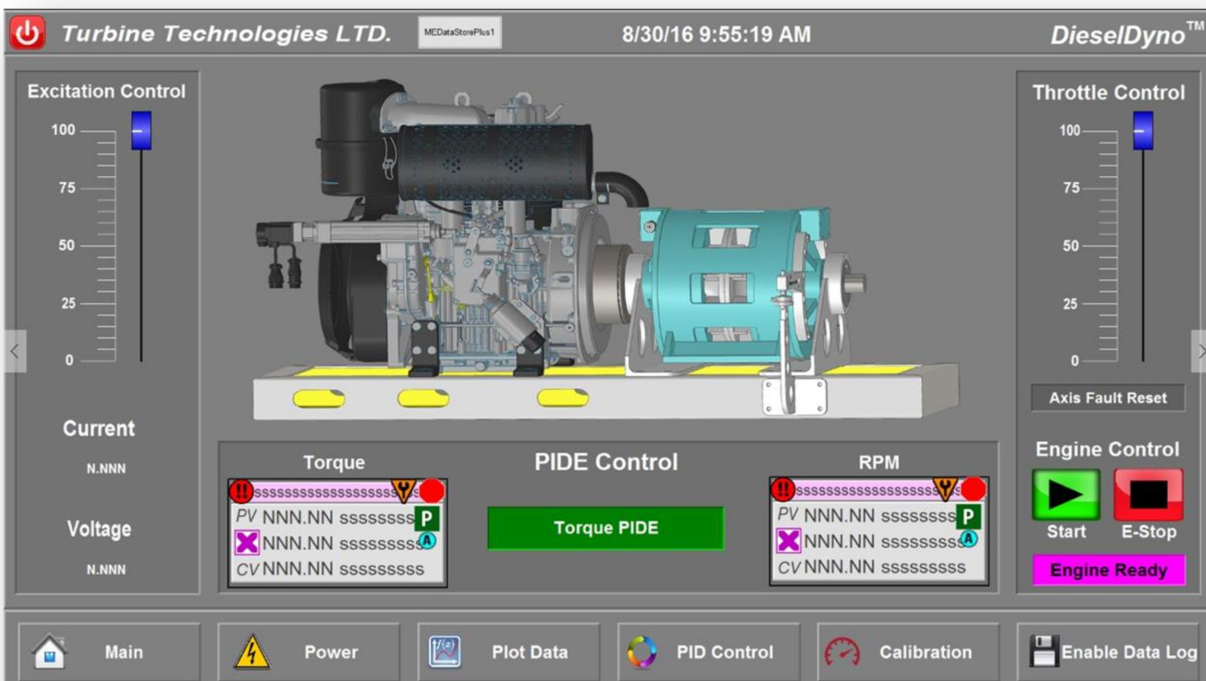
HMI Primary Dynamometer Display/Control Screens



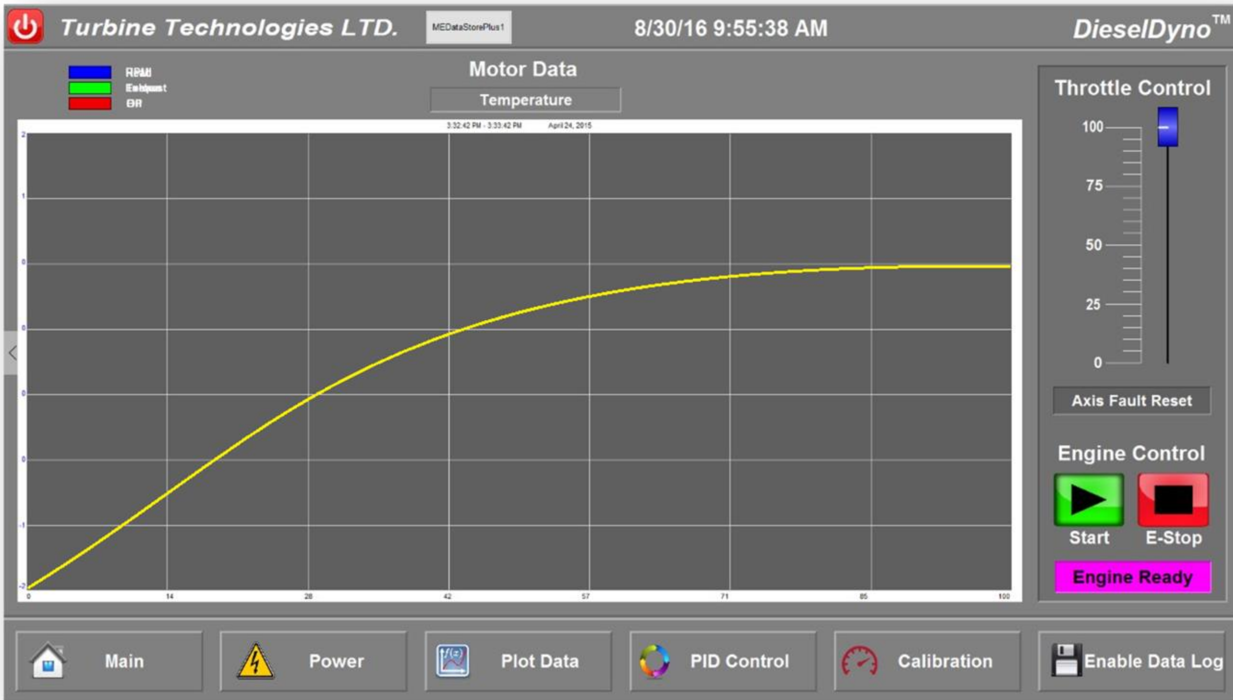
HMI Main Data/Control Screen



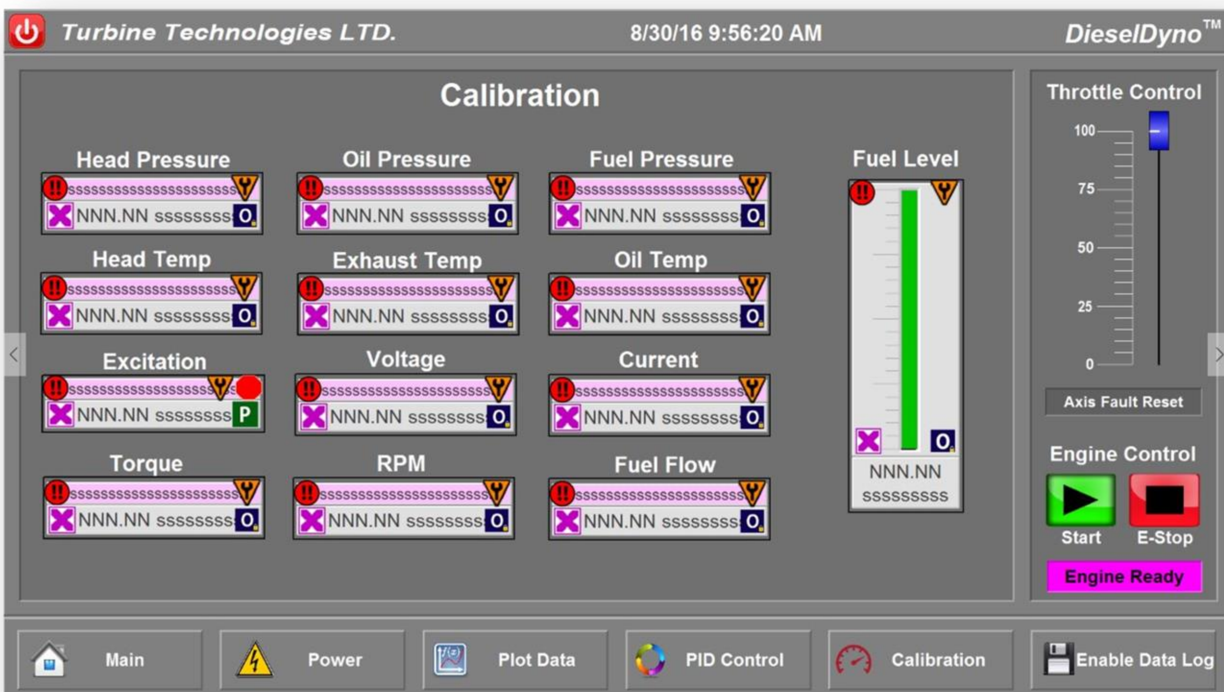
HMI Dyno Power Screen



HMI PID Programming Screen



HMI Data Plot Screen



HMI Sensor Calibration Screen

Chapter 4: Educational Opportunities

Diesel Dynatronix^{TM} puts the control of a modern industrial diesel power plant into the hands of the students.

They learn how a diesel power cycle works in operation and tie that back to classroom theory.

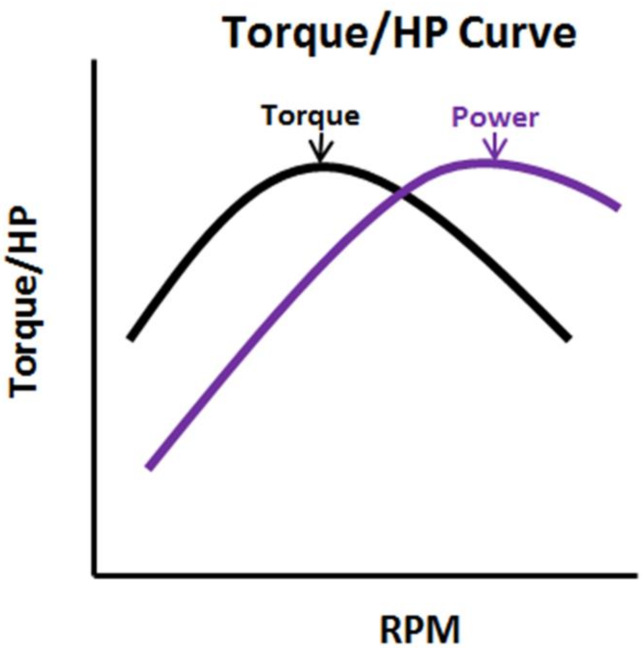
They discover an engine must be loaded to accomplish a work outcome; a dynamometer is a device that provides controlled loading so as to determine the power output/torque profile of the engine.

Engine/Dyno instrumentation is key to understanding and trusting measurements by having as much alternative/cross reference data available to verify the critical engine operational characteristics.

On-board automation takes the Diesel Dynamometer combination to a whole new level. Students can automate engine operation and loading. The PID feedback loop provides automatic engine response to changes (disruptions) in the engine loading by the dynamometer. These advanced capabilities allow students to grow their knowledge and experience from the basics of the diesel engine operation to the current state of the art engine operation methodologies.

Lab Operation 1: Performance Curves

Developing a Performance Curve (Torque/HP verses Speed) for a Diesel Engine using an Engine Dynamometer.



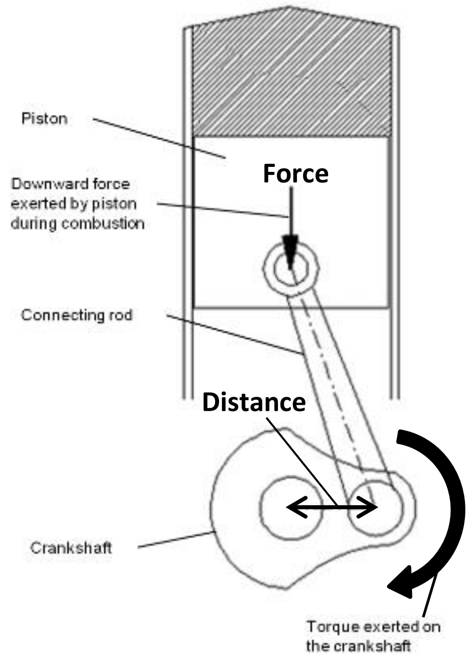
Torque/HP Curves

Knowing the performance capabilities of an engine is the primary reason to conduct and publish performance testing. Engine end-users utilize this data to source a proper engine to power a secific application. Those could be as diverse as propelling an off-road all-terain vehicle operating at various speeds with diverse terrain loading through a constant load mining industrial pump that operates 24 hours per day. Knowing the performance curves enables matching the proper "engine rig" to the application.

Building of Performance Curves

Torque

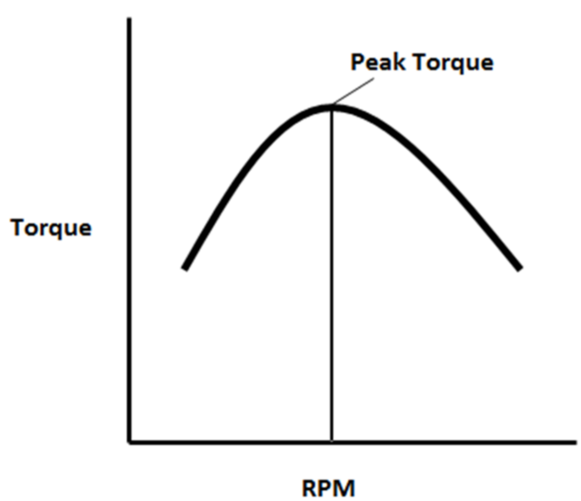
Torque in simple terms is a force that is twisting or turning, with a tendency to rotate an object around an axis. Regarding Otto and Diesel Cycle engines, it is the measure of the rotational effort applied on the engine's crankshaft by the piston (in Newton-meters or foot-pound force). Torque= Force x Distance



Torque Definition Diagram

Engines are designed and built for specific purposes and consequently their outputs vary depending on application. Torque output of automotive engines depend on their piston stroke to cylinder bore ratio, compression ratio, combustion pressures and RPM. Engines with a larger stroke length than cylinder bore diameter develop a high amount of low-end torque. The engine RPM determines the amount of torque an engine can exert.

Different engine designs provide different torque characteristics or curves, in the form of a peak type or flat curves. Most automotive engines produce useful torque output within a narrow band of the engine's entire speed range. For gasoline-powered engines, this starts around 1000 RPM and peaks in the range of 2,500 to 4,000 RPM. Diesel-powered engines start around 1,500 RPM and peak in the 2,000 to 3,000 RPM range.



Engine Torque Graph

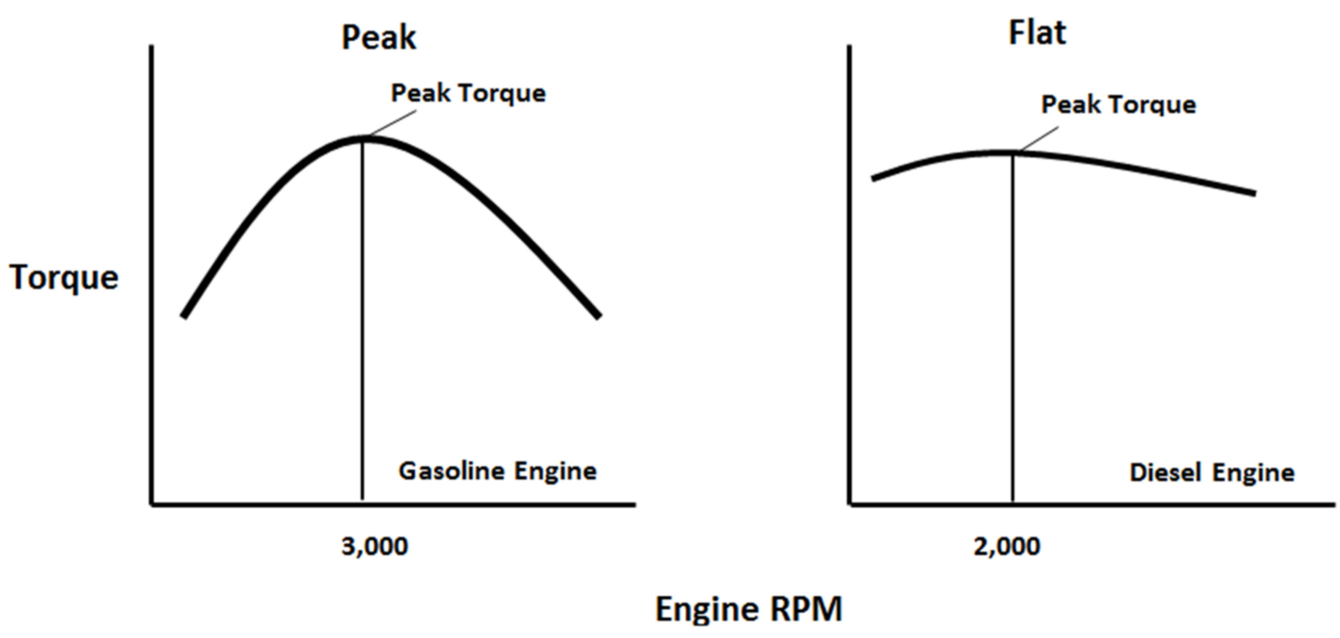
Horsepower

Torque and horse-power are considered the twin outputs of an engine. They are related and proportional to each other by speed. An engine's torque band represents its pulling ability, which dictates acceleration and driveability. This is most important while moving a vehicle from a stand-still and for climbing a slope. As a vehicle's weight or rated load increases, the torque requirement to move it increases. An engine's horse-power governs the vehicle's top speed (through transmission gear ratios), whereas the torque controls the acceleration. Weight of the vehicle and load being carried affect the acceleration rate. Horsepower is a unit of power equal to 550 foot-pounds per second (745.7 watts). If horsepower is known, the engine torque can be calculated by using: Torque=5252 x HP / RPM.

Peak and Flat Torque Curves

Most gasoline engines produce a high amount of torque at the lower end of the RPM scale. However, the torque curve exhibits a "hill shape", with the torque peaking in the middle of the engine RPM range, after which it starts to fade out rapidly. The horsepower continues to rise and reaches its maximum value later at a higher engine RPM and then fading out at the maximum engine RPM (redline).

Most modern diesel engines deliver a 'flat-curve' torque. In 'flat-curve' design, maximum torque is produced at a 'lower-to-middle-end' of the engine speed (i.e. approx. 1500 rpm onward) and its value remains almost the same or 'flat' across most of the engine speed range (2500-4000 rpm). This helps in better acceleration and effects fewer gear shifts while driving.



Peak Curve verses Flat Curve

Low-End-Torque

Manufacturers use the term “Low-End Torque” to describe an engine’s torque performance. “Low-End-Torque” is the amount of torque produced at the lower engine rpm band i.e. between 1000-2000 rpm. This rpm band is very crucial when moving a vehicle from stand-still or driving in slow-speed conditions such as in traffic. If the greater amount of torque is generated at the lower end of engine rpm, it implies that the engine has higher “Low-End-Torque” or better pulling ability at slow speeds. It also means that the engine can move the vehicle quickly from stand-still, pull heavier loads or climb a slope relatively easily, as the case may be; without revving hard.

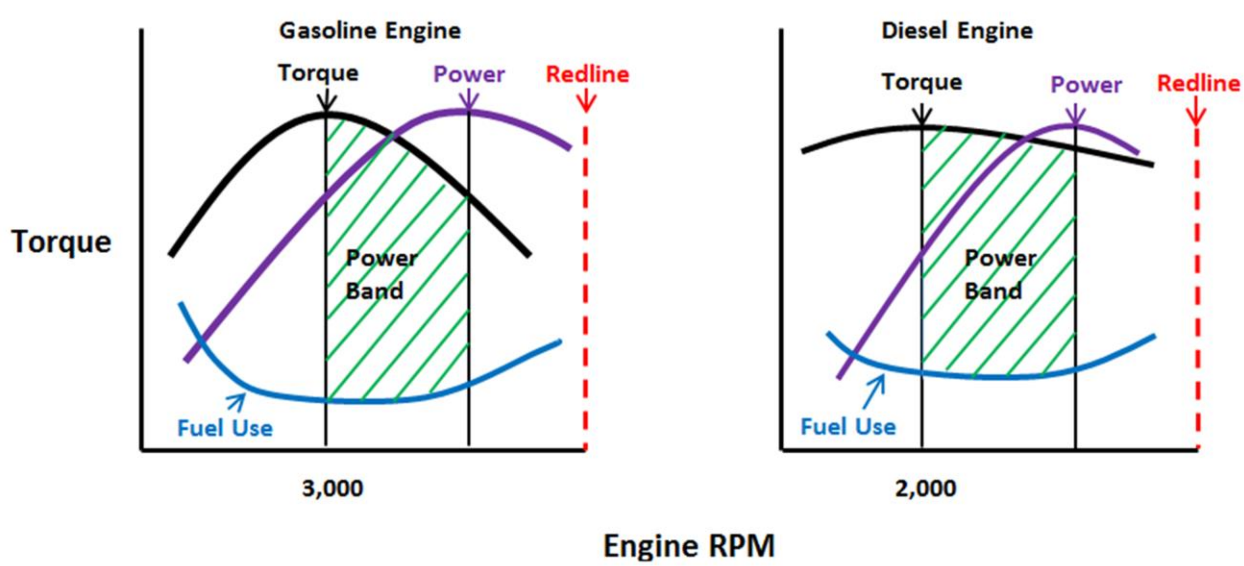
Engine Torque and Efficiency

An engine’s torque reaches its peak value at a speed where it is most efficient; that is, the engine efficiency is at its maximum at a speed where the peak-torque is produced. As the engine is raised above this speed, its torque starts to decrease due to the increasing friction of the engine’s moving parts. So, even if the engine is reved over & above the peak-torque speed; the torque doesn’t increase any further.

Engine torque is multiplied by gears. The lower the gear selected (i.e. 1st gear which has a high gear ratio); the greater is the pulling ability of the engine. Therefore, the vehicle’s pulling ability is highest in the first gear. However, if the engine is reved further in 1st gear, it reaches its limit after some time, thereby prompting the driver to shift to the next gear. In contrast, if the gears are changed before the engine torque reaches its ‘peak’ value, the vehicle might lose its acceleration as the wheels would not get enough force to rotate, compelling the driver to shift back to the lower gear.

Power Band

The best operational efficiency is obtained by changing the gears within the vehicle’s “Power-Band”. Changing gears as close to the peak torque value as possible will result in better fuel efficiency. Vehicle manufacturers publish recommended gears corresponding to vehicle speed for the best fuel efficiency.



Power Band

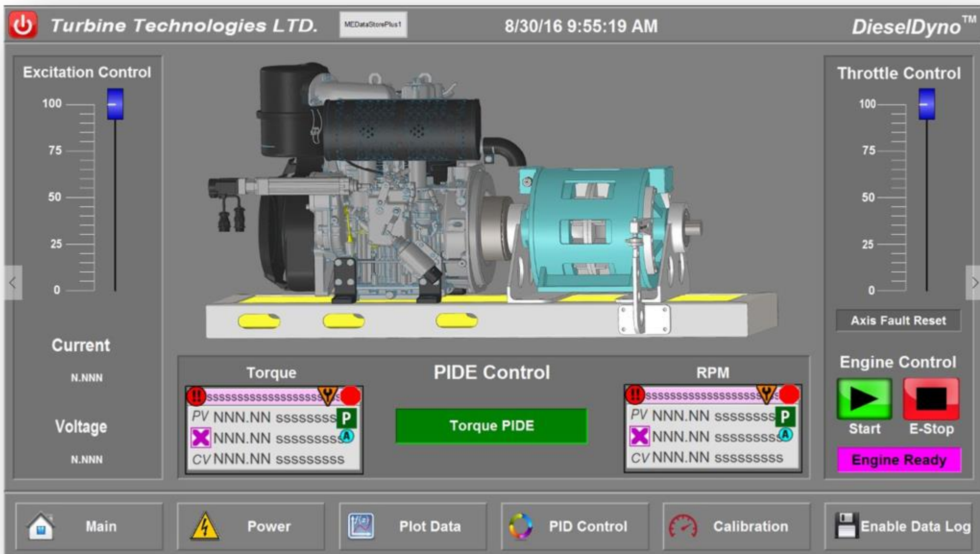
Lab Procedure

Checking

Check system fuel supply by removing front automation panel and checking fuel tank mounted on the left hand side. Add diesel fuel as needed.

Check engine exhaust line connection and free flow to outdoor environment.

Starting



Engine Operation Screen

Turn on system power master. HMI will boot up and indicate when ready.

Go to start screen

Press ENGINE START button.

Engine start sequence will initiate and engine will start and automatically adjust to idle. Allow engine to warm up before loading.

USE HMI "Throttle Control" to slowly run engine to full-power and then slowly drop it back to idle.

Check engine temperatures to confrm they are in the right magnitude over the range.

Check each DAQ screen to confirm that each sensor does provide data.

Confirm that eddy-current dynamometer is active by sliding the Excitatiton Control slider slowly upward and observing current and voltage readings below the slider and diesel engine performance changes.

If recording operational data, confirm that DAQ is operational and DATA RECORD START button is activated.

Loading Engine

1. Start data recording by pressing LOG DATA along the bottom of the HMI.
2. With engine operating at it's lowest throttle setting (idle), note engine RPM.
3. Slowly increase dynamometer excitation voltage (increae loading) until engine RPM starts to drop off. Note torque value increasing.
4. Reduce dyno excitation voltage until engine RPM returns to original idle setting.
5. Increase engine speed by 200 RPM.
6. Slowly increase dynamometer excitation voltage (increae loading) until engine RPM starts to drop off. Note torque value increasing.
7. Continue this cycle unitil engine RPM will not sustain an increase in excitation voltage.
8. Continue to increase engine RPM at the fixed excitation level until throttel reaches the end of its travel. You will experience engine RPM and torque reducing in magnitude as higher speeds are achieved.
9. Track all data elements on screen
10. Allow engine to run at full throttle for 30 more seconds.
11. Slowly reduce throttle manually while slowly reducing excitation to the dyno until engine is at idle RPM. DO NOT abruptly turn off excitation. Excitation to ZERO and engine at idle throttle.
12. After 30 seconds, press stop button on engine operation screen.
13. Press DATA RECORD STOP button in DAQ window.

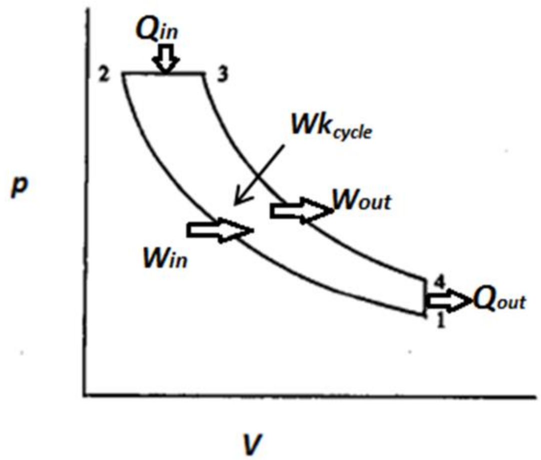
DATA ANALYSIS

Data Analysis 1: Plot Performance Curves

Data can be imported into an a spreadsheet program such as Microsoft Excel for graphing data into performance curves.

Graphing Data

Data Analysis 1: In-Depth Performance Calculations using the Air Standard Diesel Cycle



Introduction

For those students who are on an engineering track, the thermodynamics of the Air Standard Diesel Cycle (Compression Ignition) Engine are explored further in this section of the curriculum. Essentially, this topic is an application of the First Law of Thermodynamics for Closed Systems.

Air Standard

The actual Compression Ignition Cycle is a very complex topic. Our initial analysis will utilize an ideal "air standard" approach, which assumes the working fluid to be a fixed mass of air going through the complete cycle as an ideal gas. Consequently, all processes are ideal, combustion is replaced by heat addition to the air, exhaust is replaced by a heat rejection process which restores the air to its original state. This "air standard" analysis ignores the fuel with the exception of it being a heat source.

Lab Data

The data gatered from the perormance curve development will be used for our in-depth analysis.

Plotting performance curves provides data for performance calculations. To simplify calculations, the diesel engine can be analyzed with the assumption that air is the only working medium and it is a perfect gas.

The work of a cycle, Wk_{cycle}, is the enclosed area of the p-V diagram, giving us;

$$\mathbf{Wk_{cycle} = Wk_{12} + Wk_{23} - Wk_{34}}$$

For the air standard analysis (with specific heats being consant);

$$\mathbf{Wk_{12} = (1/1\text{-}k)\ (p_2V_2 - p_1V_1)\quad or\quad Wk_{12} = (mR/1\text{-}k)\ (T_2\text{-}T_1)}$$

$$\mathbf{Wk_{23} = p_2(V_3\text{-}V_2)}$$

$$\mathbf{Wk_{34} = (mR/1\text{-}k)\ (T_4 - T_3)}$$

Compression Ratio is;

$$\mathbf{r_v = V_1/V_2}$$

Cutoff Ratio is;

$$\mathbf{r_c = V_3/V_2}$$

These results can give us the net work of an idea cycle, as long as we know the properties at the 4 corners of the cycle. It should be noted that if we wish to fit the diesel cycle to actual engines and find processes 1-2 and 3-4 are not adiabatic, then polytropic diesel processes can easily be substituted. The work can then be obtained from the same equations with the *k* factor being needing to be replaced by the polytropic exponent *n*.

Kohler Diesel Engine Specifications
Cylinders: 2
Displacement: 1248 cc/76.2 cu. in.
Bore: 95 mm/3.7 in.
Stroke: 88 mm/3/5 in.
Compression Ratio: 17.5:1
Power Rating: 17.4 kW/23.3.hp
Max Torque: 75 n-m/55.3 ft. lbs.

Using the p-V diagram and data gathered for the power curve plot, let's calculate the following items of interest:

- Cut-off ratio
- Work of the Cycle, Wk_{cycle}
- Indicated Horsepower, ihp
- Mechanical Efficiency
- Mean Effective Pressure