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POWER TRAIN AND EMISSION CONTROLS IN PASSENGER VEHICLES: STUDY OF EXHAUST GAS RECIRCULATION (EGR)

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ABSTRACT

The goal of the On Board Diagnostics is to alert the driver to the presence of a malfunction of the emission control system, and to identify the location of the problem in order to assist mechanics in properly performing repairs. In addition, the On Board Diagnostics (OBD-II) system should illuminate the malfunction indicator light (MIL) and store the trouble code in the computer memory for all malfunction that will contribute to increased HC emissions.

Therefore, the power train is controlled by the power train control module (PCM) computer to deliver the required torque to the vehicle requested by the driver and to limit the vehicle emissions to the required minimum to meet Environment Protection Agency, USA regulations.

On Board Diagnostics regulations in the USA, special reference to Light and Medium duty I.C. Engine vehicles and California Motor Vehicle Pollution Control Board (MVOCB), the following OBD-II requirements are in force, i.e.

All vehicles emission systems and components that can affect emissions must be monitored. Malfunctions must be detected before emissions exceed 1.5 times the standard specified by EPA.

Malfunction must be detected within 2 driving cycle. If a Malfunction defected a Malfunction Indicator Light illuminated.

Increasing temperature inside the cylinder, HC and CO may reduce, but does not reduce the NOx. Therefore, NOx can reduce by the application of Exhaust gas Re-Circulation (EGR). NOx control system that recycles a small part of the inert exhaust gas back through the manifold to lower the combustion temperature and this system is called Exhaust Gas Re-Circulation system

KEYWORDS: Exhaust Gas Recirculation, Power train, OBD II Diagnostics.

I. INTRODUCTION

On Board Diagnostics (OBD II) systems were deigned to maintain low emissions of in USA vehicle, including Light and Medium vehicles. In 1989, The California code of Regulations (CCR) , known a OBD II, which was adopted y the California Air Resources Board (CARB).

However, automotive power train transmission systems are consisting by the following component:

1. **Torque Converter:**

It is an automatic transmission, a fluid coupling which incorporation a sation to permit a torque increase through the torque converter.

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Fig: 2(a) Torque Converter (SR 110 only)

Sources: www.stage3motorsports.com)

2. Automatic Transmission input shaft:

It is a round bar steel or other strong metal that is used to transit rotary action.

Fig: 2(b) Manual Transmission input shaft

Sources: www.autoplicity.com

3. Transmission lockup Clutch:

The main function of this is connects the engine power directly and mechanically to the automatic transaxle and pressure on the front and rear, both sides, lockup clutch become equal, which disengaged position and vehicles is running at low speed.

However, lockup clutch engaged more of operation pressurized fluid flows to the rear of the lockup clutch, while vehicle speed is high i.e. 65 km/h.

Fig: 2(c) Dampers lock up clutches.

Sources: www.onlinemechanc.com

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For example, from the different angle:

Problem: A lock up clutch with a semi angle of 12° is to transmit 15 HP at 750 rpm. The width of the face of the ¼th of the mean diameter and the normal pressure between the contact forces is not exceeding 0.85 kg/cm^2. Allowing μ= 0.2, determine the main dimensions of the clutch and the axial force required. Assume uniform wear.

Solution: We have,

$$T= \frac{H.P \times 4500}{2\pi N}$$

$$= \frac{15 \times 4500}{2\pi \times 750} = 14.35 \text{ kg/m} = 1.435 \text{ kg/cm}$$

The width or breadth of the face:

$$W = \frac{1}{4} \times \frac{d1+d2}{2} = \frac{r1+r2}{4}$$

Also, $w = \frac{r2-r1}{sin\theta}$

$$\therefore \frac{r1+r2}{4} = \frac{r2-r1}{Sin\ 12°}$$

$$\therefore \quad 4(r_2 - r_1) = 0.208 \ (r_1 + r_2)$$

$$\therefore r_2 = \frac{4.208}{3.792} r_1 = 1.11 \ r_1$$

Based on uniform wear,

$$T = \frac{\mu\pi C}{Sin\ \theta} (r_2^2 - r_1^2)$$

$$\therefore 1.435 = \frac{0.2 \times \pi \times 0.85 \times (r1)3[1.231-1\}}{0.208}$$

$$\therefore \quad 1.435 = 0.613 \ r_1^3$$

Or, $r_1 =(\frac{1.435}{0.613})1/3 = 13.25$ cm

Therefore, $r_2 = 1.11 \times 13.25 = 14.75$ cm

$$W = \frac{14.75+13.25}{4} = 7 \text{ cm}$$

Total axial force: $2\pi c\ (r2 - r1)$

$= 2\pi c\ (r_2 - r_1)$

$= 2\pi \times 0.85 \times 13.25\ (14.75 - 13.25)$

$= 2\pi \times 6.85 \times 13.25 \times 1.5 = 106.5$ kg.

4. **Throttle position Sensor:**

Fig: 2(d) Throttle position Sensor (Mercury)

The main objective of TPS, to monitoring throttle position of the Sensor. Sometimes, engine control units (ECUs) are control by the electronic throttle control (ETC).

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5. Hydraulic pump and Hydraulic Circuit:

Hydraulic circuit is consisting by group of components. i.e. pumps, actuators, Control valve, Conductors etc towards arranged to useful work. The design is depended the basis of safety of machine and personnel while the cause of power failure; and during operation with minimum losses; and cost of component used in the circuit.

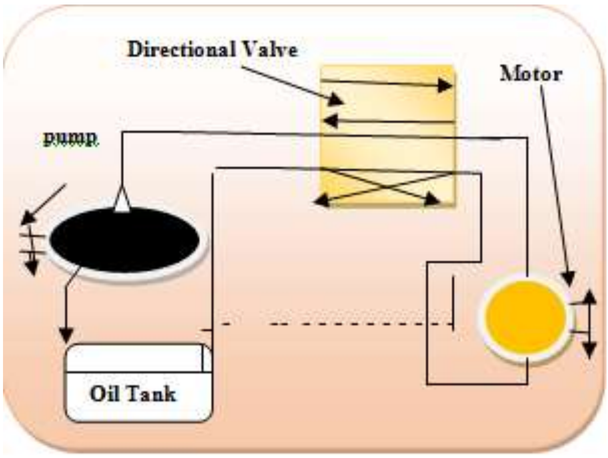

Fig:2(e) Open loop hydraulic Circuit

6. Solenoid Valves:

Fig:2(f) Solenoid Valves

Solenoid valve, which is basically used for control elements in fluids. It has offer fast and safe switching, high reliability, long service life, low control power and compact design. The objective is hat the valve is controlled by an electric current through solenoids. For example, solenoid plunger which is responsible for making the connection between

7. Vehicle speed sensor:

VSS is a monitoring device that measures the output of a transmission or transaxle in terms of wheel speed.

Fig: 2(g) Vehicle speed sensor

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8. Transmission input shaft speed sensor:

It is use for calculate the actual gear ratio of the transmission while use and operate power train control module.

Fig: 2(h) input shaft speed sensor – transmission

Gear ratio means, the relative speeds at which two gears revolve. The speeds are proportional to the gear diameter. For example, for the sliding mesh gear box :

Gear ratio: $\frac{No\ of\ teeth\ on\ main\ shaft\ Ist\ gear}{No\ of\ teeth\ on\ lay\ shaft\ Ist\ gear} = \frac{43}{17}$

∴ Ist Gear ratio: $\frac{43}{17} \times \frac{43}{17} = 6.39$,
Ist gear ratio: 6.39

2nd gear ratio: $\frac{No\ of\ teeth\ of\ main\ shaft\ 2nd\ gear}{no\ of\ teeth\ of\ lay\ shaft\ 2nd\ gear}$
$= \frac{33}{27}$
$= \frac{47}{17} \times \frac{33}{27} = 3.09$
2nd gear ratio: 3.09

II. LITERATURE REVIEW

The biggest question today, before the metropolitan population of our Country like India, in particular is "pollution is snuffing us out", and will pollution ever be controlled?

The reason for this type of thinking may be fact that in spite of several legislation from 1964 onwards, not much of progress can be visualized in this area.

There is no doubt that the progress was achieved in the last few decades in some area is very negligible in comparison with the overall picture.

In June 1999, the honorable Supreme Court of India ruled that vehicular emission had to be reduced at a much quicker pace than planned so far. In this reaction is increasing public complaints about the air quality in urban area i.e. Delhi and kolkatta.

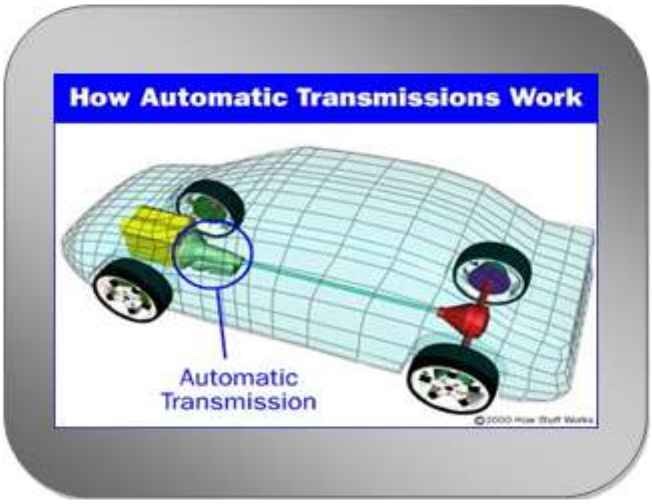

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Fig: 3(a) Torque converter is situates between the engine and the transmission

Automobile engine manufacture face the challenging engineering task to quickly find solutions, which are production feasible and technology, explained with Euro norms.

In this regard, in USA was introduced to control the automobile exhaust emission by OBD-II system (by California Air Resource Board from 1994) for the reduction of HC, NOx, CO etc.
Catalytic converter may reduce NOx (Oxides of Nitrogen) and converts to Nitrogen and Oxygen. as per Environment Protection agency, USA has been pointed out that catalytic converter does not reduce the NOx emission. Because, when the temperature is increased in combustion process, HC (hydrocarbon) and CO (Carbon monoxide) are reduced but Nox does not reduce, therefore, EGR can reduce NOx emission.

III. METHODOLOGY

The power train functions that PCM controls the emission while delivering the torque to the vehicle requested by the driver.

1. Throttle and Intake Manifold:

The throttle body assembly is an air valve and which is regulation by air flow to he engine and control of engine speed and power. Idle air control valve provides additional air flow during starting of the engine and during idle. IACV by pass the throttle to provide additional air to compensate for the loads during closed throttle. Exhaust Gas Recirculation provides exhaust gases to the intake manifold and effect of reducing oxygen content in the engine.

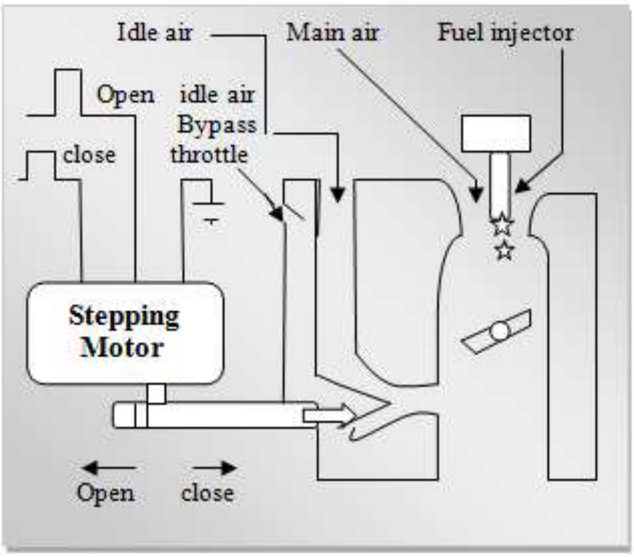

Fig: 4(a) Idle Air Control

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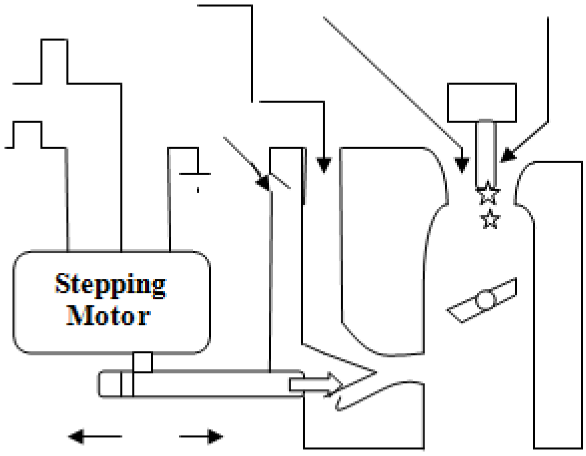

2. Cylinder:

Cylinder reduces the combustion temperature of the cylinder flame. This has the important effect of reducing the Nox (Oxides of Nitrogen) emissions which is regulated by the EPA.

3. Intake manifold:

Intake manifold is a group aluminum pipes connecting the carburetor to the inlet port. These convey the petrol air mixture to the engine cylinders. Each cylinder requires an amount of fuel determined by the density of the air in the cylinder.

4. MAP sensor:

MAP sensor is used to compute the density of the air in the intake manifold. Barometric absolute pressure is used to compute the EGR flow. The manifold vacuum is the difference between these two pressures which is measured. The required fuel is in direct proportion to this air mass which is controlled by the PCM to maintain the exact stoichiometric ratio (14.7) of air/fuel that gives the minimum HC emissions and meet regulations.

For example,
Problem: Determine for four stroke C.I. Engine,

Contd...P/5

the quantity of fuel to be injected per cylinder per cycle if consumes 0.2 kg/bhp per/hr and develop 500 bhp at 200 rpm gravity of fuel being 0.9.

Solution :

Fuel consumption per hour,
$= 500 \times 0.2 = 100$ kg
And number of cycles per hour ,
$= \frac{200}{2} \times 60 = 6000$ cycles,
∴ weight of fuel cylinder per cycle ,
$= \frac{100}{6000} \times ¼ = 0.09416$ kg.
Now, specific gravity of fuel = 0.9
∴ Density of fuel,
$= 0.9 \times \frac{1}{1000}$ = kg/c.c.
∴ Quantity of fuel injected per cylinder per cycle,
$= .00416 \times \frac{1000}{0.9}$
= 4.6 c.c.

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Combustion and Rotational dynamics consist of the following components:

5. **Engine,**
6. **Crankshaft assembly and flywheel,**
7. **Crank angle sensor,**
8. **Mass Air Flow (MAF) sensor,**
9. **Coolant Temperature sensor,**
10. **Manifold Absolute Pressure (MAP) sensor,**
11. **Engine speed sensor,**
12. **knock sensor, and**
13. **Purge solenoid.**

For Combustion and Rotational dynamics, the engine provides the mechanical power to the vehicle. The engine cylinders perform the combustion of air/fuel mixture at stoichiometric ratio (14.7). The crankshaft assembly and flywheel house the crank angle sensor which senses the position of the Top Dead Centre (TDC) of the cylinder and provides the necessary ignition spark at the correct crank angle between the reference points on the flywheel and the horizontal centerline of crank shaft. The amount of fuel melded for the combustion in the engine cylinder is a direct function of the throttle position and the mass of air through the intake manifold which is controlled by the driver's acceleration pedal. This mass of air is measured with the Mass Air Flow (MAF) sensor. The correct air mass is computed by compensating for the intake air temperature which is measured by the intake air temperature sensor. The Manifold absolute Pressure (MAP0 sensor measures the intake manifold pressure which is also used to measure the amount of air going into the cylinder as a second method to determine the amount of fuel that should be sent to the fuel injection nozzles for spraying into the cylinder.

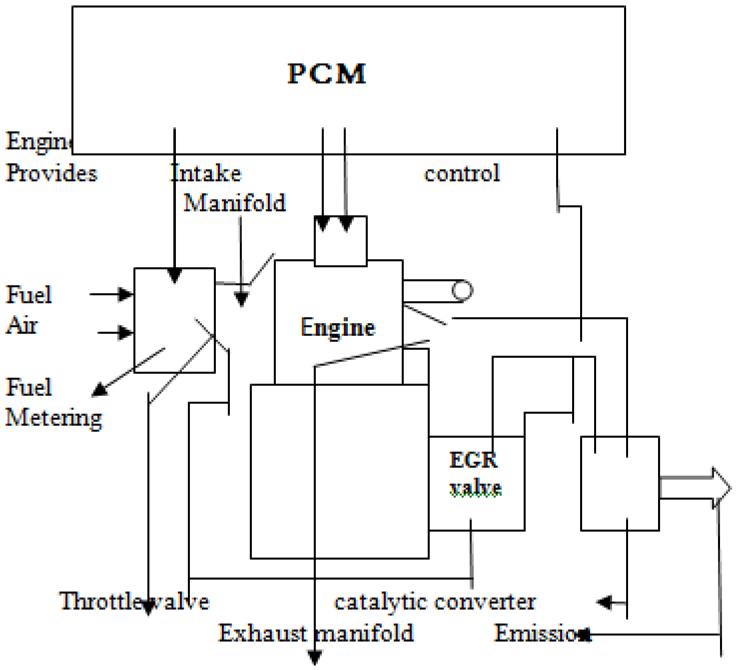

Fig: 4(a) Major Controller out-put to Engine.

This is to ensure that accurate amount of fuel is used in the cylinder to achieve fuel economy as well as to reduce emissions by efficient combustion. An engine speed sensor is needed to provide an input to PCM to compute ignition timing. Engine speed is measured by engine speed sensor similar to crankshaft position sensor. Another variable which must be measured for engine control is the throttle angle or the throttle valve position which is measured by the Throttle Angle Sensor.

The throttle plate is mechanically linked to the accelerator pedal which is operated by the driver. When the pedal is pressed the throttle plate rotates and allows more air to pass through the intake manifold. The angle of rotation of throttle plate is measured by the throttle angle sensor. This can be used to measure the mass of air going into the cylinder.

Knock is caused by a rapid rise in cylinder pressure combustion caused by high manifold pressure and excessive spark advance. It is important to detect knock and avoid excessive knock to avoid damage to the engine. Knock is detected by the knock sensor.

During engine off condition, the fuel stored in the fuel system tends to evaporate into the atmosphere. To reduce, these HC emissions, they are collected by a charcoal filter in a canister. The collected fuel is released into the fuel intake through a purge solenoid valve controlled by the PCM periodically.

IV. RESULT AND DISCUSSION

An Exhaust & Fuel system consists of the following components:

- Exhaust valve,
- Exhaust Gas line,
- Fuel pump,
- Fuel Level Sensor,
- Canister Vent,
- Fuel Feed and Metering,
- Fuel injection nozzles,
- Catalytic Converter, etc

Exhaust valves of the engine cylinders purge the exhaust through the Exhaust Gas line which then passes through the catalytic converters in which most of the HC and CO are oxidized to CO_2 and water . The extra oxygen required for this oxidation is supplied by adding air to the exhaust stream from an engine driven air and this air is called Secondary air.

For example, (From different angle)
Problem: A 8 cm × 11 cm four cylinder , four stroke cycle S.I Engine is to have a maximum speed of 3000 rpm and volumetric efficiency of 80%. If the maximum venturi depression is to be 150 cm of water, calculate the size of the venturi and the fuel orifice. Air fuel ratio needed is 12:1. List the assumption made:

Assumption:

1. The effect of compressibility on air is not considered.
2. The difference in height between entrance and the root is very small, hence neglected.
3. Flow of air through venturi is frictionless and no heat transfer takes place hence no change in internal energy.
4. The nozzle lip effect is neglible,
5. It is assumed that $K_a = .84$, $K_f = 0.6$, and
$p_f = 700$ kg/cm2

Solution:
Venturi depression:

$= \Delta Pa = \frac{150}{100} \times 1000 = 1500 \text{ kg/cm}^2$

Maximum amount of air passing through the venturi/sec $= \frac{\pi}{4}\,(8)^2 \times 11 \times 4 \times \frac{3000}{2\times 60} \times 0.8$

$= 43200$ c.c.

$= 0.0432 \text{ m}^3$

Velocity of air at throat ,

$$U_2 = Kef\sqrt{\frac{2g.\Delta pa}{pa}}$$

P_a at N.T.P. $= \frac{p}{RT} = \frac{1.027\times(10)4}{29.27\times 273} = 1.284 \text{ kg/m}^3$

$$U_2 = 0.84\sqrt{\frac{2\times 9.41\times 1500}{1.284}} = 127 \text{ m/sec}$$

Maximum amount of air passing through the venturi/sec:

$= U_2 \times A_2$

$= 0.0432$ (neglecting the effect of compressibility)

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$\frac{\pi(d2)2}{4} = \frac{0.0432}{127}$

$\therefore d_2 = \sqrt{\frac{0.0432 \times 4}{127 \times \pi}}$
$= \sqrt{4.34 \times (10) - 4}$
$= 2.08 \times 10^{-2}$

Throat diameter of venturi = 20.8

Again, $\frac{Wf}{Wa} = \frac{Kf\,.Af}{Ka\,.A2}\sqrt{\frac{Pf}{Pa}}$

$\frac{1}{12} = \frac{0.6 \times 127 \times Af}{0.84 \times .0432}\sqrt{\frac{.oo}{1.284}}$

$A_f = \frac{0.84 \times .0432}{12 \times .6 \times 127}\sqrt{\frac{18.35}{(10)4}}$
Or, $\frac{\pi d(r)2}{4} = 1.695 \times 10^{-6}$
$d_f = \sqrt{\frac{1.695 \times (10) - 6}{\pi}}$
$= 1.47 \times 10 -^{1}$ cm
= 1.47 mm.

Oxygen sensor is used to monitor the residual oxygen (after catalysis in the converter) in the exhaust gases. The oxygen sensor output is calibrated to measure the air/fuel ratio (which is proportional to oxygen in the exhaust gases) in the engine cylinders. This ratio called Lambda, is one (1) for stoichiometric (14.7) air/fuel. This is this target for realizing minimum emissions.

The oxygen sensor is used as stoichiometric detector and is connected in a closed loop in a Limit Cycle Control. The oxygen sensor output is switch signal (ON/OFF) that brings back the Air Fuel Ratio to 1 when it varies between 0.93 to 1.07.

EPA regulations require linear EGR system monitoring to determine if there is a restriction in the EGR system. The linear EGR flow diagnostics is performed to detect any malfunction of the linear EGR system. The diagnostics is based on the fact that in a properly functioning system and there is a direct correlation between linear EGR flow rate and manifold air pressure (MAP) changes.

The following functions are performed by the linear EGR flow diagnostic.

Enable Linear EGR Flow Diagnostics,
Monitor decal Test Start conditions,
#Monitor decal enables criteria,
performed decal started.

Manage decal test:
perform decal intrusive testing,
perform decal open,
perform decel sample,
perform decel close,
Monitor decel intrusive testing.

The following functions are performed by the linear EGR flow diagnostic.
Manage decel Abort and Rest,
Control between Test Times,

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determine EGR pass/Fail status,
Report EGR Flow Fault Status.

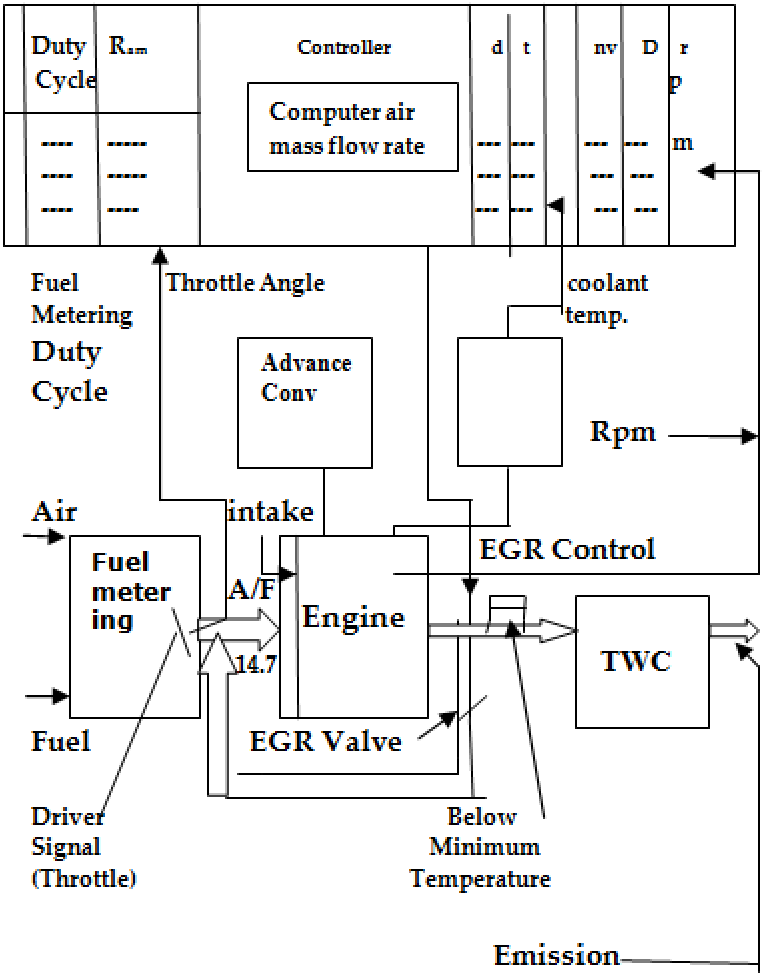

Fig. 5(a) Open Loop Control

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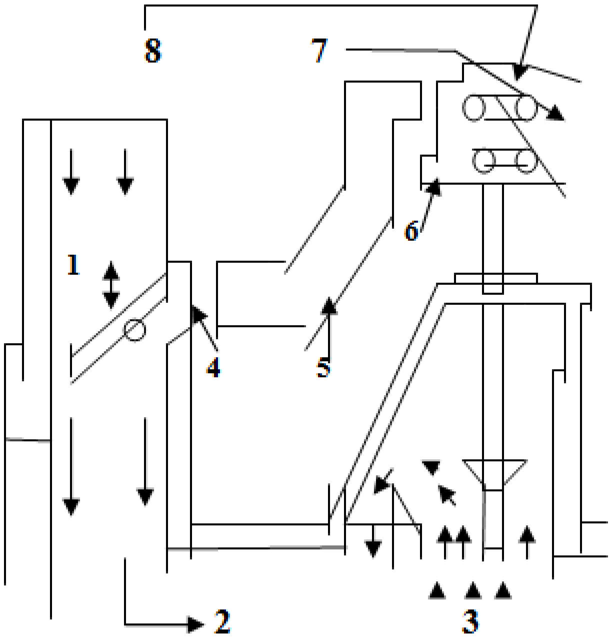

Fig: 5(b) Exhaust Gas Recirculation System:

1» Throttle valve,
2 » Intake Manifold,
3» Exhaust Gas,
4» Vacuum Port,
5» Vacuum Tube
6» Diaphragm arm
7» Vacuum Chamber,
8» EGR Valve etc

V. TYPE OF DATA

As per Experimental data of four stroke single cylinder engine and compression ratio is variable on spark ignition engine and it was found that 35% recycling have got reduced 84% to 91% of NOx reduction(Slightly higher fuel consumption) and reduce CO has lesser percentage. Engine is directly connected to DC electric Dynamometer (Dynameters as a device for determine the power of an engine) and maximum power developed the engine the all speed and collected exhaust gas sample and analyzed by suitable exhaust gas analyzer method.

1. Effect of Air-Fuel ratio:-

It is most important engine variable to affects NOx emission and performance of engine depends. Air fuel ratio reacts and concentration NOx emission, shifted to rich side, bsfc shift to rich side and percentage of recycling increasing.

2. Effect of Recycling:-

bsfc increase than percentage of recycling increases. This mixture becomes lean mixture therefore extra fuel required urgently, and engine output increases. As percentage of recycling increase and temperature of exhaust increase, therefore, late burning of mixture.

3. Effect of spark ignition timing:-

Spark is retarded peak combustion temperature increases, NOx reduce, and this is achieved at higher fuel consumption and HC emission. At increased speed even without recycling, spark timing has to be advanced for proper combustion. Therefore, advanced to provide more time for spark ignition timing by complete combustion.

4. Effect of speed:-

NOX emission increase with the increased speed. At higher speed need more fuel to overcome greater frictional losses.

5. Fuel Consumption:

- 35 % recycling as a result fuel consumption, between 26% to 31%.
- 35% recycling in 1200 rpm to 1800 rpm, fuel consumption 3.85% to 28%.
- NOx emission is higher speed; therefore, EGR may reduce CO also.

6. EGR trouble:

- Poor engine performance may cause EGR trouble, example, rough engine idle could cause leaky EGR valve or valve gasket.
- Poor part fuel performance and rough acceleration cause thermal vacuum switch defective. If manifold is not clean, clean out the passages.
- Detonation causes damage valve and thermal vacuum switch

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VII. DEFINITION/ACRONYMS/ABBREVIATION

Definition

Air Injector: This system of injecting fuel, into the combustion chamber of a diesel engine using a blast of compressed air.

Pintle: A small extension of the needle valve tip projecting through the discharge nozzle. When the needle lifts, the oil passes through the opening between the circumstance of the orifice and that of the pintle.

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Smog: A term coined from the words, "Smoke" and "fog", first applied to the froglike layer that hangs in the air under certain atmosphere conditions. Now, generally used to describe any a condition of dirty air and or fumes or smoke.

Throttle valve: The butterfly valve of a petrol engine.

Thrust: axial force acting on a shaft.

Volumetric Efficiency: Ratio of the volume discharged from a pump to the piston displacement of the pump. In diesel engines a term often used instead of the correct term 'charge efficiency'

Acronyms

Idle Air Control valve (IACV): The valve is an electronically controlled throttle by pass valve which allows air to flow around throttle plate (which is closed due to low engine rpm and vehicle being stationery) and produces the same effect as if the throttle slightly opened.

Solenoid: A type of electro-magnet often used to operate the starter motor switch.

Abbreviation

CARB = California Air Resource Board.
CCR = California Code of Regulations.
DTC = Diagnostic Trouble Code,
FTP = Federal test Procedure.
I.C. ENGINE = Internal Combustion Engine.
MIL = Malfunction Indicator Light.
MAP = Manifold Absolute Pressure

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