PPU College Of Engineering and Technology

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Mechanical Engineering Department

Automotive Engineering Program

Bachelor Thesis

Graduation Project

Construction And Development Of Internal Combustion Engine Laboratory

Project Team

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Hebron – Palestine

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Abstract

This project aims to design a laboratory to give the students practical knowledge about internal combustion engines to measure power, efficiency, torque and fuel consumption and how to modify these parameters. After making a layout for this lab, the first part focuses on the electrical dynamometer and the hydraulic dynamometer to measure the power for the engines. The second part is about the computerized engine testing. This device contains an engine which has a pressure sensor inside the cylinder, so the combustion under various conditions could be monitored on the screen using data acquisition card and computer software to analyze the signal and graph the P- α diagram and the actual cycle. The third part concentrates on the computerized car dynamometers which use a dynamometer to test the whole car. The sheets will be made for the experiments so the students can make the calculations. The objectives are to operate the devices, make the tests, and analyze the signals under various operating conditions for the engine.

الفكرة لمختبر محركات الاحتراق الداخلي هو تصميم مختبر لإعطاء الطلاب المعرفة العملية عن المحركات لقياس طاقتها, كفاءتها, عزم دورانها, استهلاكها للوقود وكيفية تعديل هذه المتغيرات. الجزء الأول يركز على الديناموميتر الكهربائي والهيدروليكي لقياس قدرة المحركات.

الجزء الثاني هو عن جهاز المحرك المحوسب والذي يحتوي جهاز استشعار الضغط داخل الاسطوانة حتى يمكن رصد الاحتراق تحت ظروف مختلفة باستخدام الحاسوب و البرامج لتحليل الإشارة و رسم تخطيط للضغط مع درجات عمود المرفق بالإضافة للدورة الفعلية.

الجزء الثالث يركز على ديناموميتر السيارات المحوسب الذي يقوم باختبار السيارة بالكامل. وسيتم عمل اوراق التجارب لكل جهاز بحيث تكون جاهزة للطلاب السنة القادمة.

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Chapter One

Introduction

1.1 Introduction

Internal-Combustion Engine is any type of machines that obtains mechanical energy directly from the expenditure of the chemical energy of fuel burned in a combustion chamber.

Internal combustion engines are the main source of power in the transportation vehicles and a lot of other applications .There is a great tendency to develop these engines to increase their efficiency, power, reducing fuel consumption and controlling its emissions. From this point , the importance of internal combustion engine raised. In order to achieve these goals, the internal combustion engine laboratory must be available.

The laboratory is designed to provide direct experience with the experimental methods used in internal combustion engine research and development. Through the using of laboratory, a set of engine performance and emissions data will be taken from an operating spark-ignition engine and compression-ignition engine using different types of dynamometers.

Another part of this project deals with computerized system that is used to measure pressure inside combustion chamber by using pressure sensor. The data will be processed, analyzed and interpreted in the context of the course lecture material.

Finally, this project will deal with the chassis dynamometer that measures power, torque for the engine and the wheels. The other functions of the chassis dynamometer that can be made are the load simulation and the RPM tests.

1.2 Lab. Equipments

In the university, the devices which used in the university is three devices some of it is old and need rehabilitation and others is new and will be connected and programmed. This devices is been selected as close to the standers of internal combustion engines laboratories and to be as assistance to the internal combustion engines course.

1.2.1 Dynamometers:

In real life, vehicles always operate against a resistance. This resistance could be rolling friction, slope, air or inertia resistance. The dynamometer loading simulates the total of these resistances. Therefore the steady state performances of internal combustion engines are tested on dynamometers. The dynamic testing of engines mounted on vehicles are done on chassis dynamometers. The dynamometers used for engine testing may be hydraulic or electrical.

The function of the dynamometer is to impose variable loading conditions on the engine under test, across the range of engine speeds and durations, thereby enabling the accurate Measurement of the torque and power output of the engine[1].

The following dynamometers are available in the lab. Each of them has its own distinct advantages and disadvantages compared to those of its rivals.

1) Hydraulic Dynamometer

The use of hydraulic dynamometer is the best selection to measure the performance of the internal combustion engines, by sequence of experiments under a different operation conditions , the student can do this experiment to study the engine performance. The basic working principle of the dynamometer is that the coupling force arises from the change in momentum of water as it is transported from the rotor vanes and back. This water circulation absorbs the engine power under testing.

In this dynamometer, water flow proportional to desired applied load is used to create resistance to the engine. A controlled flow of water is directed at the center of the rotor in each absorption section. This water is then expelled towards the outside of the dynamometer body by centrifugal force as shown in figure 1.1.

This dynamometer is available in the laboratory. It is connected by coupling mechanism to spark ignition engine. This engine works on two different types of fuel: the first is gasoline and the other is LPG (liquid petroleum gas). The power and torque measurements at different load and speed are made for both fuels. The taken results used to plot the power and the torque curves. Other tests can be done on this engine, such as the fuel consumption.

This device does not work and it needs maintenance for the engine and the hydraulic dynamometer. The importance for this dynamometer is that it uses a real vehicle engine. Right now it is maintained and calibrated and working.

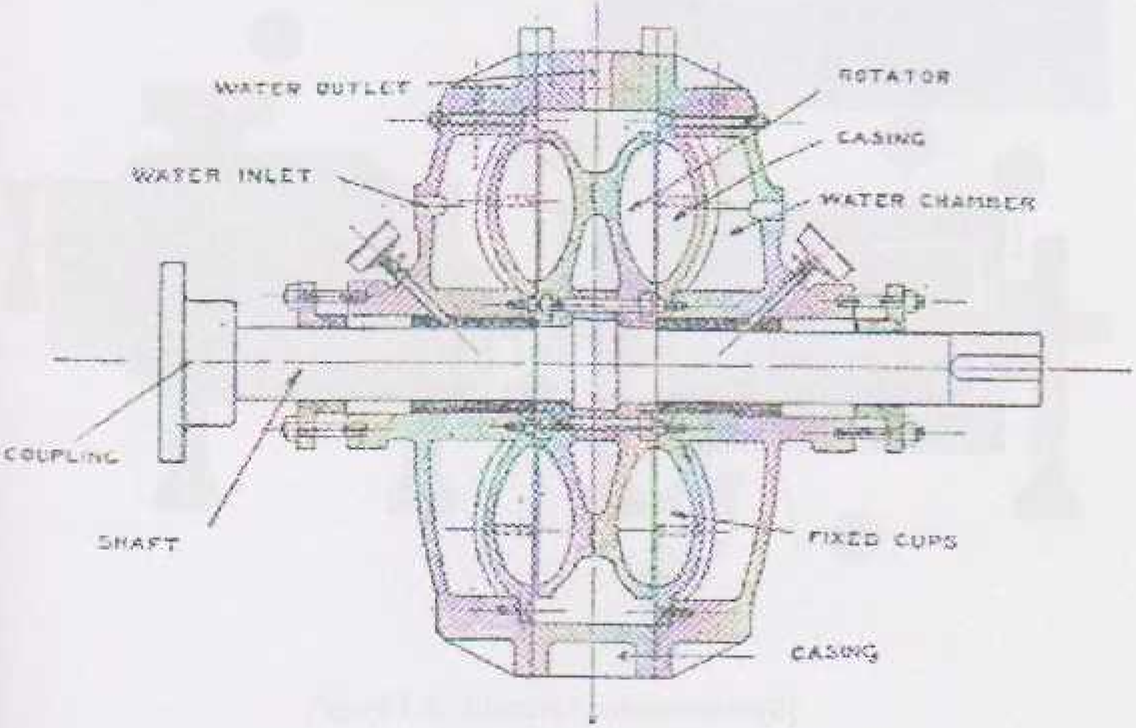


Figure 1.1: Hydraulic dynamometer parts[2]

2) Electrical Dynamometers

This dynamometer is connected to a diesel engine to measure the brake power of this engine and the brake torque at various speeds and various loads to plot the power and torque curves.

However the generator may be cradled and the torque exerted by the stator frame may directly be measured. This torque arises from the magnetic coupling between the armature and stator and is equal to the engine brake torque. DC or AC type electric generators of may be used in these dynamometers. AC type electric dynamometers have better dynamic response characteristics and are used in cycle simulation tests.

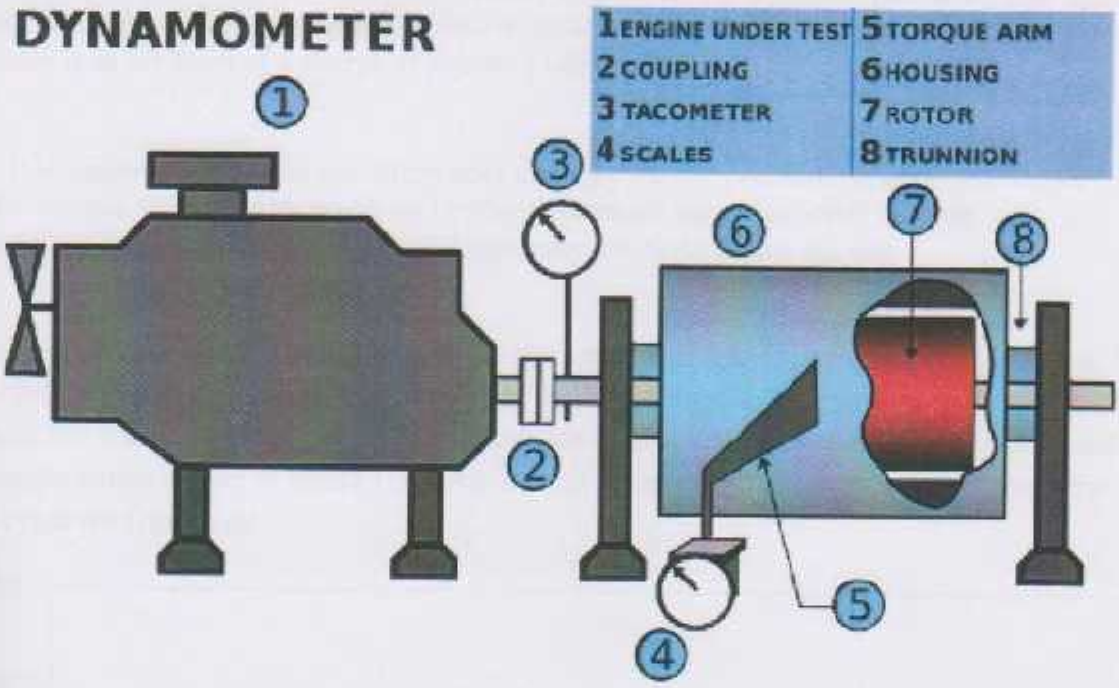


Figure 1.2: Electric dynamometers[2]

1.3 Computerized Spark Ignition Engine:

1.3.1 Cylinder Pressure Measurement

The primary source of information about the combustion that takes place inside the cylinders of reciprocating internal combustion engine is the cylinder pressure. The cylinder pressure can be measured using piezoelectric pressure sensor. The output from a piezoelectric transducer is in the form of a charge or signal is taken and sent to the amplifier.

It is important to notice the differences among cylinder pressure versus crank angle, cylinder volume versus crank angle, and cylinder pressure versus cylinder volume because these data form the basis of the classic pressure and volume curves.

The pressure sensor is used to measure the pressure inside the cylinder and the sensor is connected to data acquisition system that sends the information and signal to the computer. The computer has a software to show the graph that clarifies the relation between the pressure and the crank angle which shown in figure 1.3 ,pressure and volume P-V diagram and also graph the actual cycle for Otto-cycle .

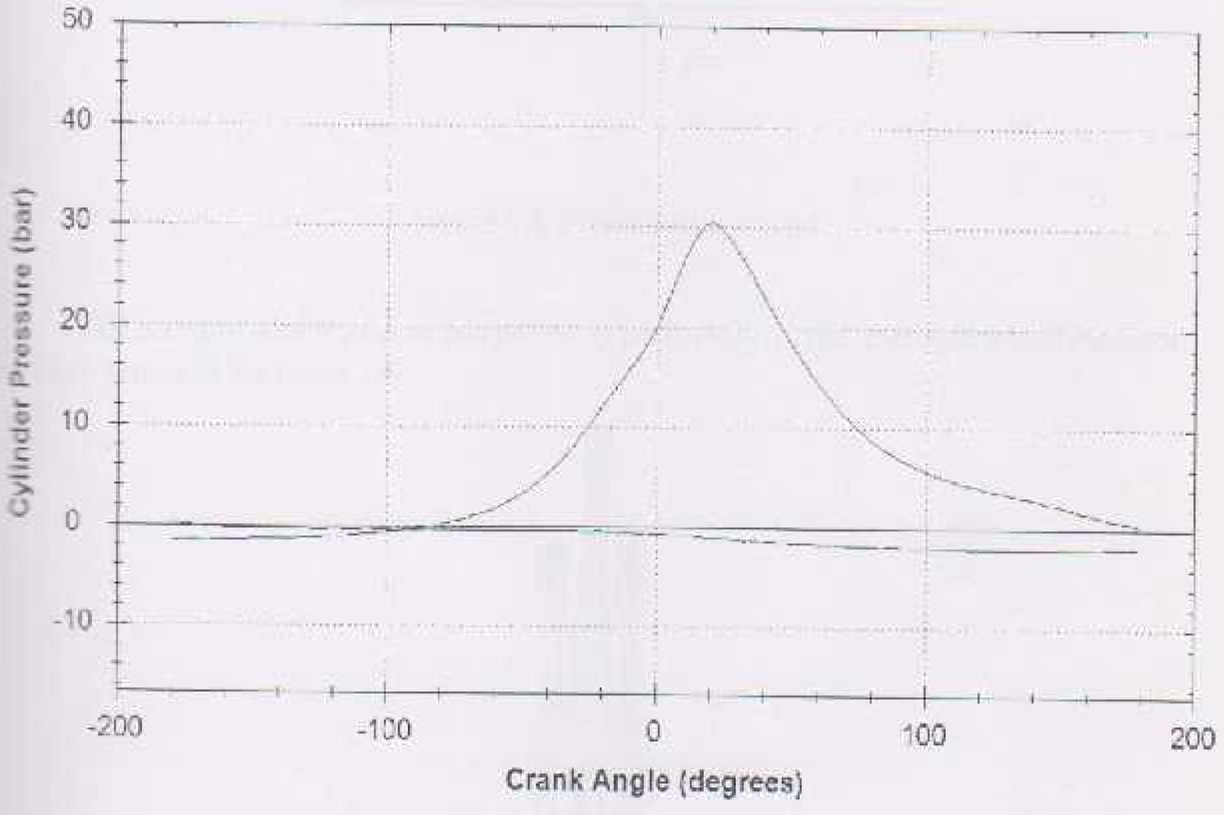


Figure 1.3: Combustion chamber pressure signal[3]

1.3.2 The Piezoelectric sensor

The physical principle behind piezoelectric pressure transducers is the piezoelectric effect, first discovered by Pierre and Jacques Curie in 1880. The piezoelectric effect causes a quartz crystal to become electrically charged when there is a change in the external forces acting on it.

When using a piezoelectric transducer as the sensing element in a data acquisition system, the element has to be connected to a charge amplifier, which converts the electrical charge to a voltage or a current.

Illustration of a piezoelectric crystal (e.g. quartz) with a force being applied to it in figure 1.4. When the force is applied to the crystal, the electrons within the crystal redistribute to make one side of the crystal positively charged and the other negatively charged.

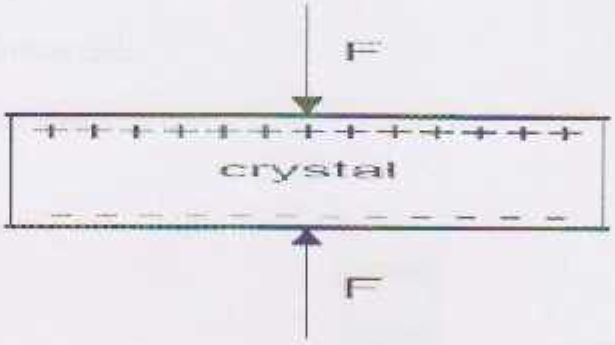


Figure 1.4: Piezoelectric crystal

The pressure sensor used in this project is piezoelectric type. Piezoelectric combustion pressure sensor in the figure 1.5.

Figure 1.5. Piezoelectric pressure sensor[4]

3) Chassis Dynamometer

There is another type of the dynamometers used in this laboratory; this dynamometer is used to measure the power, the torque of the engine and the output power to the wheel by using roller eddy current dynamometer that shown in the figure 1.6. This advanced dynamometer has multifunction to make and multi test can be measure.

The tests that the chassis dynamometer can make are:

1 – Measure the power output from the engine and the wheel.

2- Measure the torque output from the engine and the wheel.

3- Plot the output curves of the measurements.

4- Load simulation test.

5- Speedometer check

Figure 1.6: The chassis dynamometer[5]

1.4 The laboratory layout is shown in the figure 1.8

The layout is set as shown to the best way in which the devices arranged in the laboratory, the devices arranged depending on the area in the laboratory and the ventilation of the exhaust gas to be close to the window and the location of the voltage supply inside the laboratory.

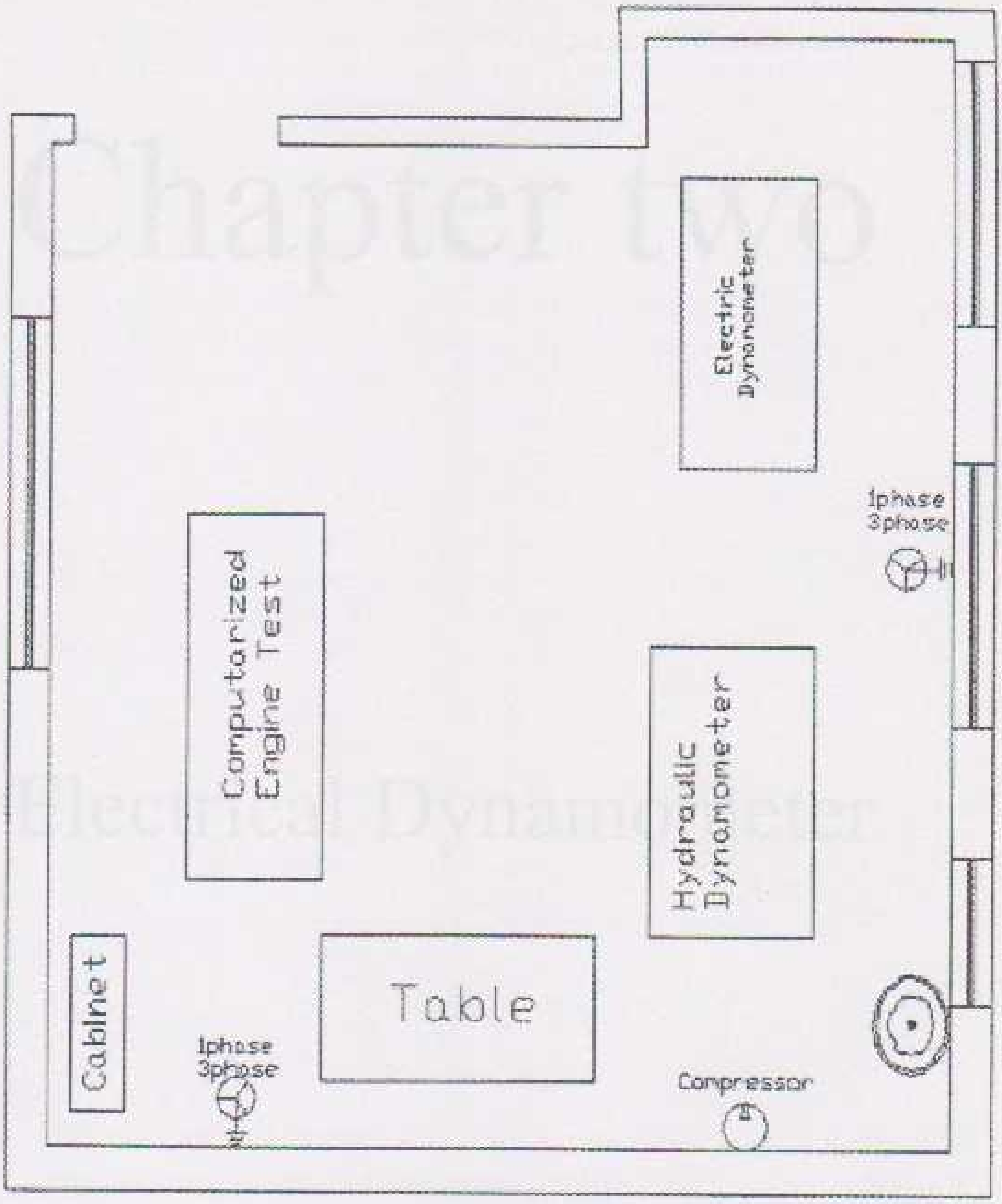


Figure 1.8: laboratory layout

Chapter two

Electrical Dynamometer

2.1 Introduction

Electric motor/generator dynamometers are a specialized type of adjustable-speed drives. The absorption/driver unit can be either an alternating current (AC) motor or a direct current (DC) motor. Either an AC motor or a DC motor can operate as a generator that is driven by the unit under test or a motor that drives the unit under test. When equipped with appropriate control units, electric motor/generator dynamometers can be configured as universal dynamometers. The control unit for an AC motor is a variable-frequency drive and the control unit for a DC motor is a DC drive. In both cases, regenerative control units can transfer power from the unit under test to the electric utility. Where permitted, the operator of the dynamometer can receive payment (or credit) from the utility for the returned power[2].

In engine testing, universal dynamometers can not only absorb the power of the engine, but also drive the engine for measuring friction, pumping losses and other factors. Electric motor/generator dynamometers are generally more costly and complex than other types of dynamometers.

The dynamometer to be used in the lab is an engine dynamometer which measures torque directly from the engine's crankshaft (or flywheel), when the engine is removed from the vehicle. These dynamometer do not account for power losses in the drivetrain, such as the gearbox, transmission or differential etc.

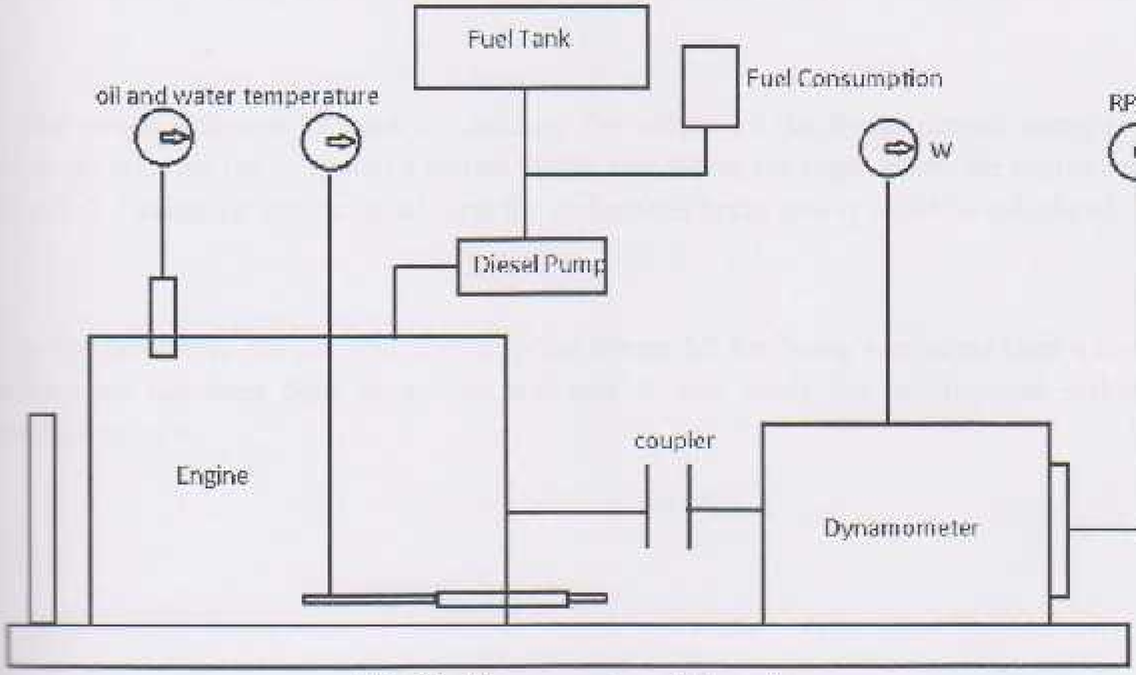


Fig 2.1: Dynamometer with engine

2.2 Engine test unit components as shown in figure 2.1:

1) Engine
2) Electrical dynamometer
3) Coupling
4) Fuel tank
5) Fuel pump
6) Tachometer
7) Rotor
8) Torque arm
9) Fuel consumption meter
10) Temperature sensor

2.3 Principle of operation

At the beginning the electrical dynamometer will be used as a starter(electrical motor) to start the engine rotation movement. As the engine starts to move the coupling will transfer the torque from the engine to the dynamometer. A load will be applied to the dynamometer trying to stop the engine at different speeds, at this point torque can be calculated using the torque arm.

The torque arm can be used to calculate the torque on the dynamometer using a spring balance to measure the force and a known length arm. From these parameter the torque could be calculated. Taking the engine speed form the tachometer brake power could be calculated.

In the laboratory the test unit shown in the figure 2.2 has being connected then a complete maintenance has been done to it. The test unit is now ready for running and making the experiments on it.

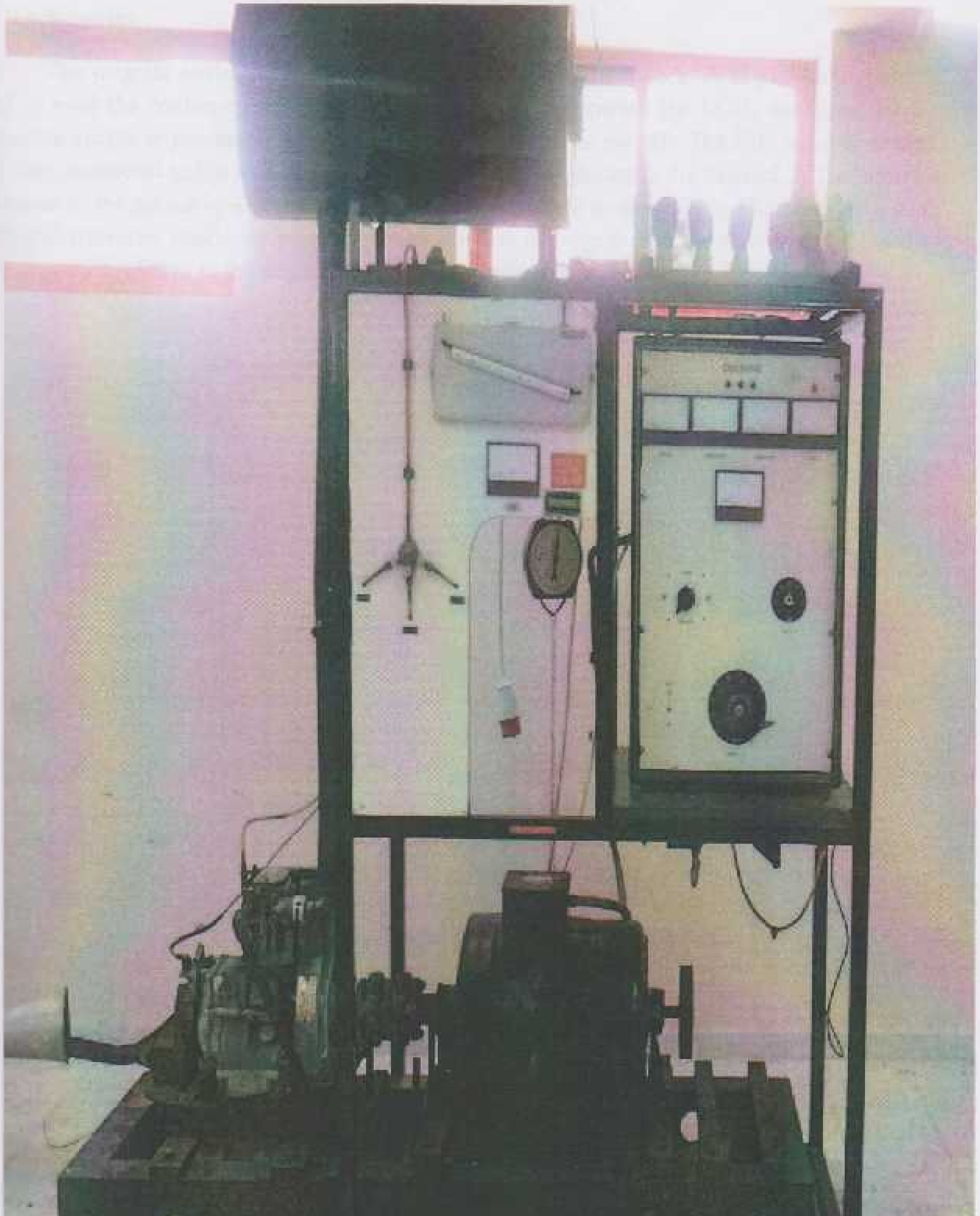


Fig 2.2: Engine test unit.

2.4 Tachometer

The original analog tachometer in the test unit does not work. A digital tachometer is used to read the engine speed instead of the old one. To operate the LCD, the signal by the induction sensor is processed in the microprocessor which is pic18F. The PIC is programmed, and then connected to the sensor. The LCD is connected as shown in the figure 2.3. The signal is produced in the sensor by electrical induction and transferred to the PIC. In The first step analog to digital converter inside the microprocessor convert the signal then the signal is processed to give an output relative to the engine speed which finally displayed on the LCD.

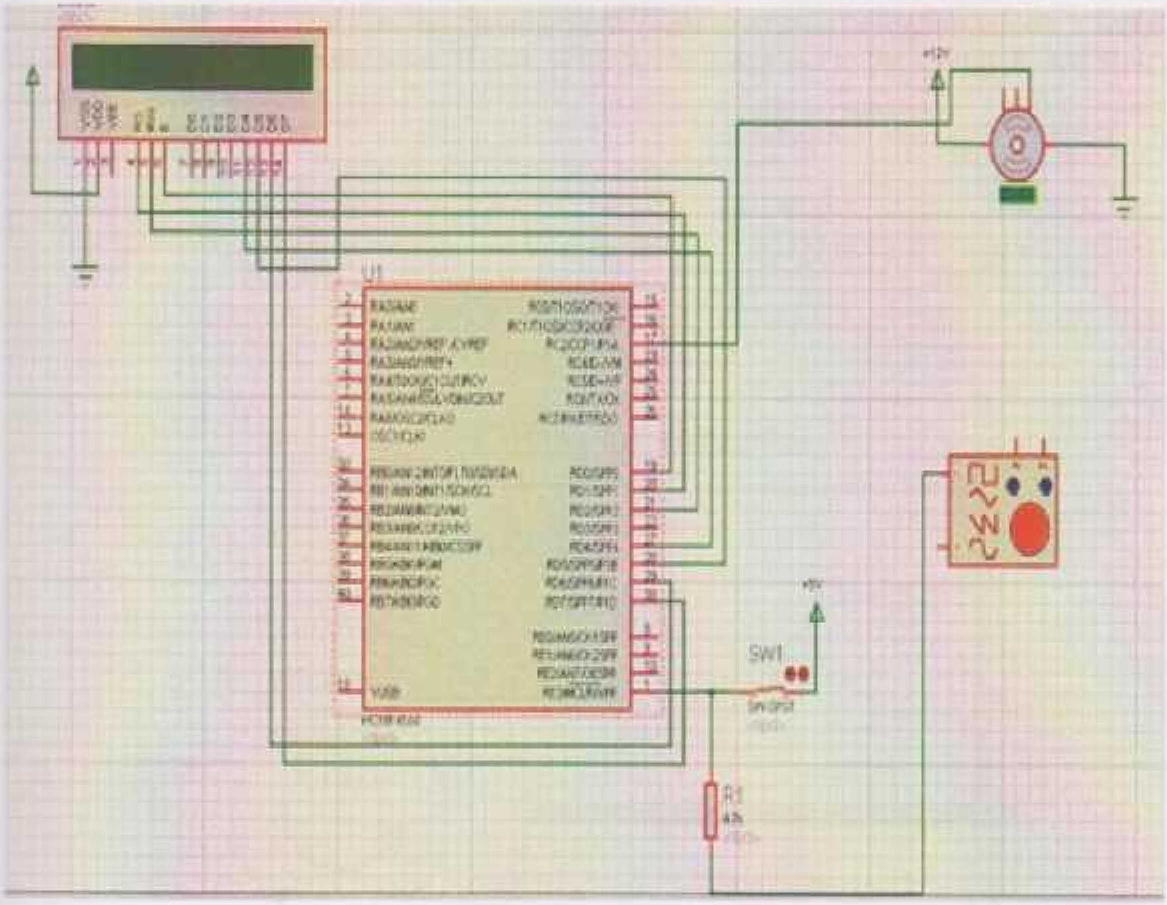


Figure 2.3 : Circuit Diagram Of PIC Connection

2.5 Engine parameters

To analyze actual cycle of an engine one needs to connect the engine to a dynamometer for controlling the speed and applying a load. one also needs to instrument the engine to measure such parameter as fuel flow rate, cylinder pressure versus volume ,the residual friction ,the coolant temperature, the oil temperature, and the spark of fuel injection timing.

The method most commonly employed to measure torque is shown in the figure (2.3). The dynamometer is supported by bearing and restrained from rotation only by a strut which is Connected to a load cell. Whether the dynamometer is absorbing or providing power, a reaction torque is applied to the dynamometer. Hence, if the force is applied to the strut is F, and then the torque applied to the engine is:

Engine torque (T):[N.m]

$$T=F*R \tag{2.1}$$

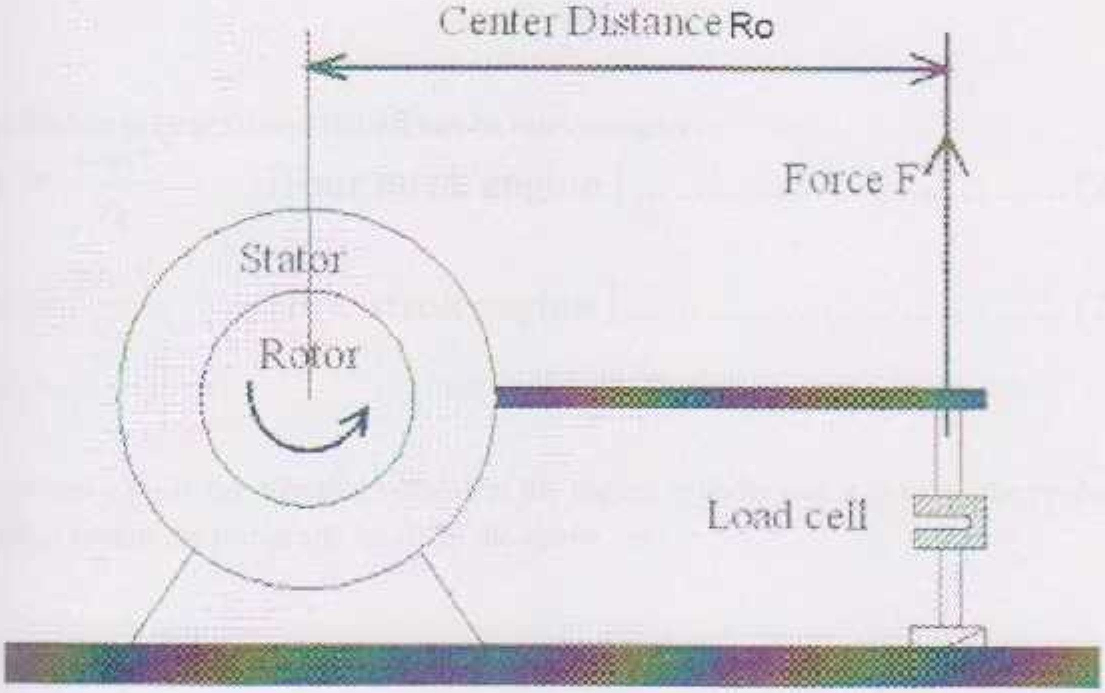


Fig 2.3: Calculation of torque[1]

The power delivered from the engine and absorbed by the dynamometer is called brake power, this power is the usable delivered by the engine to the load ,and it is equal the product of torque and angular speed as:

$$Bp = \frac{2*\pi*N*T}{60} * 10^{-3} \quad (2.2)$$

Where:

Bp: brake power [KW]

T: engine torque [N.m].

N: engine speed [rpm].

Note that torque is a measure of an engine ability to do work. power is the rate at which work is done.

A parameter that scales out the effect of engine size is the brake main effective pressure, which is defined as the work per unit displacement volume. Theoretically, The constant pressure can be exerted during each power stroke to produce power (work) equal to brake power ,is called (bmep).

Mean effective pressure (mep) [N/m^2] can be calculating by :

$$mep = \frac{4*\pi*T}{V_d} \quad \text{[Four strok engine]} \quad (2.3)$$

$$mep = \frac{2*\pi*T}{V_d} \quad \text{[Tow strok engine]} \quad (2.4)$$

where , V_d is the effective volume in the engine cylinder and it is equal the product of the surface area of the piston and length of the stroke , as :

$$V_d = A * S \quad (2.5)$$

Where :

A: the surface area of the piston [m2].

S: the length of stroke[m].

From the definition, the brake power can be determined from the mean effective pressure as:

$$Bp = \frac{bmep * V_d * n}{60} \quad \text{.......................................} (2.6)$$

Where

$$n = \frac{N}{2} * \text{number of cylinder (four stroke engine)} \quad \text{..................} (2.7)$$

$$n = N * \text{number of cylinder (two stroke engine)} \quad \text{..................} (2.8)$$

Unit of N is [rpm].

The power of the combustion gas exerted on the head of the piston is called indicated power (Ip) . it is expressed as :

$$Ip = \frac{Imep * V_d * n}{60} \quad \text{.......................................} (2.9)$$

Imep: indicated main effective pressure[N/m^2] .

Ip :indicated power[w].

The brake specific fuel consumption ,bsfc,is a measure of engine efficiency .In fact bsfc and engine efficiency are inversely related, so that the lower the bsfc the better the engine . By the definition, the brake specific fuel consumption is the fuel flow rate $\dot{m}_{fuel}$

Per the brake power BP. brake Specific fuel consumption (bsfc)[g/kw.h]:

$$bsfc = \frac{\dot{m}_{fuel}}{bp} \quad \text{.......................................} (2.8)$$

The mass fuel flow rate can calculated by using a stop watch to know the time of known the volume of fuel consume and the density. Mass flow rate $\dot{m}_{fuel}$ [kg/s] given by :

$$\dot{m}_{fuel} = \frac{V_* \rho}{\tau} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

Where :

V: a known fuel volume[m^3]

P : The density of the fuel [kg/m^3].

τ: The time of fuel consumption[sec]

The thermal efficiency is defined the power per the lower heating value and mass fuel consumption .The brake thermal efficiency ($\eta_{th,b}$) [%] given by:

$$\eta_{th,b} = \frac{bp[w] * 3600}{\dot{m}_{fuel}\left[\frac{kg}{h}\right] * LHV\left[\frac{J}{kg}\right]} * 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.11)$$

Where LHV is the lower heating value , which it is defined the heat released when one kilogram of fuel burned in complete combustion .

Indicated thermal efficiency ($\eta_{th,i}$) [%] given by :

$$\eta_{th,i} = \frac{bi[w] * 3600}{\dot{m}_{fuel}\left[\frac{kg}{h}\right] * LHV\left[\frac{J}{kg}\right]} * 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.12)$$

The thermal efficiency dependant on many parameter likes equivalence ratio ,compression ratio, engine speed ,fuel type ,ignition timing ,the wall temperature and other .

Another performance parameter of importance is the volumetric efficiency (ζ_v)

. It is defined as the actual volume flow rate of air inducted in to cylinder divided by the theoretical volume at the stander temperature and pressure.

$$\eta_v = \frac{\dot{v}_{act}}{\dot{v}_{the}} \quad \text{...} (2.13)$$

Where the actual volume flow rate of air can be measured using the air flow meter .

$$\dot{v}_{the} = V_d * n \quad \text{...} (2.14)$$

The volumetric efficiency is influenced by number engine parameters including valve size, valve timing ,valve lift ,and intake manifold configuration .

The mechanical efficiency of an engine is defined as the ratio of the brake power to the actual net indicated power .

Mechanical efficiency (η_m) is the ratio between the brake power and the indicated power .

$$\eta_m = \frac{Bp}{Ip} * 100\% \quad \text{..} (2.15)$$

The air –fuel ratio is defined as the ratio of the mass flow rate of the air to the mass flow rate of the fuel ; this ratio will be stoichiometric if the products of the combustion reaction are only carbon dioxide and water and nitrogen .The air –fuel ratio (A/f)[%] given by :

$$A/_F = \frac{\dot{m}_{air}}{\dot{m}_{fuel}} * 100\% \quad \text{..} (2.16)$$

The fuel equivalence ratio (ϕ) is defined as the actual fuel-air ratio divided by the stoichiometric fuel-air ratio .

$$\phi = \frac{F/A_{act}}{F/A_{stl}} * 100\% \quad \text{..} (2.17)$$

2.6

Experiments

Engine Performance Calculation

Objective:

1) Measure the torque of the engine
2) Calculate engine power
3) Measure the engine brake specific fuel consumption
4) Get known with engine volumetric efficiency

Theory

Engine torque is normally measured with a dynamometer. The engine is clamped on a test bed and the shaft is connected to the dynamometer rotor. Figure 2.4 illustrates the operating principle of the dynamometer. The rotor is coupled electromagnetically, hydraulically, or by mechanical friction to a stator, which is supported in a low friction bearings. The stator is balanced with the rotor stationary. The torque exerted on the stator with the rotor turning is measured by balancing the stator with weight, springs, or pneumatic means.

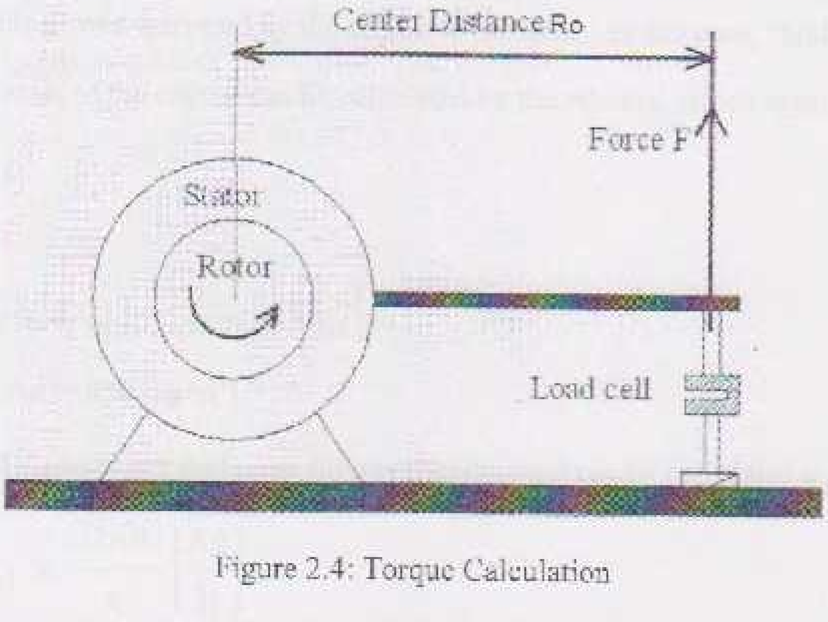


Figure 2.4: Torque Calculation

Using the rotation in fig.1, the torque exerted by the engine is:

$$T = F \times R \ [N.m] \quad \text{..........} (1.1)$$

Where:

F: the force acting on the load cell.

R: the distance between the center of the rotor and acting force= [25cm].

Where:

F: the force acting on the load cell.

R: the distance between the center of the rotor and acting force= [25cm].

The brake power delivered by the engine and absorbed by the dynamometer is the product of the torque and angular speed:

$$Bp = \frac{2 * \pi * N * T}{60} * 10^{-3}$$

Where:

N: is the crankshaft rotation speed [rev/s].

T: the torque exerted by the engine [N.m].

Note that the torque is a measure of an engine's ability to do work; power is the rate at which work done.

The value of engine power measured as describe above is called brake power. This power is the usable power delivered by the engine to the load – in this case, "brake".

The fuel mass of the engine can be calculated by the relation, which says:

$$m_{fuel} = V * \rho$$

Where:

V=the volume of fuel, which can e used [m^3].

ρ= the density of fuel= 820 [kg/m^3].

Another definition is a fuel mass flow per second and can be calculated as in the relation:

$$\dot{m}_{fuel} = m_{fuel} \times \frac{3600}{\tau}\left[\frac{kg}{h}\right]$$

Where

T: the time which can be calculated[s].

In engine test, the fuel consumption is measured as a flow rate-mass flow per unit time. A more useful parameter is the specific fuel consumption (sfc) – the fuel flow rate per unit power output. It measures how efficiently an engine is using the fuel supplied to produce work:

$$sfc = \frac{\dot{m}_{fuel}}{bp}$$

and we have the brake thermal efficiency, which would be estimated by this equation:

$$_{th,b} = \frac{bp[w] * 3600}{\dot{m}_{fuel}\left[\frac{kg}{h}\right] * LHV[\frac{J}{kg}]} * 100\%$$

Where:

LHV: lower heating value of diesel engine= 42.5[J/Kg].

The final parameter we have in this experiment is air mass flow while its equation is:

$$\dot{m}_a = 4.87 \times 10^{-4} (2.44 \times \Delta p)^{0.5}$$

Where:

Δp= pressure difference which equals:

$$\Delta p = \rho \times g \times h \times \sin\theta$$

Where:

ρ=density of water=100[Kg/m^3].

g:acceleration of gravity = 9.8[m/s^2].

θ:14.

The last thing is the volumetric efficiency which equal:

$$_v = \frac{\dot{V}_{act}}{\dot{V}_{the}}$$

Where:

$\dot{V}_{act}$: the actual volume $= \frac{\dot{m}_a}{\rho}$.

$\dot{V}_{theoritical}$= cylinder area*n.

Procedure:

a) Brake power calculation

Brake power can be measured first by turning the engine on then apply the load by the dynamometer, we can then see the force on the balance in the Newton and engine rotation speed as shown in the figure 2.5 and 2.6

Figure 2.5 : Newton Meter

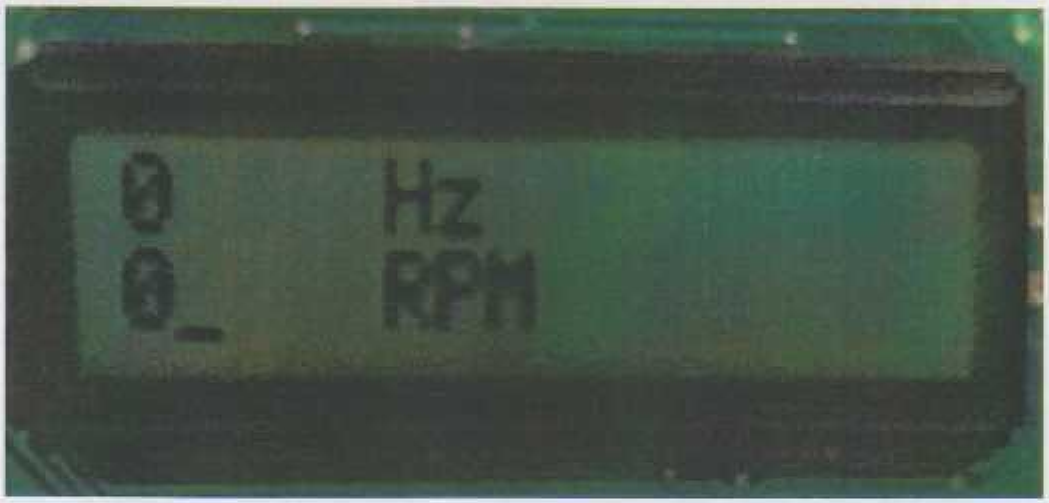


Figure 2.6 : RPM Counter

b) Brake specific fuel consumption.

Starting by open the tank and the engine valve, after the gauge filled with the fuel, the tank valve should be closed and then use stop watch to calculate the time to consume 10ml as sown in the figure 2.7 .

Figure 2.7 : Fuel Flow Meter

c) Air mass calculation.

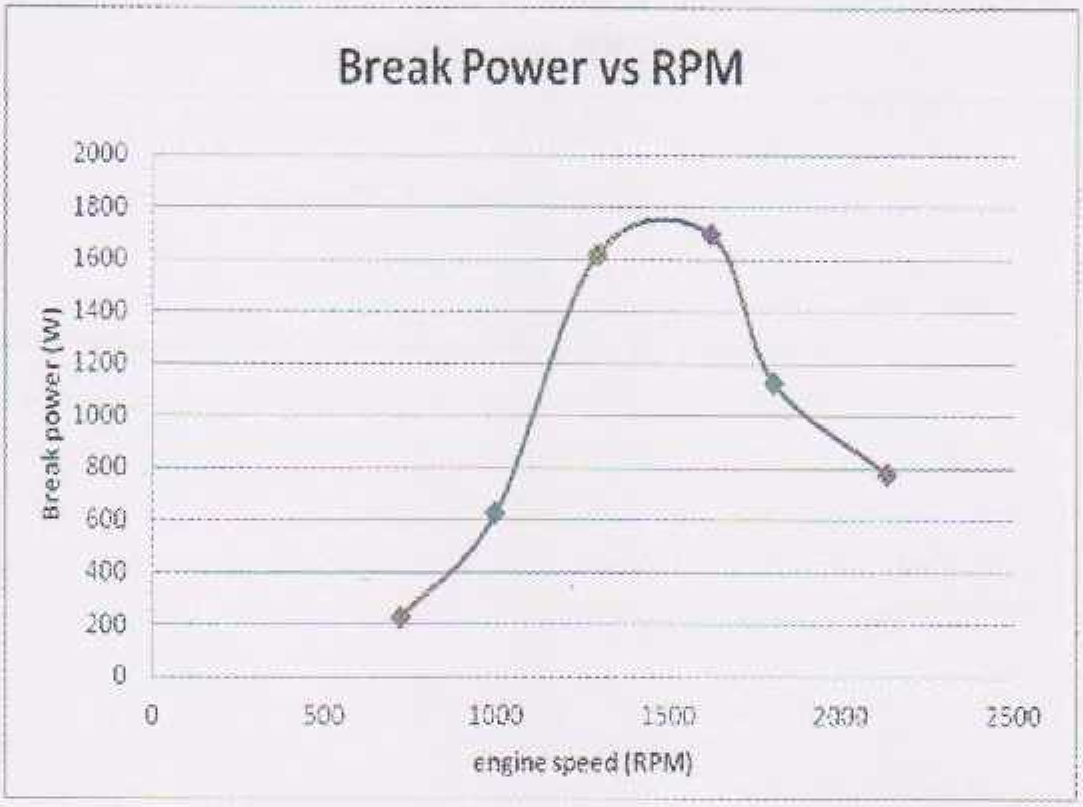
As engine operated at specific speed we can read the air flow by notice the displacement of water in mm as shown in the figure 2.8 .

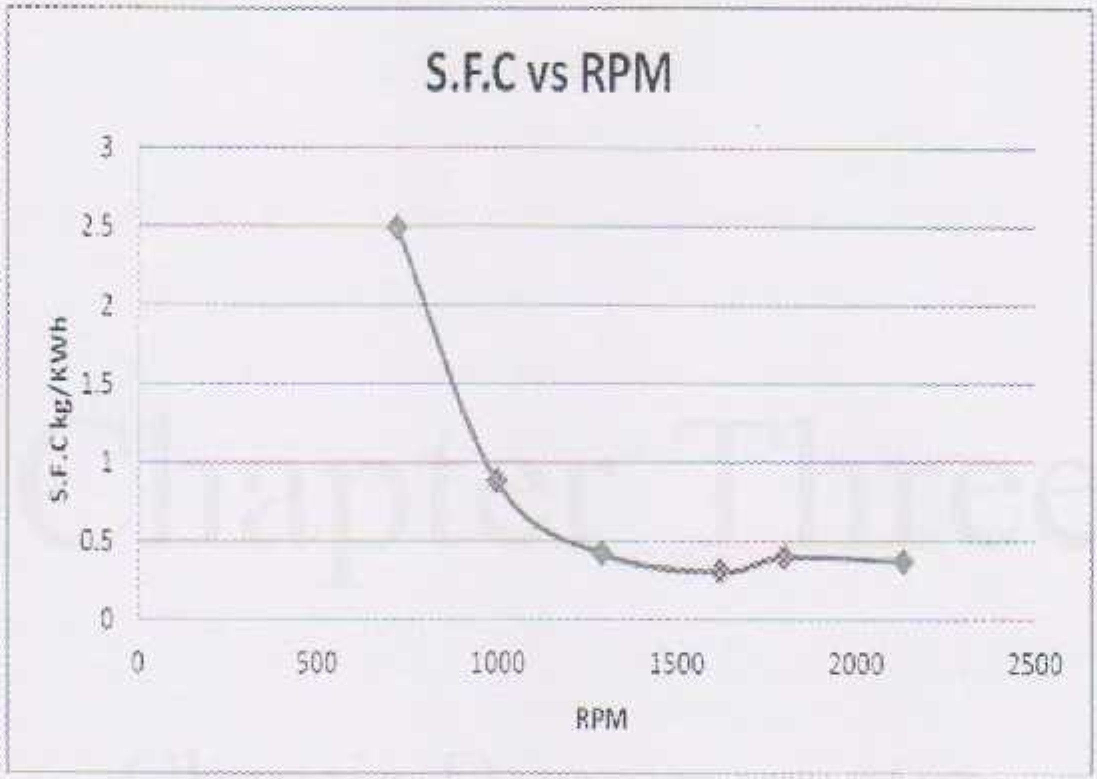
Figure 2.8 : Air Flow Meter

Calculation:

Table 2.1 : Measurement Results

N RPM	T N.m	m_{fuel} Kg	$\dot{m}_{fuel}$ Kg/h	Sfc Kg/KWh	$\eta_{th,b}$	$\dot{m}_a$ Kg/h	Bp W	η_v	A/F
720	3	8.2	0.5634	2.492	33.99	5.96	226.08	14.62	10.59
996	6	8.2	0.55405	0.8859	9.5	7.3	625	17.5	13.18
1290	12	8.2	0.688	0.4246	19	11.932	1620	25.4	17.34
1620	10	8.2	0.5286	0.3113	27.1	11.162	1695	24.29	21.1
1800	6	8.2	0.456	0.403	21	16.33	1130	32	35.83
2130	3.5	8.2	0.310	0.38	21.3	16.87	780	33	54.4




S.F.C vs RPM
3
2.5
2
1.5
1
0.5
0
S.F.C kg/KWh
0
500
1000
1500
2000
2500
RPM

Chapter Three

Chassis Dynamometer

3.1 Introduction

A chassis dynamometer measures power delivered to the surface of the "drive roller" by the drive wheels. The vehicle is often parked on the roller or rollers, which the car then turns and the output is measured.

Modern roller type chassis dynamometer systems use the roller which improved traction and repeatability over smooth or knurled drive rollers. Modern chassis dynamometers can do much more than display RPM, horsepower, and torque.

A chassis dynamometer is used to simulate the driving on a road inside a laboratory under controlled conditions. The vehicle is driven on rollers while the dynamometer simulates the inertia of the vehicle as well as the drag and friction on the vehicle (known as "road load" in the vehicle testing).

Chassis dynamometer testing allows a better assessment of the benefits of new fuels and vehicle technologies, and is absolutely essential to assessing the performance of vehicle.

These multifunction of this dynamometer create a need for using this modern device to do many experiments in terms of measuring the power of the engine and torque in addition to do load simulation.

This chapter will shed some light on the experiments that the students can apply on this device and this includes:

1-How to install and fix the car on the dynamometer.

2 -The procedure of doing each experiment.

3- Plotting the power and torque diagrams.

4 -Do the theoretical calculation for each experiment.

The user manual for this dynamometer will be stated in the appendix .

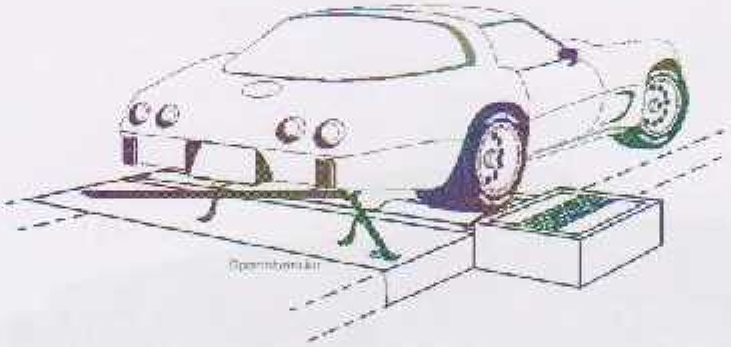
3.2 Installation[6]

* Fix the vehicle on the device as shown in figure 3.1.

This step is done for each experiment in the same way.

1- Attach the tightening straps to the vehicle towing loops.

2-The anchoring must be tight, but should not pull down the vehicle.



Figureure 3.1: Installation of vehicle[6]

*- Connect Oil Temperature Probe

1- Remove the oil measurement dip stick from the engine.

2- Adjust the length of the oil temperature probe to the length of the original dip stick by using the cone plug.

3 -Replace the oil dip stick with the oil temperature probe.

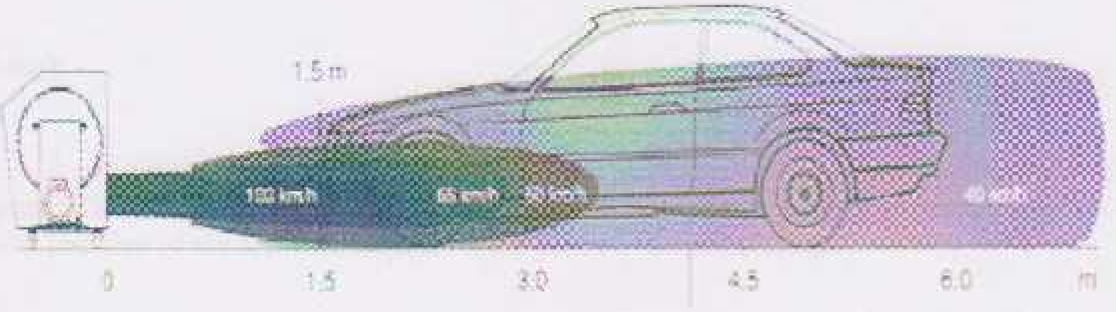
4- Close the oil measurements sleeves with the cone plug.

*-Position Cooling Air Fan as shown in figure 3.2

1- Position the cooling air fan in front of the vehicle's engine cooler.

2- To make sure that the fan remains in place during operation, use the fixing levers on the steering rollers of the fan.

3 -Switch on the air cooling fan.



Figureure 3.2: Cooling air fan[6]

4-Bring the Vehicle up to Operating Temperature

5- Vehicle Ready-for-Testing

The vehicle is ready for testing when all the preparation steps for testing have been completed

3.3 Load simulation

Experiment No (1)

Constant traction

Objective:

1- To measure the climbing power of the vehicle.

2- A steady incline (sloping surface) is simulated in this mode.

Theory :

A pre-set traction value activates the eddy-current brake immediately which maintains a constant traction for the duration of the measurement. The values to be set are oriented on the model and size of the test vehicle and on the desired inclination angle.

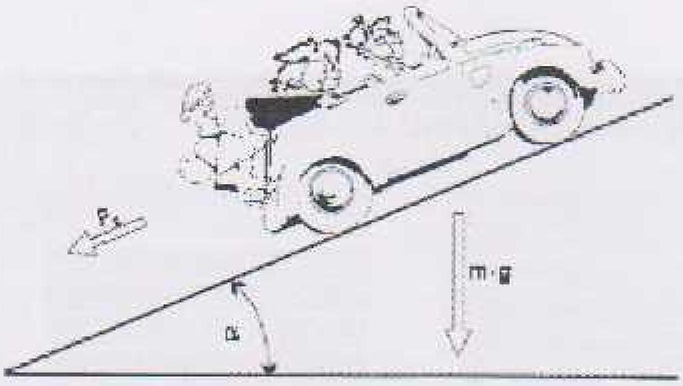
The higher the value entered for the traction the larger the angle of inclination. The simulated slope can be driven in any gear or speed. The eddy current brake effectiveness remains constant at all speeds.

The following equation is used to calculate the climbing force and the climbing power

$$P = \frac{m \times g \times \sin\propto \times v}{3600} \qquad (3.1)$$

$$F = m \times g \times \sin \propto \qquad (3.2)$$

Example:



Figureure 3.3. Load simulation for climbing car[6]

Calculation of the traction F.

$$F = m \times g \times \sin \propto$$

Calculation of the climbing power P.

$$P = \frac{m \times g \times \sin \propto \times v}{3600}$$

With v = km/h and the following values:

. Vehicle weight m = 1500 kg
. Angle of inclination $\alpha = 9°$
. Speed v = 100 km/h
. Acceleration due to gravity g = 9, 81 m/s2

Result is:

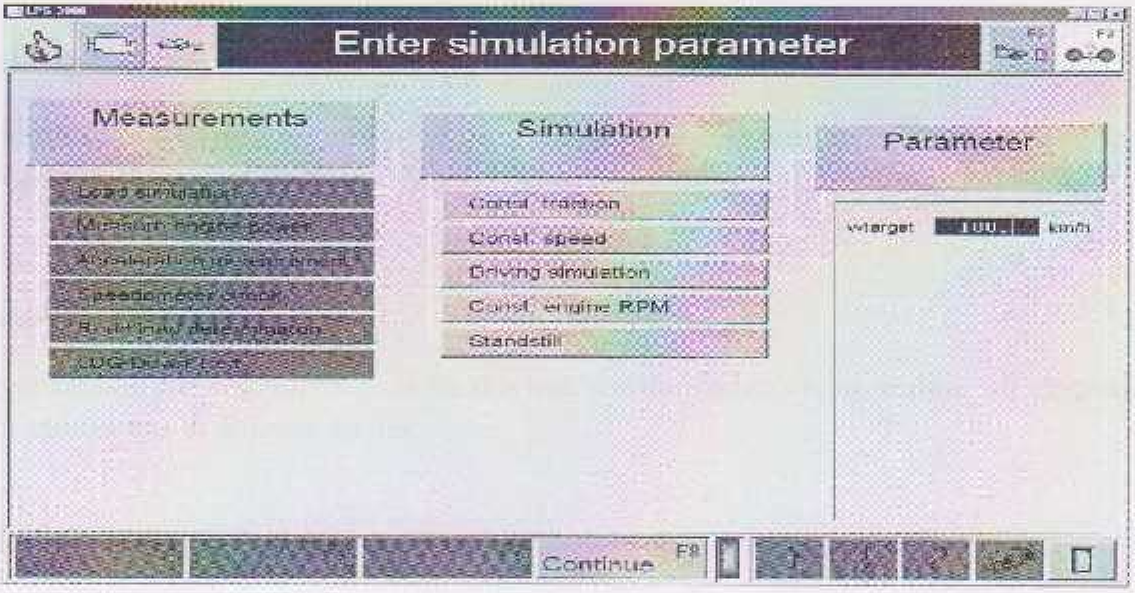
F = 2302 N and P = 64 kW = 89 PS

Procedure:

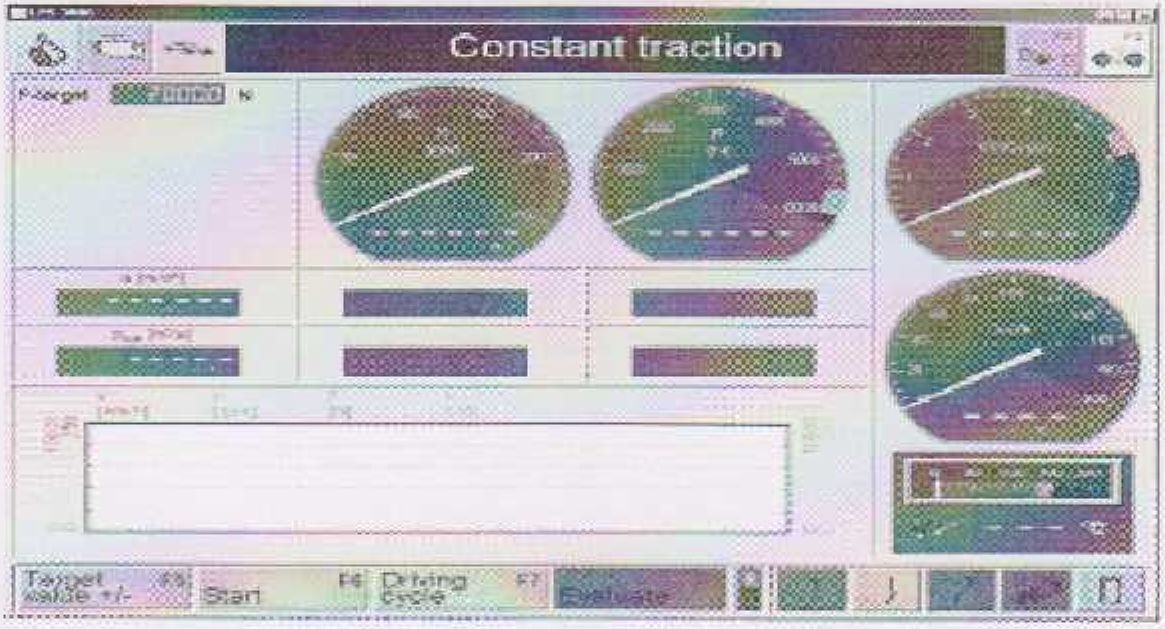
1- Position the vehicle on the dynamometer and fix it if necessary (see section 3.1).

2- Call up the menu LOAD SIMULATION and then the menu point CONSTANT TRACTION.

The following screen appears:



Figureure 3.4: load simulation screen[6]



Figureure 3.5: constant traction screen[6]

3 - Enter the target value of the traction F Target using the digit keys.

4 - Use the button F8 CONTINUE.

5 - Start the measurement.

Calculations:

The students must take different values of the inclined angle as in the previous example and do the calculation.

Diagrams:

The dynamometer plots output diagram for this test, and the students must analyze this diagram and plot another one at different angles.

3.4 Measure Engine Power

Experiment No (2)

Discrete Measurement

Objective:

To determine the maximum power during discrete measurement by using curves for wheel and engine performance which are displayed graphically.

Theory :

Discrete power measurement makes it possible to approach pre-defined points and hold them for a specified time as a function of the speed or RPM. These target points must be set before testing begins.

The Start- and End speeds or RPM as well as the test increments and hold time are entered by the inspector.

Hold time is defined as the length of time which the pre-set approached RPM and/or speed is held constant. The hold time assures a stable test point so that for example enough time is left for a fuel consumption test to be done.

The power deliver from the engine and absorbed by the dynamometer is called break power, this power is the usable delivered by the engine to the load.

The engine power can be calculated from the following relation:

$$Bp = \frac{2*\pi*N*T}{60} * 10^{-3} \quad (3.3)$$

Where:

BP: break power.

T: engine torque [N.m].

N: engine speed [rpm].

Procedure:

1- Position the vehicle on the dynamometer and fix it if necessary (see section 3.1).

2 - Call up the menu MEASURE ENGINE POWER and then the menu point Discrete MEASUREMENT.

3 Select the measurement type and enter the parameter via the digit keys into the entry boxes.

The following screen appears:

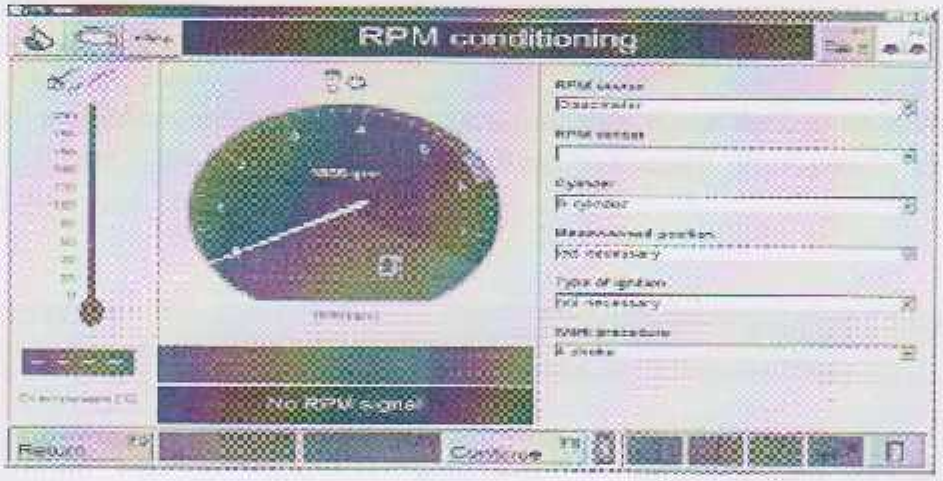
Figureure 3.6: Discrete measurement screen[6]

4 - Select the vehicle data as shown in figure 3.7.

Figureure 3.7: vehicle data screen[6]

5 - Use the button F8 CONTINUE.

6- Select the RPM source or the RPM sensor and the appropriate box as shown in figure 3.8.

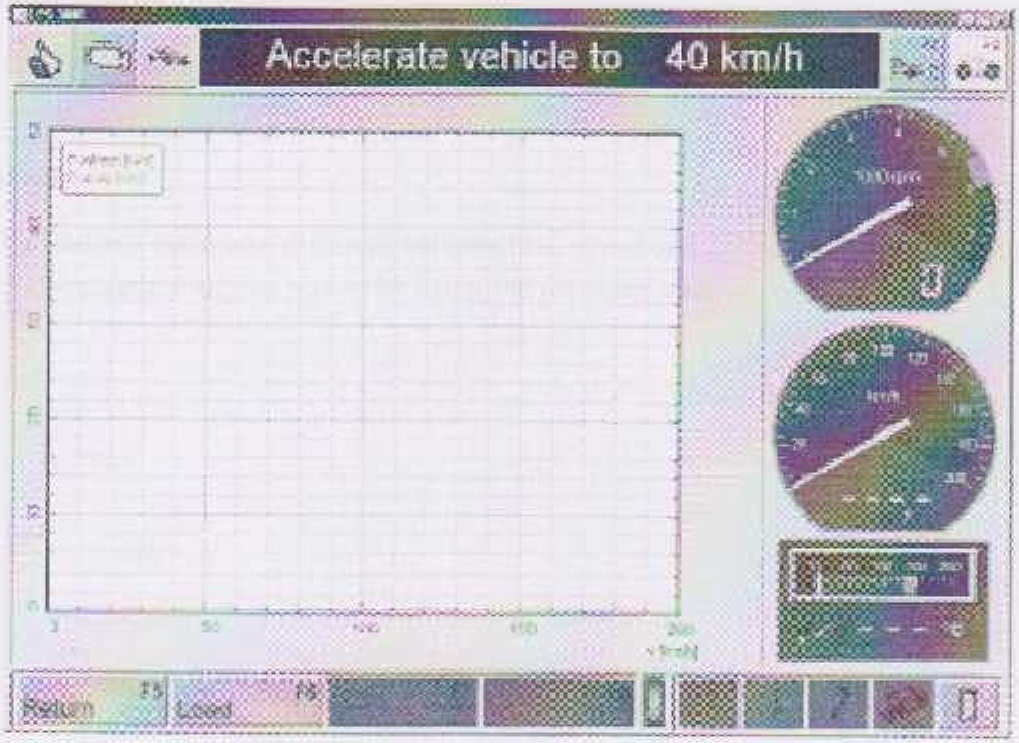


Figureure 3.8: Rpm signal screen[6]

7- Use the button F8 CONTINUE.

9 - Accelerate slowly and consistently up to start speed.

10 - Give full throttle when the Start speed is reached. The dynamometer starts recording measurement data. The measurement should be done without shifting in the next to last or last gear.

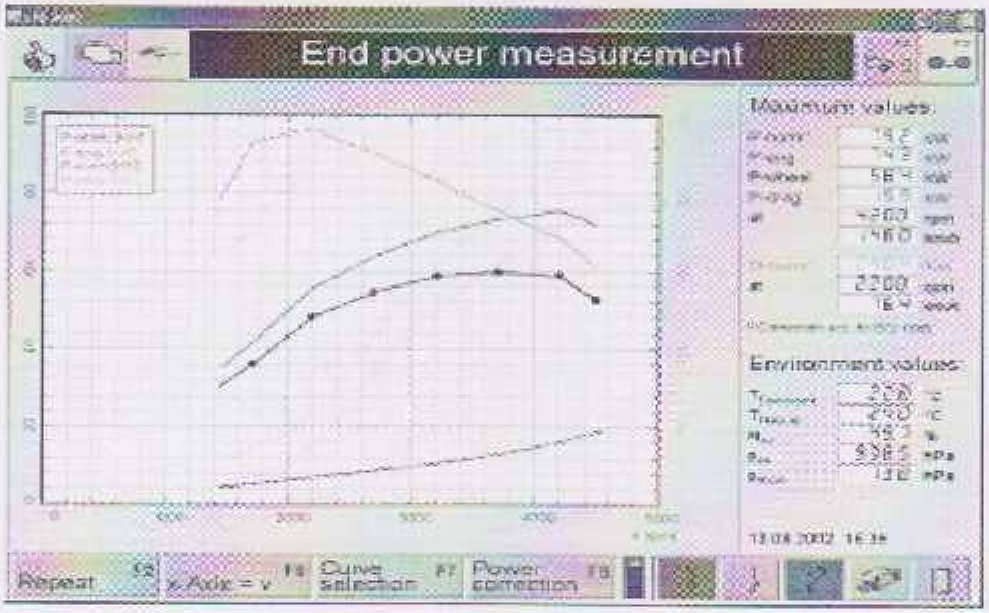


Figureure 3.9: Start recording measurement data[6]

11- With the throttle fully depressed the first set measurement point is approached. The eddy-current brake of the roller set maintains the vehicle or RPM speed about 5 sec.

12 - The brake is then released and the next measurement point is approached. The inspector maintains full throttle during the entire test time.

13 - After all measurement have been taken, the information line at the bottom of the screen indicates to the inspector that the clutch can be released "Press clutch" as shown in figure 3.10.



Figureure 3.10: The power curves[6]

Calculations:

The students must take different values of the speed and of the torque from the output curves to calculate the engine power by using the previous relation.

Diagrams:

The dynamometer plots output diagram for this test, and the students must analyze this diagram.

Figureure 3.11: Engine power curve[6]

Chapter Four

Hydraulic Dynamometer

Hydraulic dynamometer

4.1 introduction

Hydraulic dynamometers are machines that measure the power of an engine by using a cell filled with liquid to increase its load. The turbulent action of the water absorbs the power of the engine. The load is controlled by the water inlet. The power is converted into heat which is carried away by the continually flowing water. Dynamometer with vertical Instrument Panel measures engine torque and power continuously from an absorption brake and produces value of torque and power for various RPM bands.

4.2 Principle of operation figure 4.1

The dynamometer is regulated by means of the amount of water. The rotor and case blades form the working space. The braking water enters this space via a water inlet at the bottom, the ring channels behind the stator inserts, and the inlet holes in the stator.

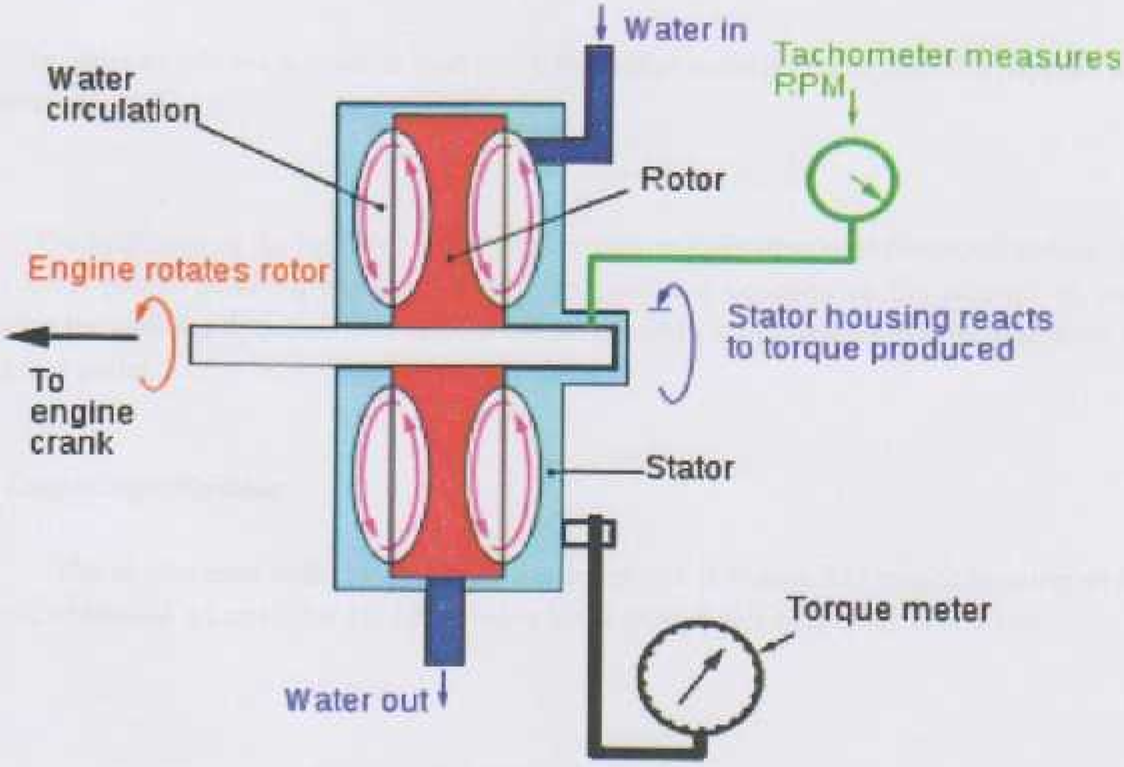


Figure 4.1 Hydraulic dynamometer[2]

The water supply from below, together with the venting holes in the ring channel behind the stators, ensures that the water entering the brake is free of air bubbles and pressure locks. The water emerging from the inlet holes of the stator is accelerated by the rotating rotor, due to centrifugal force, and passed on to the stator.

Due to the exchange of energy between the rotor and stator blades, the input torque on the rotor is transferred to the stator or dynamometer case and displayed by means of suitable measuring devices (balance, electrical load cell).

The input power is converted into heat and is removed by the braking water. Regulation of the water ring is carried out by means as a pressure relieved control valve with several electric drive at the braking water outlet.

As the speed of the rotating water ring increases with the dynamometer speed, and as the pressure rises in the following space, the outlet control valve is connected such that the cross-section is reduced as the speed increases.

In order to achieve a specific load point, the outlet valve is closed until the required load point is reached.

The thickness of the resulting water ring is thus an indication of the selected torque. The maximum power handling capacity of the dynamometer depends on the amount of water flowing through the dynamometer and on the permissible temperature difference between the inlet and outlet.

4.3 Engine Specification

The engine used with the hydraulic dynamometer is Mazda 323 engine running on the petrol, additional a Lovato kit for LPG fuel is build on it. Engine capacity is 1600 cc.

4.4 Mounting Test Stand to the Engine

The Engine Performance Test Stand with vertical Instrument Panel was bolted to the engine crankcase by using an adapter flange as shown in Figure 4.1. The adapter flange has to be made in accordance with the bell housing of the engine. The bell housing has to be centered to the Engine Performance Test Stand by means of the adapter flange as shown in Figure 4.2.The rotor shaft of the Test Stand was connected to the engine clutch disc by the interchangeable connection shaft shown in Figure 4.3.

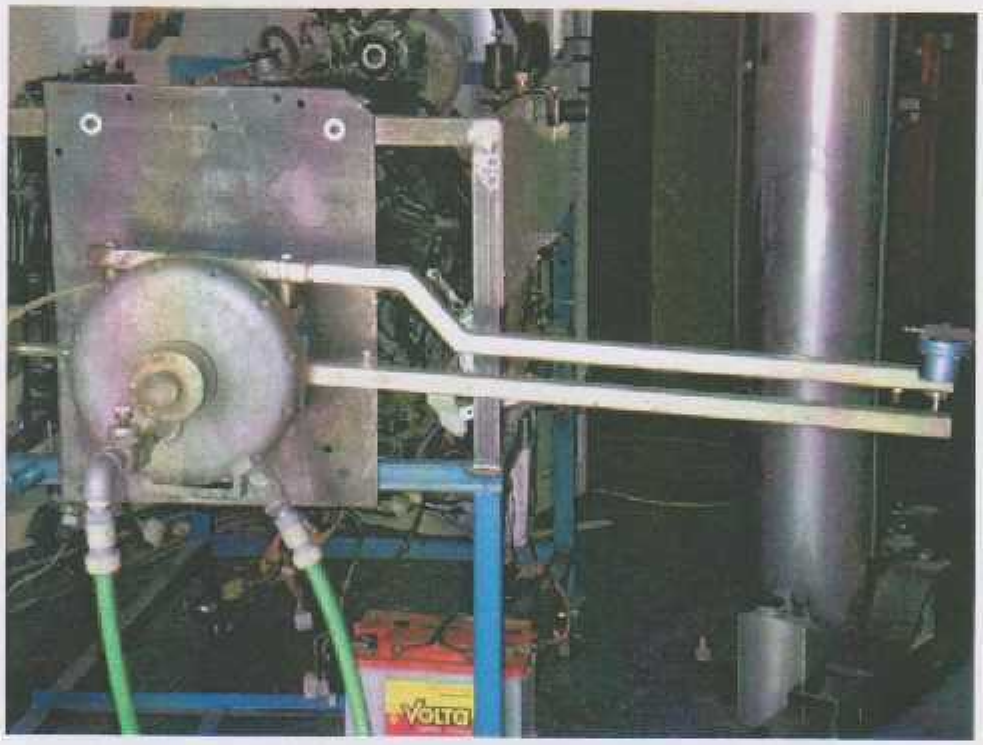


Figure 4.2: Test stand bolting to the Engine Crankcase

Figure 4.3: Adapter Flange

Figure 4.4: The Interchangeable Connection Shaft

4.5

Experiments

Power measurement

Objectives:

1) Measure the brake power of the engine running on petrol.
2) Measure the brake power of engine running on LPG.

Theory:

On a rotating shaft, the torque is doing the work, and the shaft's rotational speed is time-dependent, so shaft power is the product of its rotational speed and its torque. Using arbitrary units, the power formula for a rotating shaft is:

Power Shaft = Rotating Speed × 2π × Torque

When using Newton-meters for torque, revolutions per minute (RPM) for shaft speed, and kilowatts for power, shaft power can be expressed with the following formula:

1 [W] = 1 [N.M/sec]

1 [kW] = 1 [W] × [1kW/1000W] × [1min/60 sec]× [2 π rad/1 rev]

$$P[\text{kW}] = \frac{\text{T Q [N.M]} \times \text{Rev's [RPM]}}{9549}$$

Procedure :

1. Run the engine and wait until reaches its normal operating temperature.
2. Connect tachometer to measure the RPM.
3. Connect torque meter to measure the torque.
4. Activate the cooling water.
5. Activate the load /unload valve 5 min. to get the warm-up time.
6. Open throttle valve until reaching full load, at the same time activate brake torque at higher case.
7. Fixed throttle valve at full load or (at the RPM you want) and activate the load/unload valve to measure the torque at various engine speeds.
8. Record the results.
9. Calculate and draw the results.

Calculation and results:

Table 4.1: The Recorded Data and the Calculating Gasoline and LPG Power

No.	Engine speed (RPM) n	Gasoline Fuel Torque (Nm) TQ_1	Gasoline Fuel Power P_1 (kW)	LPG Fuel Torque (Nm) TQ_2	LPG Fuel Power P_2 (kW)
1	1000	200.0	20.94	173.3	18.15
2	1500	183.3	28.80	143.3	22.51
3	**2000**	150.0	31.41	126.7	26.53
4	2500	100.0	26.18	73.3	19.20
5	3000	63.3	19.90	46.7	14.66

Brake power and torque curves figure 4.5 & 4.6

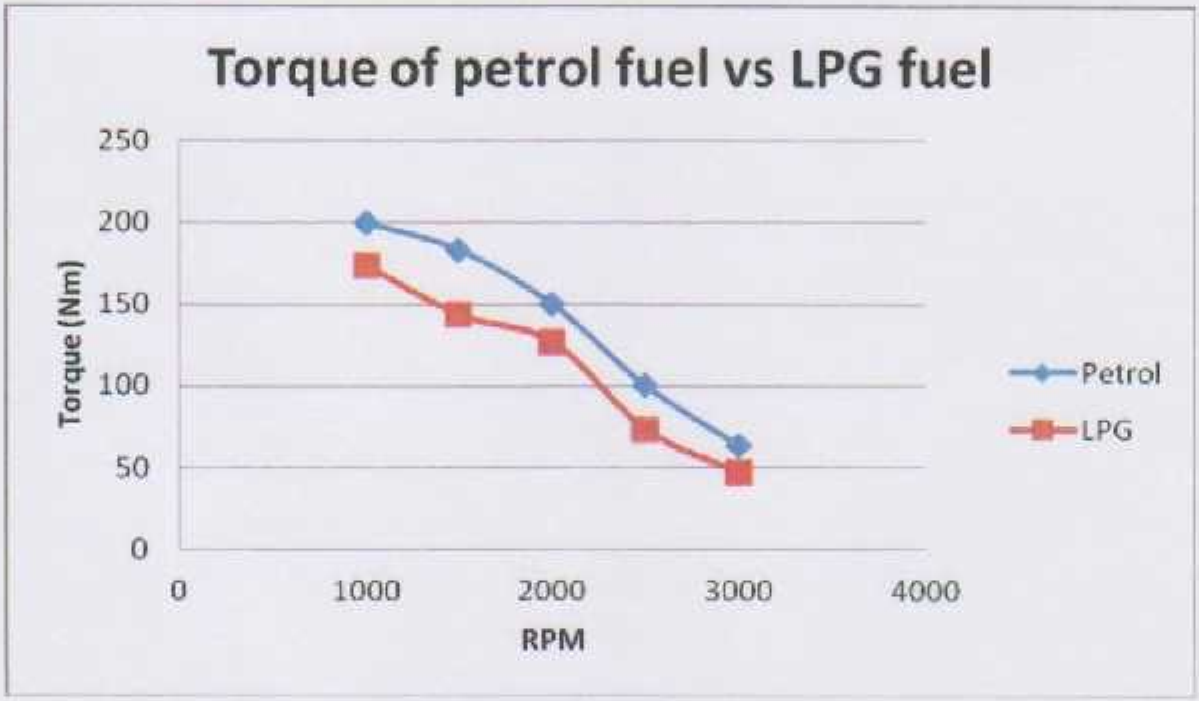


Figure 4.5: Torque of petrol fuel vs. LPG fuel.

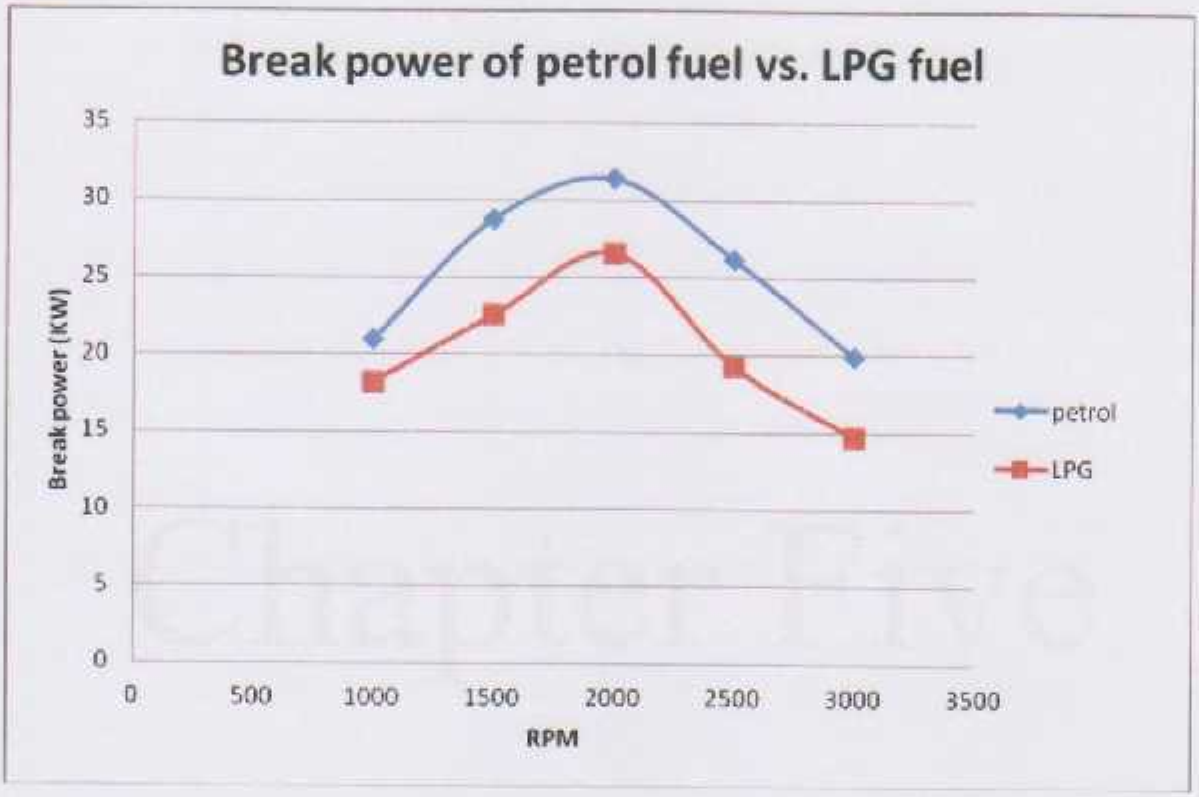


Figure 4.6: Brake power of petrol fuel vs. LPG fuel

Chapter Five

Computerized Spark Ignition

Engine

5.1 Introduction

Development and optimization of modern internal combustion engines is inconceivable without the knowledge of what is happening in the cylinders. Measurement and analysis of the variation in cylinder pressure is the only source of the data needed to optimize efficiency, and engine output.

Reciprocating piston internal combustion engines are basically heat engines in that they essentially convert the chemical energy from the air/fuel mixture into mechanical work and heat by means of combustion as shown in Figure 5.1.

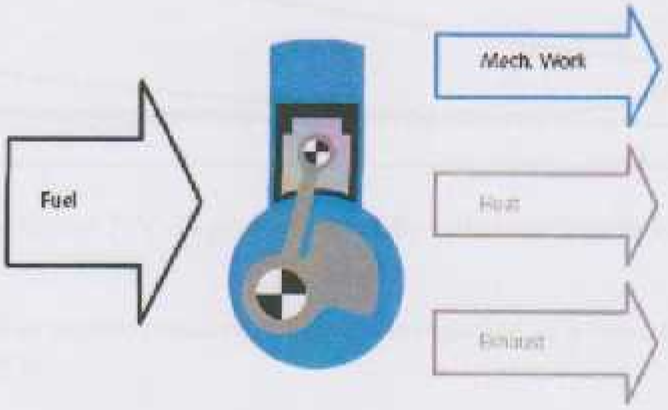


Figure 5.1: Conversion of chemical energy from fuel into mechanical Work and heat[9]

Developers aim to extract from the conversion as high a proportion of mechanical work as possible, that is to maximize efficiency. The magnitude and variation with time of the cylinder pressure acting on the piston are significant in this respect. This pressure curve represents the combustion and hence the way in which the energy conversion takes place in the engine.

Consequently, the total mechanical work on the piston over a cycle is a function of the pressure and the associated change in combustion chamber volume. Figure 5.2 show the P-V diagram .

Based on this knowledge, Nikolaus Otto and Rudolf Diesel pioneered the use of indicators of combustion chamber pressure and allowing simultaneous recording piston position.

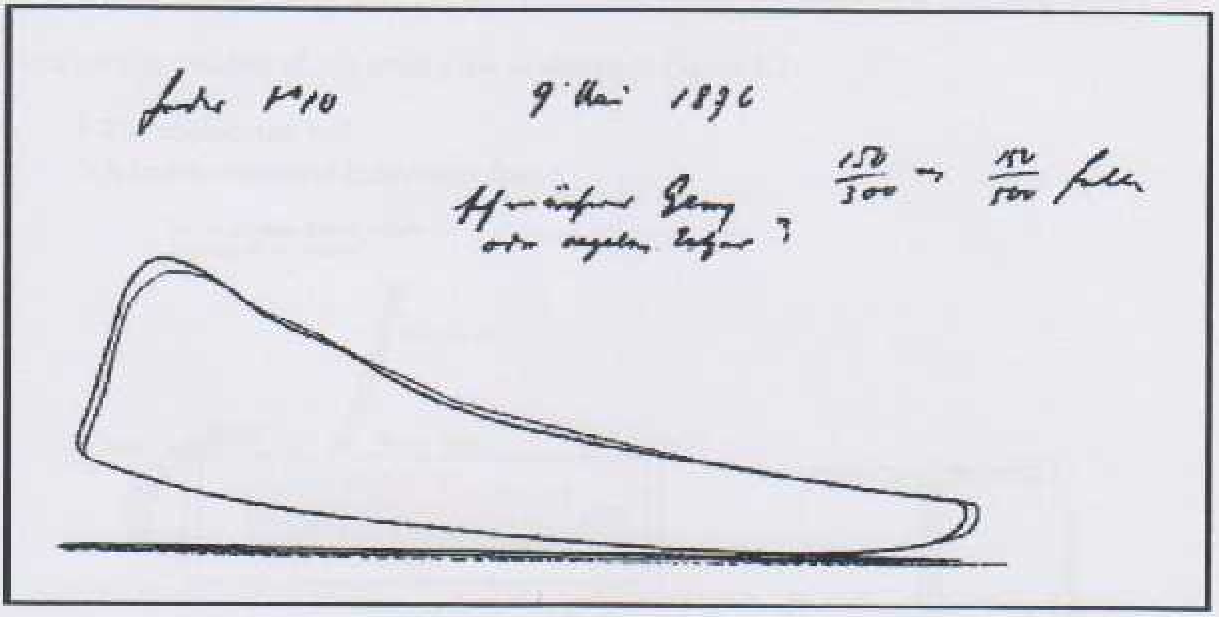


Figure 5.2: Indicator P-V diagram recorded by Nikolaus Otto in 1876.[9]

Combustion analysis or engine pressure indication is regarded as a basic tool in engine development and is the key to:

1- improving efficiency
2- increasing engine output power
3- reducing emissions
4- prolonging engine life

5.2 Computerized Spark Ignition Engine

The internal combustion engine laboratory contains computerized single cylinder engine .This computerized engine and all tools related can help the students to understand the issues occurring inside the engine cylinder such as variation in pressure in the four strokes and the student can notice the actual cycle and the graph of the pressure versus crank angel, to compare the theoretical knowledge gained during his study with the actual one and to gain the experimental skills.

The computerized spark ignition engine includes pressure sensor inside combustion chamber, engine analyzer, encoder, flow meter and data acquisition system. all of this system component and how it work we discussed it below .

The apparatus consists of two main parts as shown in Figure 5.3:

1-The engine test bed
2-A bench –mounted instrument frame

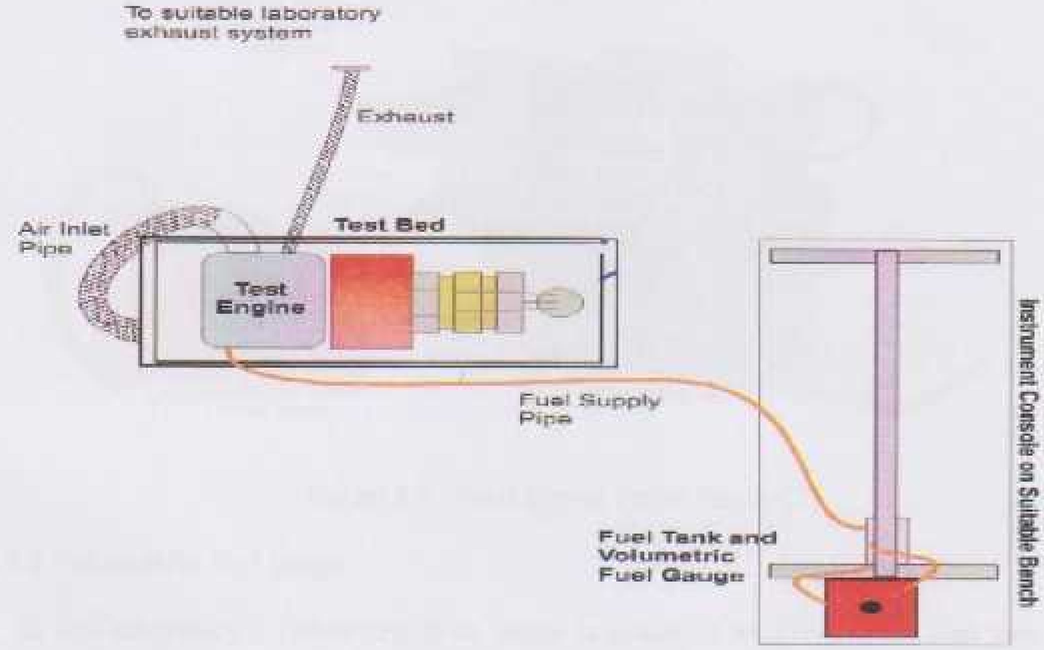


Figure 5.3: Engine test bed and instrument frame[7]

5.3 System Parts

The computerized spark ignition engine consists from these parts:

5.3.1 Four- Stroke Petrol Engine

modified four –stroke petrol engine has modified cylinder head and crank output shaft . These are to accept the optional cylinder head pressure sensor and crank angel encoder .

the engine specifications are :

1-Overhead valve
2-A conventional carburetor with manual choke
3-Electric spark ignition
4-Splash lubrication

forced air –cooling is provided by the fins around the engine . the engine is started by handle and cord, wrapped around a pulley on the flywheel .

The flywheel has a permanent magnet fixed to it edge , as the fly wheel turns , the magnet passes the primary winding of the electric ignition coil and forces an electric current to flow in the coil . The ignition system uses this to create spark at the spark plug.

The engine include an on off switch that connects the primary winding to ground to stop the ignition circuit , this stops the engine .Figure 5.4 shown the four stroke engine .

Figure 5.4 : Four Stroke Petrol Engine[7]

5.3.2 Volumetric fuel gauge

In this laboratory a volumetric flow gauge is available to measure the fuel flow which is a manually operated fuel pipette, to be used with suitable timer or stopwatch . Figure 5.5 shown the Fuel Flow Meter.

Figure 5.5: Fuel Flow Meter[7]

5.3.3Engine Cycle Analyzer

The engine cycle analyzer consist of two parts:

1- A Hardware unit interface with charge Amplifier. The hardware unit includes LED indicators to show the process readiness, encoder top dead center position and PC communication status.

2-Dedicated software, to log the data, crate charts of pressure against crank angle and pressure against volume. The figure 5.6 shown The Engine Cycle Analyzer

Figure 5.6: Engine Cycle Analyzer[7]

5.3.4 Crank Angle Encoder

The crank angle encoder contains a precision marker disk with a trigger mark and 360 angle marks which are scanned by a transmission photoelectric cell. Their light intensity is regulated in order to compensate for any soiling. The disk and the photoelectric cell are encased in dustproof housing. Figure 5.7 shown Crank Angle Encoder.

Figure 5.7: Crank Angle Encoder[7]

5.3.5 Pressure sensor

In piezoelectric pressure sensors, the pressure acts on the surface of a diaphragm which converts it into a proportional force. This force is transmitted to a crystal, giving rise to an electric charge on the opposing surfaces. The pressure sensor has the ability to measure the pressure of combustion under high temperature environment. The pressure sensor is connected to the engine analyzer and charge amplifier to process the signal and output it to the computer software. Figure 5.8 shown the Pressure Sensor.

Figure 5.8: Pressure Sensor.[4]

5.4 Connection of the devices:

In the lab, the devices connections are according to the product catalog. The encoder first connected to the engine, fitted on its place and then plugged to the engine analyzer. The engine analyzer is connected to the computer which is containing the software for the engine analyzer to read the results and analyze it.

After the connection is done, the Encoder is calibrated the top dead center for the piston so it will give accurate reading to the engine analyzer.

The pressure sensor carefully fitted to the engine head, and then its wiring is carefully plugged to the engine analyzer.

The calibration for the pressure sensor is done using the engine analyzer and the computer software. The fuel supply for the engine is by the volumetric fuel gauge and the tank. The volumetric fuel gauge is used to measure the fuel consumption

By connecting and operating all the devices the P-α and the P-V diagram is plotted on the computer.

5.5 Engine specification:

Table 5.1: Engine specification[7].

Item	Specification
Dimensions (when fitted to Base Plate)	Width 400 mm Height 400 mm Depth 300 mm
Net Weight (with Base Plate)	20 kg
Fuel Type	Petrol (Gasoline)
Fuel Tank	Red - Painted steel with vent and filler cap
Exhaust outlet	Nominally 1"BSP
Ignition system	Electric
Absolute Maximum Power	4.4 kW (6 hp) at 4000 $rev.min^{-1}$
Continuous Rated Power	2.6 kW at 3000 $rev.min^{-1}$ 2.9 kW at 3600 $rev.min^{-1}$
Bore	67 mm
Stroke/Crank Radius	49 mm/24.5 mm
Connecting Rod Length	85 mm
Engine Capacity	172 cm^3 (0.172 L) or 172 cc
Compression Ratio	8.5:1
Oil Type*	SAE20, SAE30 or Multigrade 10W-30
Oil Capacity	0.65 Litre

5.6 Safety Recommendation:

1- Never use the apparatus without guards or any protective covers in place.
2- Do not touch the test engine or the exhaust pipe while the equipment is running .
3- Keep away from the air inlet of the Airbox when the test engine is running .
4- Never work alone with this machinery . A qualified lecturer or supervisor must present whenever it is used .
5- All user must wear ear and eye protection as shown in figure 5.9.
6- Use suitable gloves when you work with fuel or its connection.
7- Make sure that the test area is well ventilated and contains suitable fire extinguishers.

Figure 5.9 : Ear and Eye protection Tools[7]

5.7 Helpful Advice :

1- Do the experiment in teams of at least two people , one person to operate the controls , the other to take result .
2- As with all instrument connected to active experiments, the readings will vary slightly while you record them , use your best judgment and decide a good average figure .

Figure 5.10 shown the Computerized System in the laboratory

Figure 5.10 : The Computerized System in the laboratory

5.8

Experiment No (1)

Fuel Consumption Calculation

Objective:

To measure the fuel consumption by the engine at various speed

Theory:

Fuel consumption calculation:

The fuel mass of the engine can be calculated by the relation, which says:

$$m_{fuel} = V * \rho \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5.1)$$

Where:

V=the volume of fuel, which can used [m^3].

=8ml*10^-6

ρ= the density of fuel= 740 [kg/m^3].

Another definition is a fuel mass flow per second and can be calculated as in the relation:

$$\dot{m}_{fuel} = m_{fuel} \times \frac{3600}{\tau} \left[\frac{kg}{h}\right] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5.2)$$

Where

τ: the time which can be calculated[s].

in engine test, the fuel consumption is measured as a flow rate-mass flow per unit time

Procedure:

1- Fill your fuel tank with the correct fuel for your test engine
2- Connect the exhaust pipe of the engine to the laboratory exhaust system.
3- Open both valves on the Fuel Gage-(turn the valves so that they are in-line with the fuel pipe).
4- Make sure that the fuel has passed down the fuel feed pipe to the test engine .
5- Turn on the engine cycle analyzer and make reset.
6- Make sure that your computer is operating and has started the TecQuipment software .
7- Turn the ignition switch to the on position and run the engine .
8- Allow the engine to reach normal operating temperature.
9- For the manual fuel gauge . Shut the fuel inlet valve and use stopwatch to measure the time taken to drain 8ml at various engine speed as shown in the figure5.11.
10- Record all test engine results and fill the table .

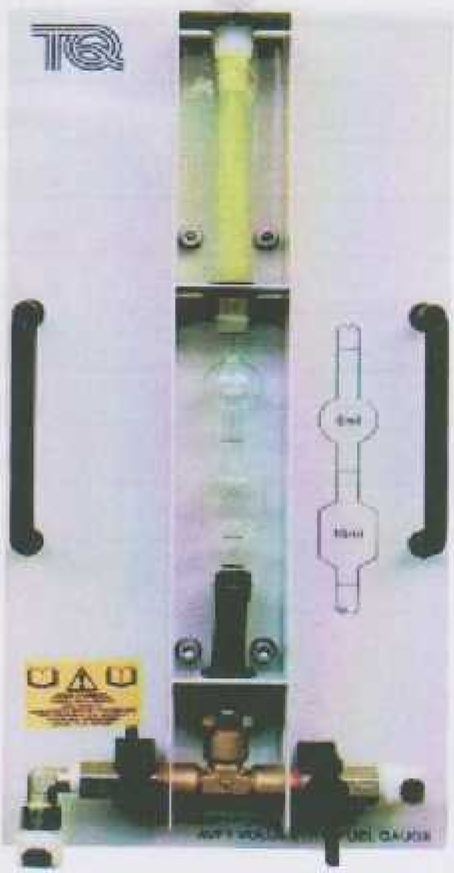


Figure 5.11: Fuel Flow Meter[7]

Shut down :

1- Use the engine throttle to reduce the engine speed to minimum.
2- Allow the engine to run for two minutes at minimum speed.
3- Turn the ignition switch to off position .
4- Turn off the fuel supply to the engine .

Calculations:

Table 5.2: Fuel Mass Flow Rate

Engine Speed (RPM)	Time(s)	Fuel Mass flow rate(kg/hr)
1750	01:11:15	0.299
1950	01:03:41	0.336
2150	00:58:26	0.365
2350	00:56:33	0.378
2550	00:52:24	0.407
2750	00:49:43	0.431
2950	00:47:21	0.451
3150	0:45:66	0.466
3350	0:45:30	0.470
3550	0:44:4	0.480
3750	0:43:42	0.490

Diagrams:

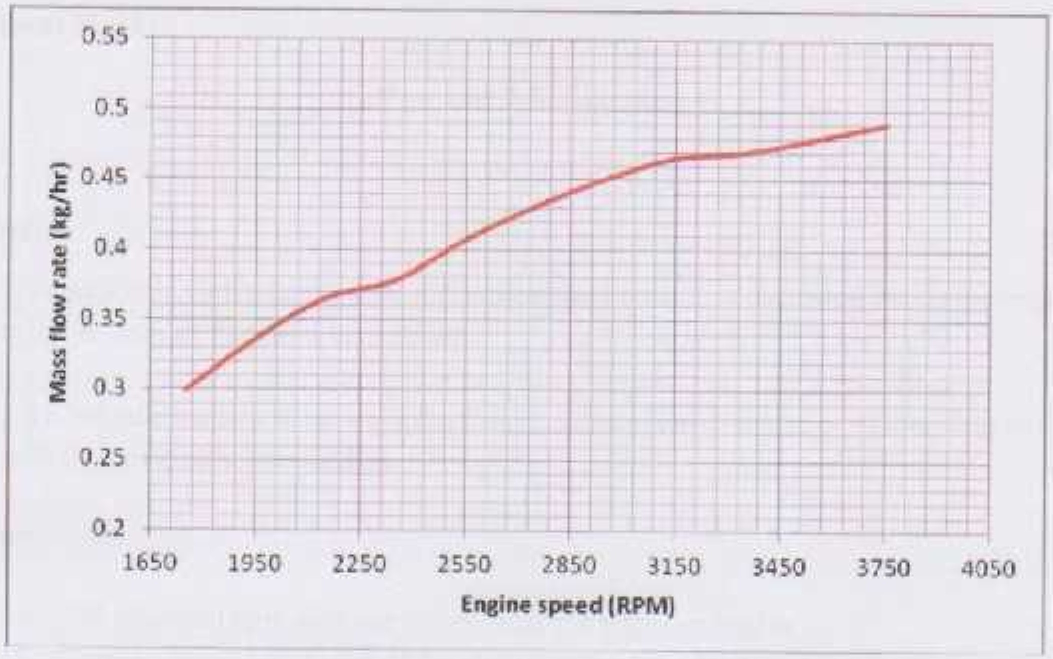


Figure 5.12: Mass flow rate of the fuel.

Results discussion:

From the above figure 5.12, the mass flow rate increases as engine speed increases.

5.9

Experiment No (2)

P-α and P-V Diagrams

Objective:

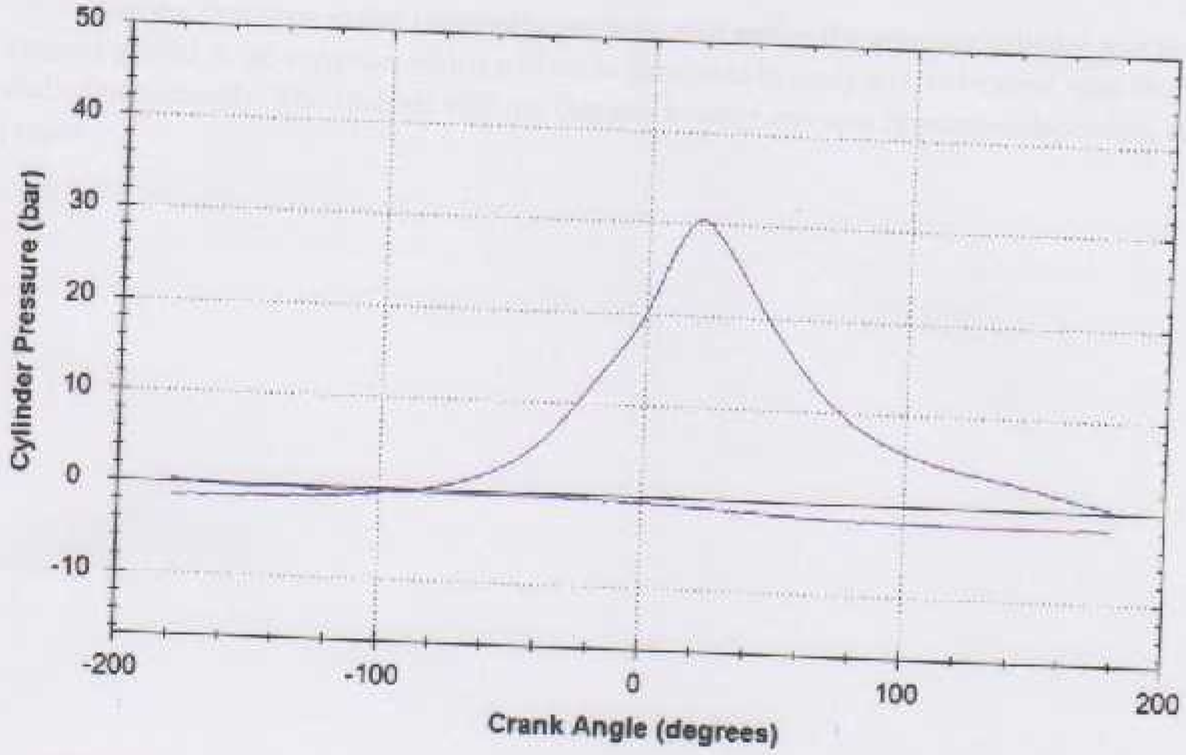
1-To facilitate understanding the thermodynamic processes occurring inside the engine cylinder such as variation in pressure.

2-To help the student to notice the actual pressure cycle (p-α and p-V) diagrams compared with the theoretical knowledge.

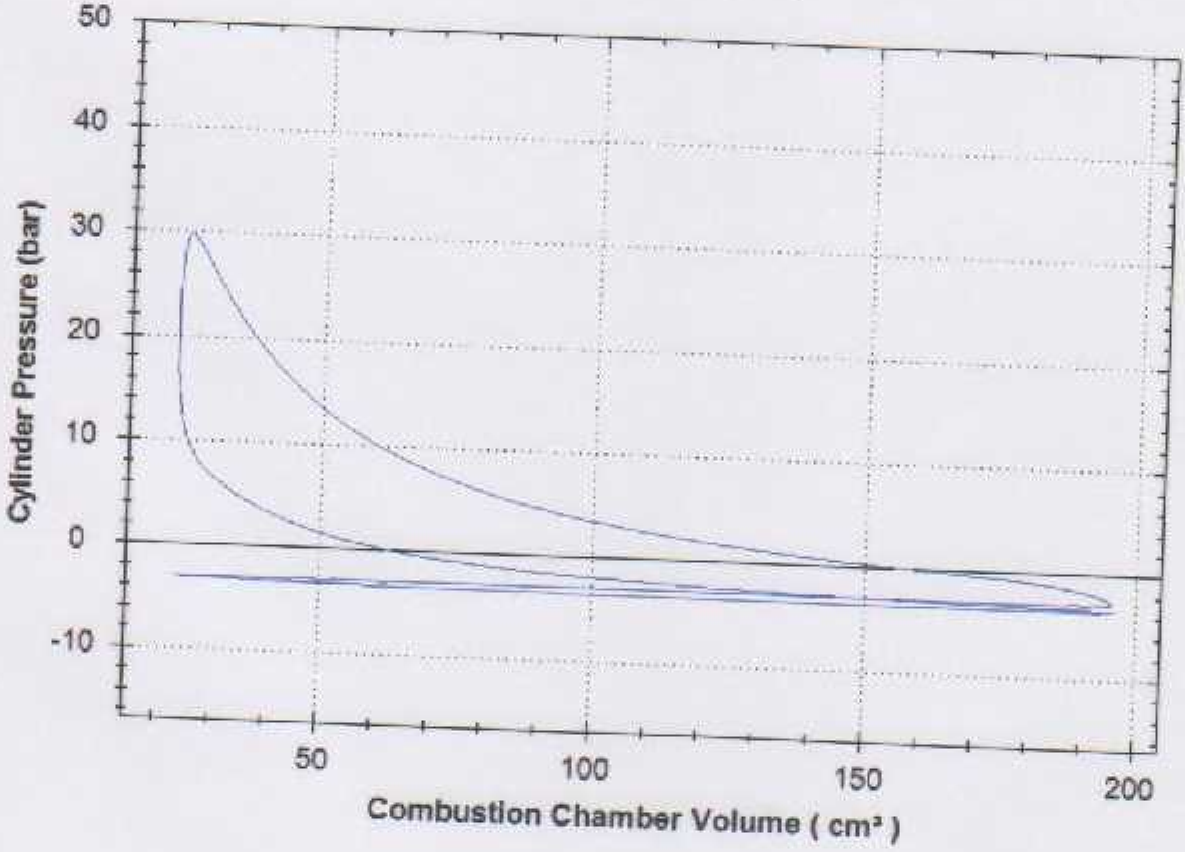
Procedure:

1- Fill your fuel tank with the correct fuel for your test engine
2- Connect the exhaust pipe of the engine to the laboratory exhaust system.
3- Open both valves on the Fuel Gage-(turn the valves so that they are in-line with the fuel pipe).
4- Make sure that the fuel has passed down the fuel feed pipe to the test engine .
5- Turn on the engine cycle analyzer and make reset.
6- Make sure that your computer is operating and has started the TecQuipment software .
7- Turn the ignition switch to the on position and run the engine .
8- Allow the engine to reach normal operating temperature .
9- Make connection between engine cycle analyzer and the pc computer.
10- After engine reach the normal operating temperature make the reset to the engine cycle analyzer .
11- Record all test results .
12- Turn off the engine .

Diagrams:



50
40
30
20
10
0
-10
Cylinder Pressure (bar)
-200
-100
0
100
200
Crank Angle (degrees)



50
40
30
20
10
0
-10
Cylinder Pressure (bar)
50
100
150
200
Combustion Chamber Volume (cm³)

Results discussion:

For the first time in the University, students will notice the pressure cylinder and the P-V diagram plotted in the computer which will make them able to apply and understand what they have studied theoretically. The students will get chances to carry out new researches depending on this project .

Conclusion

After the project is finished successfully, the objectives are achieved, all of the devices have been assembled especially after maintaining some parts. The devices are operated and the experiments have been done.

The laboratory is now ready for the students to make experiments and for using it to make a researches on the engines. The results gained by all devices are real and close to the standards. The internal combustion engines laboratory is finished as it should be.

Recommendation

1) A loading unit must be added to the test bench in order to facilitate the students understanding the engine operation under various conditions(load).
2) Convert the control and the measurements from manual to computerized using the DAQ.
3) Safe methods must be used during the experiments, by following the instructions strictly.
4) It is necessary to build an advanced ventilation system.
5) The need for appropriate protective wear to the student when making the experiment.

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