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Novel Configuration for Air Flow Rationalization and Turbo Lag Reduction in CRDI Engine

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Abstract- The power output of a CRDI engine at any particular cycle depends on the oxidation of diesel inside the cylinder. As air-fuel ratio should be maintained within tight limits; the amount of air available inside the cylinder determines the maximum power output at a particular cycle. During acceleration mode and particularly during turbo lag periods, the quantity of air available in conventional CRDI engines is not sufficient to meet the desired torque demand. To overcome the problems encountered during acceleration and deceleration; a novel concept and control strategy are presented in this paper.

Index Terms- Common Rail Direct Injection, Turbo lag, Supercharger, Variable Geometry Turbo Charger, Air fuel ratio, Multi air technology

I. Introduction

The diesel injection system of an engine is a multivariable nonlinear system. The engine speed, composition, temperature of the coolant, pressure of diesel inside the common rail, the inlet manifold pressure, the accelerator thrust value are fed into the ECU of the engine to calculate the quantity, timing, & pattern of the diesel to be injected into the combination chamber. Common rail diesel fuel injection system block diagram shown in Fig. 1 below is a fuel injection system for a typical four cylinder four stroke CRDI system [1]. The system consists of a pre- pressure pump to deliver fuel to the high pressure pump from the fuel tank. The high pressure pump pumps fuel to the common rail, which has a pressure regulator that controls the pressure of the fuel inside the common rail. The common rail is connected to the fuel injectors through high pressure fuel lines and the high pressure fuel is readily available at all instants to the fuel injectors. The fuel injectors are controlled by an ECU of the system and are activated just before the TDC of the power stroke of each piston. The rate of flow, the pressure, the timing and the pattern are controlled by the ECU, taking into account the various input parameters sent by the following sensors engine speed sensor, CAM position sensors, VGT sensor, coolant temperature sensor, ambient temperature sensor and the accelerator sensor. An optimal volume of fuel is injected into the combustion chamber which burns with the high temperature air available in the combustion chamber to produce useful mechanical energy, forcing the piston to the BDC.

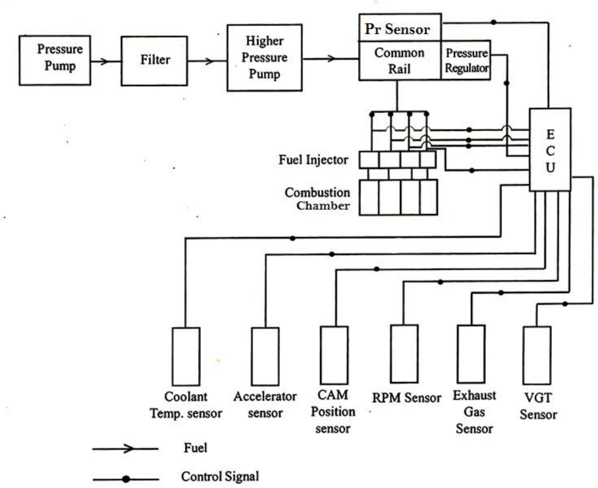

Fig . 1 Common rail direct Injection system for Diesel Engine

II. MULTI AIR SYSTEM

This is an electro- hydraulic valve actuation system developed by FIAT. In this system direct control of air quantity, cylinder by cylinder is made possible by introduction of a hydraulic chamber with a solenoid valve between the cam and the valve. The mass of air entering the combustion chamber can be controlled without using the throttle. This breakthrough technology is implemented in the 2009 model production gasoline engines [16].

In the conventional gasoline engines the air trap in the cylinders are controlled by keeping the opening of the intake valves constant (i.e. keeping the valve lift constant) and adjusting the upstream pressure by manipulating a throttle valve; whereby wasting about 10% of the input energy in pumping the air charge from a lower intake pressure to the exhaust atmospheric pressure. With this technology the complete degree of freedom to control the mass of air on a cylinder to cylinder basis is made possible. More over the system is relatively simple, the power requirements are low, the components are intrinsically fail safe and the cost is also low.

The system consists of a piston moved by the cam lobe that is connected to the intake valve through a hydraulic chamber that is controlled by a solenoid valve. The displacement of valve imposed by the mechanical cam is completely effected when the solenoid valve is closed, because the hydraulic chamber acts as a solid body. When the solenoid valve is open the displacement of the valve due to the profile of the cam is not transmitted to the valve as the hydraulic chamber does not transmit the cam schedule to the intake valve.

The final part of the valve closing is controlled by a dedicated hydraulic brake to ensure soft and regular landing phase for all engine operating conditions.

The solenoid valve is always closed for maximum power. The solenoid valve is open for early intake valve closing for low-rpm torque. The required mass of air based on the torque demand can be made to flow in to the combustion chamber. Multiple actuation modes can be combined in the same intake stroke, so as to enhance turbulence and combustion rate at very low speeds. When conditions dictate internal exhaust gas recirculation, it can be made possible. Different valve opening and closing angles can be effected during cold start and warm up periods.

III. VGT AND ITS EFFECTS ON REDUCING TURBO LAG

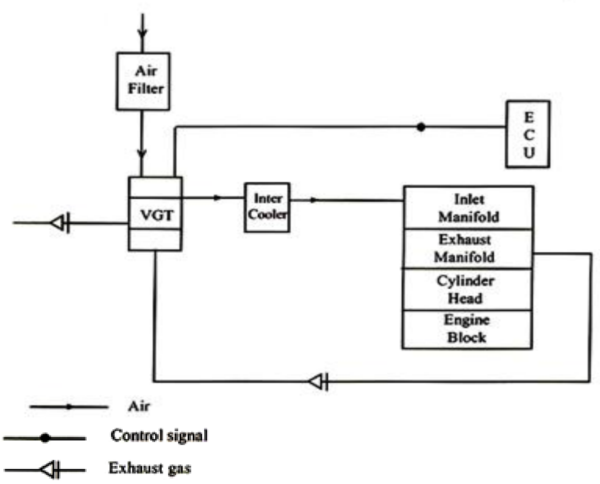

Fig .2 Air flow of Common Rail Direct Injection Diesel Engine

Turbochargers are used in diesel engines for recovering part of the heat lost in the exhaust gases and boosting the power output of the engine with the same displacement. In the past few years, in order to improve the efficiencies and to reduce pollution, complex systems like variable geometry turbo charger (VGT) and fixed Geometry Turbocharger (FGT) were fitted with high pressure and low pressure EGR [7].

VGT is variable geometry turbocharger used in the air circuit of a common rail diesel engine. The geometry of the turbocharger is varied by a signal from the ECU. When the speed of an engine is low, the quantity of exhaust gases which drive the turbocharger is also low. When the engine needs to be accelerated from low speeds, the first input parameter change the system receives is the accelerator thrust. When the accelerator thrust signal changes, the ECU immediately responds by commanding the injector to supply more fuel to the combustion chamber. The ECU also orders the VGT to change the geometry so that the exhaust gases could spin the turbine to higher speeds and to deliver more air into the combustion chamber of the engine, so that the desirable air fuel ratio is achieved to burn the fuel in the combustion chamber. But, in spite of the geometry variation in the turbo charger, because of low volume of exhaust gases available, the speed of the turbine does not increase instantaneously. It takes at least three seconds in a typical 1.5 lt. CRDI diesel engine, to achieve desirable power output. This time lag is called turbo lag. At this point there is more unburnt fuel in the exhaust which can be seen in the form of soot. So, reducing the turbo lag becomes important to improve drivability, to reduce fuel consumption and reduce undesirable exhaust emissions.

IV. ANALYSIS OF EXISTING METHODS FOR CONTROLLING TURBO LAG

A Releasing the accessories

One of the common methods used to increase low end torque in common rail diesel is to switch off the air conditioner compressor and alternator [5] when abrupt accelerator thrust values are received by the ECU from the accelerator sensor. As the A/C compressor and alternator are directly coupled to the engine this action releases the torque already utilized by the A/C and alternator to increase the torque available at the fly wheel; which produces additional acceleration of the vehicle. This increases the drivability of the vehicle; although there is no immediate reduction in turbo lag. As the ECU of the CRDI engine is able to switch on/ off the air conditioner, this additional torque is released during the period. This technique is followed in most CRDI passenger vehicles.

B Electric super charging

AVL an automotive research group has come out with a concept of electric super charging, where an electric super charger is connected in parallel to the turbo charger, in the air circuit of the CRDI engine [3]. When acceleration is needed, the super charger is commanded to increase the speed from 5000rpm to about 70000 rpm which is achieved in about 1/3rd of a second, which is very good [2]. In this method the reduction of turbo lag is achieved by injecting air in the inlet manifold [4]. On simulating a four cylinder direct injection, turbo charger (radial turbine and centrifugal compressor) with air injection in the inlet manifold, the results were extremely good. The simulation was done for three conditions.

1) Normal Airflow from turbocharger
2) Additional Airflow to inlet manifold at 2.5 bar
3) Additional Airflow to inlet manifold at 3 bar

The turbo lag was reduced from about four seconds to less than one second. The power response also increased significantly. However, the negatives are, it requires about 350 amps of 12 Volt DC current for achieving this speed within that time. A normal battery fitted in a mid sized vehicle powered by a 1.5 to 2 lit. CRDI engine cannot support this super charger. An additional Li - Al battery is needed for the purpose which could be prohibitive for a small/medium size passenger vehicle.

C Power assists systems

A turbo charger power assist system (TPAS) has been developed [6]. The extent to which the system can reduce the diesel engine turbo lag is determined via the numerical solution of a minimum time optimal control problem.

A previously developed model of a diesel engine with VGT & EGR is augmented with the model of a permanent magnet synchronous motor (PMSM) to create the model turbo electric assist system (TEA) [7]. A TEA system has been able to improve acceleration performance, reduce turbo lag, reduce soot emissions and improve fuel economy [9-15].

Mitsubishi Heavy industries have designed a hybrid turbo charger based on the above principle and tested on a 2L engine. Test results were extremely encouraging with efficiency increasing to about 8-12% [8]. The turbo lag was reduced from 4 seconds to about 1.3 seconds. However the system requires a 72 volt battery where as the passenger car are normally fitted with a 12 volt battery. Hence, a novel concept by which additional air directly injected into the combustion chamber is proposed.

V. CONFIGURATION OF PROPOSED SUBSYSTEM

The figure shown below is the air flow system for the conventional CRDI engine. The additional components are (i) accumulator, (ii) pressure regulator valve. The pressure of air in the inlet manifold is of a particular range. When the inlet manifold pressure is low; and when the torque demand is high, the pressure regulator valve lets the air to flow from the accumulator to the inlet manifold. When the turbo charger is operating at high speed and when the torque demand is low, the pressure regulator allows the high pressure air in the inlet manifold to flow into the accumulator and is stored there. So during conditions of turbo lag, the high pressure air stored in the accumulator flows into the inlet manifold and then into the cylinder. This in turn creates a condition in which more diesel can be oxidized in the cylinder releasing additional power till the demand for more torque prevails. As the accumulator serves as a buffer, the quantity of air entering the cylinder during the deceleration is also regulated, whereby reducing the energy spend by the engine during the compression and exhaust strokes of the deceleration cycles [16].

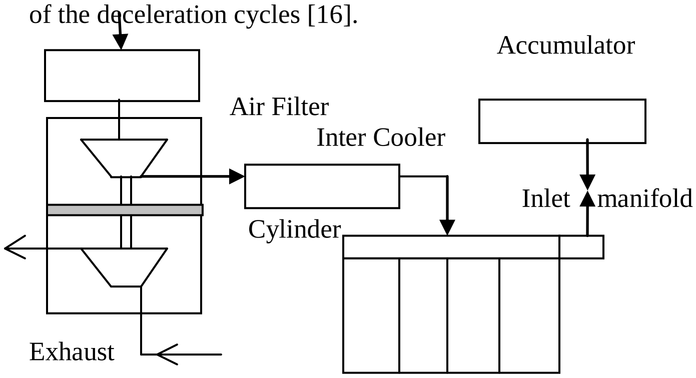

Fig.3 Air supply system with accumulator and injector

The subsystem presented above is completely compatible with the multi air (hydraulic-solenoid) cam systems designed by FIAT. Although these cam systems were designed for gasoline engines, they can be adopted for CRDI engines to accurately control the quantity of air entering each and every cylinder in every operating cycle; based on the load and or torque demand at that instant. The turbulence of air entering the cylinders can also be controlled. As mentioned previously, depending on the torque demand, the pressure regulator valve is actuated by the ECU to control the direction of air flowing into and out of the accumulator.

During idling conditions with minimum load (ie when A/c compressor and alternator are switched off); air entering a few cylinders can be completely blocked. During part load, some cylinders can be completely filled with air so that complete combustion is made possible in selective cylinders. This gives compete degree of freedom for operating the cylinders individually based on the torque demand and or load. During turbo lag conditions as high pressure air is stored in the accumulator; this air can be directed into the inlet manifold by operating the pressure regulator valve using the ECU. So, additional mass of air flows into the cylinders and additional torque is produced.

During the instants (cycles) when no energy need to be developed by the engine, the air entering the cylinder is blocked using the multiair cam mechanism. By blocking the air entering the cylinder, the energy expended by the engine during the compression and exhaust strokes of that particular cycle can be saved thereby increasing the brake thermal efficiency of the engine. During compression strokes, some of the heat generated in the cylinder is transferred to the coolant of the cooling system. As only part of the heat lost during compression is recovered during expansion, some loss in energy is saved. So each cylinder is controlled separately and the quantity and pattern of injection of diesel is determined after knowing the mass of air in the preceding suction stroke. The only energy expended during the non-combustion cycles are only due to friction and inertia. As AFR is maintained within tight limits, the formation of particle matter and carbon-monoxide will be reduced further. The formation of nitrous oxide due to large mass of air and low mass of diesel particular at high temperatures are also reduced as this condition no longer exists.

VI. CONCLUSION

The subsystem has many advantages over the existing electric super charger system which requires 350 amps current for acceleration. The switching off of the air conditioner can be adapted for this configuration too. The proposed subsystem has just two simple components; accumulator and pressure regulator valve. The subsystem doesn't require high power battery, complex power electronics or electric compressor. Reduction in noise, vibration, un-burnt fuel emissions and fuel consumption are anticipated. The addition of the subsystem will lead to better acceleration and deceleration characteristics with improvement in efficiency. As desirable air fuel ratio is maintained for all the operating cycles, the EGR and its connections can be avoided thereby reducing the pumping loses.

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