Enhancement of the Engine Acceleration by Using Intake Manifold Boosting of Spark -Ignition Engine

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Submitted to the College of engineering and technology

In partial fulfillment of the requirements for the degree of

Bachelor degree in Automotive Engineering

Palestine polytechnic university

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`Palestine Polytechnic University

Collage of Engineering

Mechanical Engineering Department

Hebron – Palestine

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Supervisor Signature

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Testing Committee Signature

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Chair of the Department Signature

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First and for most we should offer our thanks, obedience and gratitude to Allah.

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Anyone who helped us

Abstract

Intake manifold Air injection is a widely used approach to reduce the fuel consumption and improve acceleration performance of spark - ignited engines while retaining the maximum power output. Significant part of engine produced power is generally required to overcome vehicle inertia acceleration which is an essential parameter in engine sizing.

Supplying air by an additional valve, the boost valve, to the intake manifold can be used to overcome the acceleration problem. The compensation method is referred to as intake manifold boosting assistance. The aims of this project are to show the effectiveness of intake manifold boosting on a spark -ignited engine and to show that intake manifold boosting can be used as an enabler of strong downsizing. Prototype of the boost assisting system will be given and a control strategy will be presented.

ملخص

أظهرت النتائج ان حقن الهواء في مجاري السحب يعمل على تقليل استهلاك الوقود في محركات البنزين كما وتعمل على زيادة كميه الطاقة الناتجة من الاحتراق . ان زيادة كميه الطاقة مهمة للتغلب على كتله المركبة أثناء عمليه التسارع , كما وتعمل على تحسين المرحلة الانتقالية لعمل المحرك عند تغير الحمل بشكل مفاجئ .

ان عمليه حقن الهواء في مجاري السحب عن طريق استخدام حاقن هواء مساعد تعمل على تطوير التسارع في المركبة.

الهدف من هذا المشروع هو إظهار اثر زيادة كميه الهواء وزيادة ضغطه في محركات البنزين وسيتم إظهار كيفيه التحم في هذا النظام وطريقه عمله .

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CHAPTER ONE

INTROCUCTION

Contents:

1.1 General outlook

Boosting pressure is an increasingly popular method for improving drivability and reducing the harmful emissions of an Internal Combustion (IC) engines. A boosting pressure utilizes energy from the exhaust gases and uses it to pressurize the air at the inlet to the cylinders. This allows for the density of air in the cylinder to be greater than the density of ambient air, which allows more power to be produced for a given engine size which improving drivability. It has also been shown that use of boosting pressure results in reduction of the harmful emissions.

Spark-Ignition Engines have the disadvantage of poor drivability under transient running conditions when the vehicle inertia require significant part of engine power. Quick changes in accelerator pedal do not result in instantaneous response of the turbocharger and consequently vehicle acceleration. This delay has negatively impact on drivability and emissions because of unfavorable air-fuel ratio and need for larger engine sizes. Reduced air flow in the combustion chamber while fuel is injected causes inadequate air fuel (rich mixture) resulting in increased formation of emissions such as particulates, CO, CO_2 and NOx which contribute to environmental pollution and increase fuel consumption.

1.2 Objectives of this project

The objectives of this project can be summarized in the following points:

1. Improving vehicle acceleration without need for larger engine sizes.

2. Improving the fuel economy.

3.increasing engine power .

1.3 Literature review

This project focus on improving gasoline engines responses. This response is a major issue limiting in terms of drivability and emissions. A literature review has been carried out looking at different methods for solving these problems. The various techniques that have been studied or developed so far for improving boosting pressure can be classified as follows:

1. Variable Geometry Turbine (VGT).

2. Electrical boost pressure supply.

3. Air injection inside intake manifold.

discuss of these techniques is presented in the chapter 2.

1.4 Project idea

After knowing these techniques and after knowing the advantages and disadvantages of each techniques , we decide to choose the intake manifold air injection method because it does not exceed the inertia as the other methods do, and it need acceptable budget which is suitable for us.

1.5 Project Schedule

The project schedules for first semester include collecting data and analyzing of data and modeling. Table 1.1 show this.

Table 1.1 Project time-schedules for first semester

process	week															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Collecting data and literature	/	/	/	/	/											
Analyzing of data				/	/	/	/	/								
modeling							/	/	/	/	/	/				
Writing the documentation						/	/	/	/	/	/	/	/	/	/	
First presentation																/

The project schedule for second semester shows in table 1.2

Table 1.2project time – schedules for second semester

process	week															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Preparing The combustion engine	/	/	/	/												
Buying Mechanical And pneumatic part				/	/	/	/	/								
Building experimental Setup							/	/	/	/	/	/				
Check the project parts And perform The initial experiment												/	/	/		
Perform final experiment													/	/	/	
Writing the documentation													/	/	/	
Final presentation																/

1.6 Project Budget

The apparatus requirements are Air tank, Solenoid valve, Pressure sensor.

The budget of the project also include printing costs and study and survey. The following table shows the estimated cost of each one.

Table 1.3 project budget

Element	Description	Cost(NIS)
equipments	Manifold pressure sensor	150
	Air injector (solenoid valve)	150
	Throttle controller	125
	Over stream valve controller	90
	Air tank	150
	Boost valve	220
Total cost		885

CHAPTER TWO

ENGINE BOOSTING FOR IMPROVING ACCELERATION

Contents:

2.1 Introduction

Mean Value Engine Model (MVEM) is the basis of control design for advanced internal combustion engines. The engine performance transient process usually takes a few cycles. The MVEM provides an adequate accurate description of the engine dynamics with reasonable approximation by ignoring the heat loss and sub-cycle events. MVEM is very important for engine system control development, especially when the modern engine becomes more and more complicated when equipped with throttle and after-treatment systems. Usually the MVEM is developed based on data from engine tests, which is a costly and time consuming process. In this chapter, the air path MVEM modeling method is discussed for a gasoline engine, to demonstrate the effectiveness of this new method. This approach is used to get the MVEM for control design even before the prototype engine is available.

2.2Boosting system

Boosting is positive pressure force more air into the engine created by device such as turbo or supercharger. It can create more pressure inside the cylinder resulting more power. Increasing boost will force more air into the engine, so more fuel can be added to increase the power in this cycle.

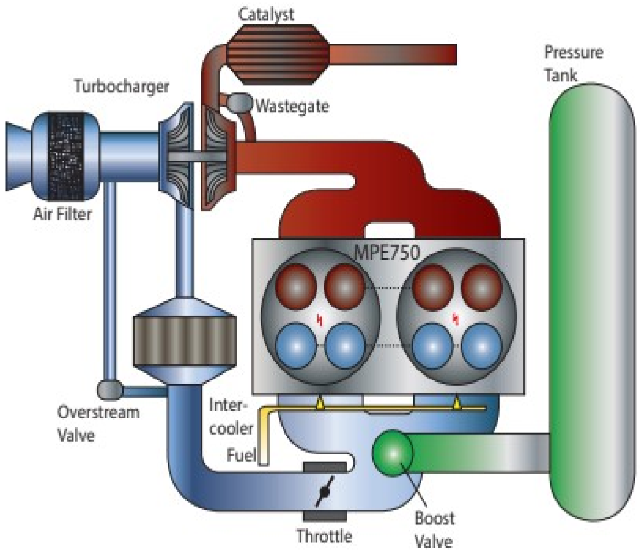

Figure 2.1 System structure of a SI engine with intake manifold boosting [1].

2.3 Methods to improve the boosting pressure

1. Variable geometry turbine (VGT).

2. Electrical boost pressure supply.

3. Air injection.

2.3.1 Variable Geometry Turbine (VGT)

Due to the geometry and different speed range operation, there is mis-match between the exhaust gas flow of the internal combustion engine (ICE) and the radial flow of the turbocharger. If the geometry (flow area) of the turbine is designed to match the full speed and load of the engine (large area). At low and medium speed the response of the turbocharger will be poor. An ideal turbocharger should be able to provide the required intake air pressure (boost) regardless of the operating point of the engine (speed and torque). This is not possible due to the fact that the speed of the turbocharger shaft depends on the mass flow of the exhaust gases, which depends on the engine operating point.

For a fixed geometry turbocharger, at low engine speed, the exhaust gas mass flow is low, therefore the speed of the turbocharger shaft is low, which means low air boost. On the other hand, at high engine speed, the exhaust gas mass flow rate is high, the speed of the turbocharger shaft high as well, which translates in high intake air boost (pressure).

The advantages of VGT engine transient response compared with its conventional turbocharged counterpart are illustrated and quantified in Fig. 2.2 for typical automotive transient tests, namely engine acceleration and performance over a transient Cycle, respectively.

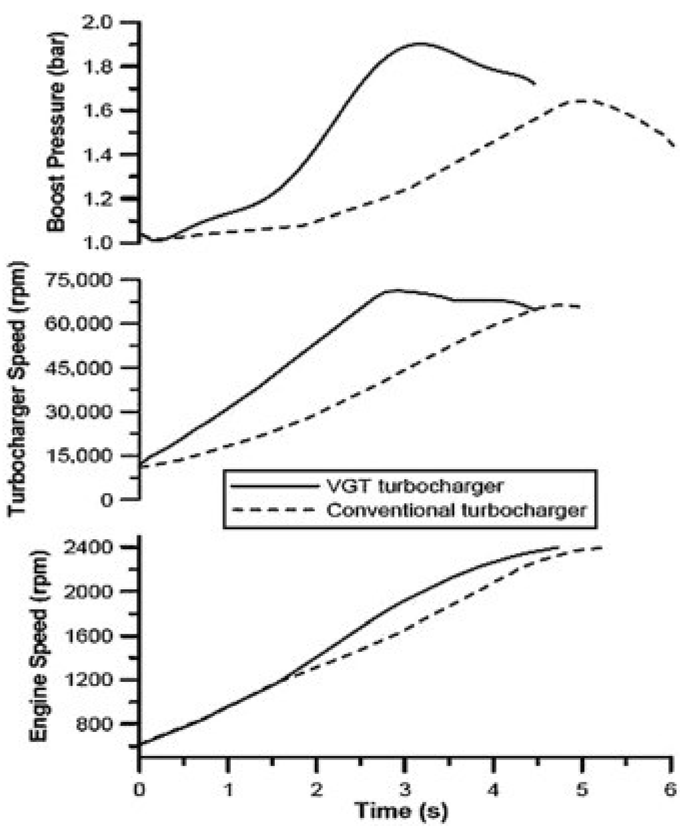

Figure 2.2effect of VGT on engine speed development during second gear acceleration from 600 rpm (six cylinder, turbocharged gasoline engine of 11 L displacement volume, installed on a 20ton truck). [2]

2.3.2 Electrical boost pressure supply.

An electrical booster comprising a charge pump for generating a boost voltage over a boost line. The booster comprises a comparator which is supplied by a voltage divider with a voltage proportional to the boost voltage, and by a reference source with a low reference voltage, and which, depending on the outcome of the comparison, enables or disables the charge pump. A voltage limiter is connected between the boost line and ground; and a acceleration circuit accelerates the voltage increase on the acceleration line following low-power operation in which the paths toward ground are interrupted for reducing consumption.

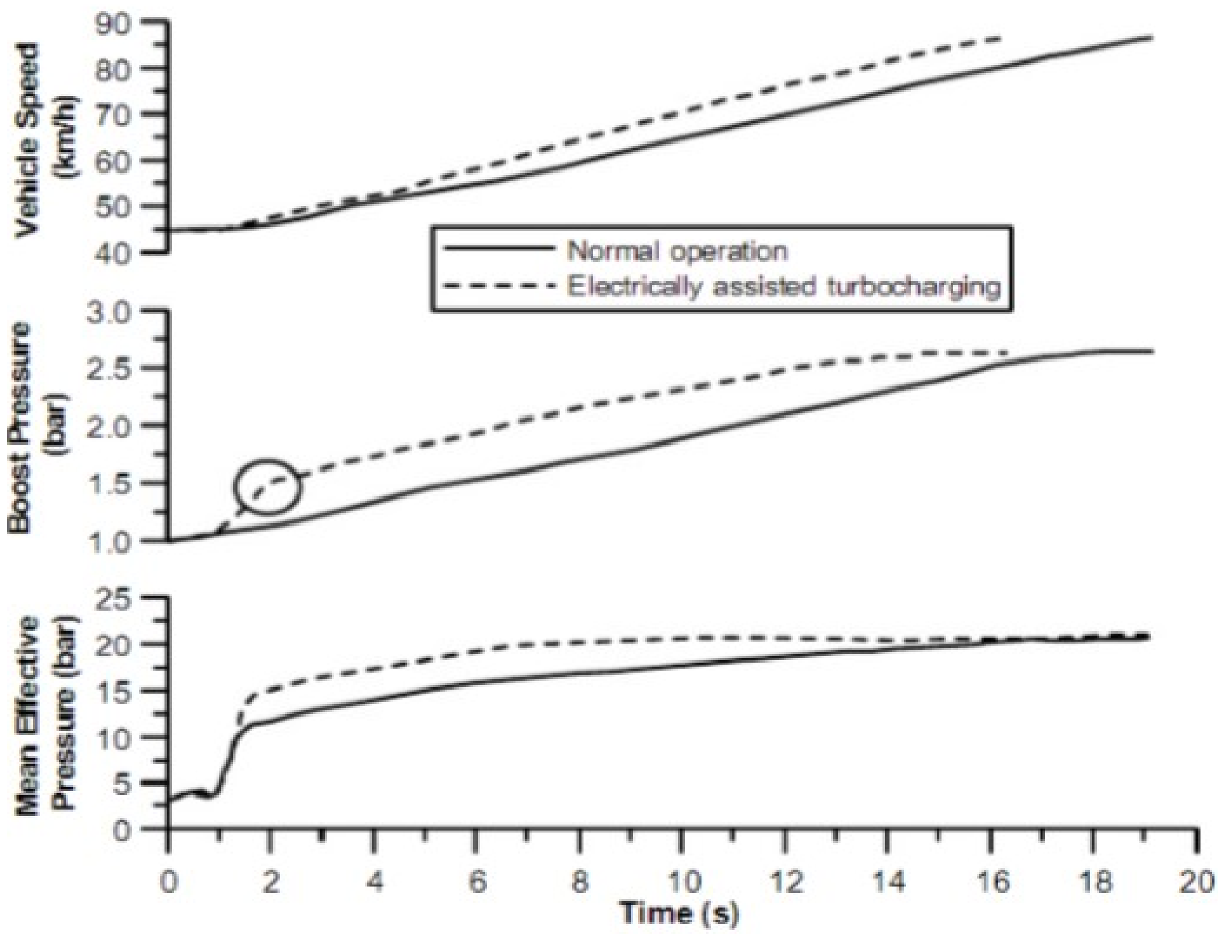

Figure 2.3 Acceleration performance of a gasoline -engine vehicle with electrically assisted turbo charging. [3]

2.3.3 Air injection

Injecting pressurized air stored in a tank into the compressor or inlet manifold or the turbine wheel. Injecting air on to the compressor wheel is, generally, more successful than air-injection onto the turbine blades, since it is more efficient to drive the compressor directly instead of increasing its boost pressure mechanically from the turbine side; moreover, the air that is injected in the compressor side is instantly available to the engine for combustion. Consequently, direct increase of air-supply is achieved and the duration of combustion discrepancies is reduced since the high airflow into the engine cylinders can match the increased fuel quantity in just a few cycles; with the resulting high exhaust gas energy aiding faster turbocharger and engine response.

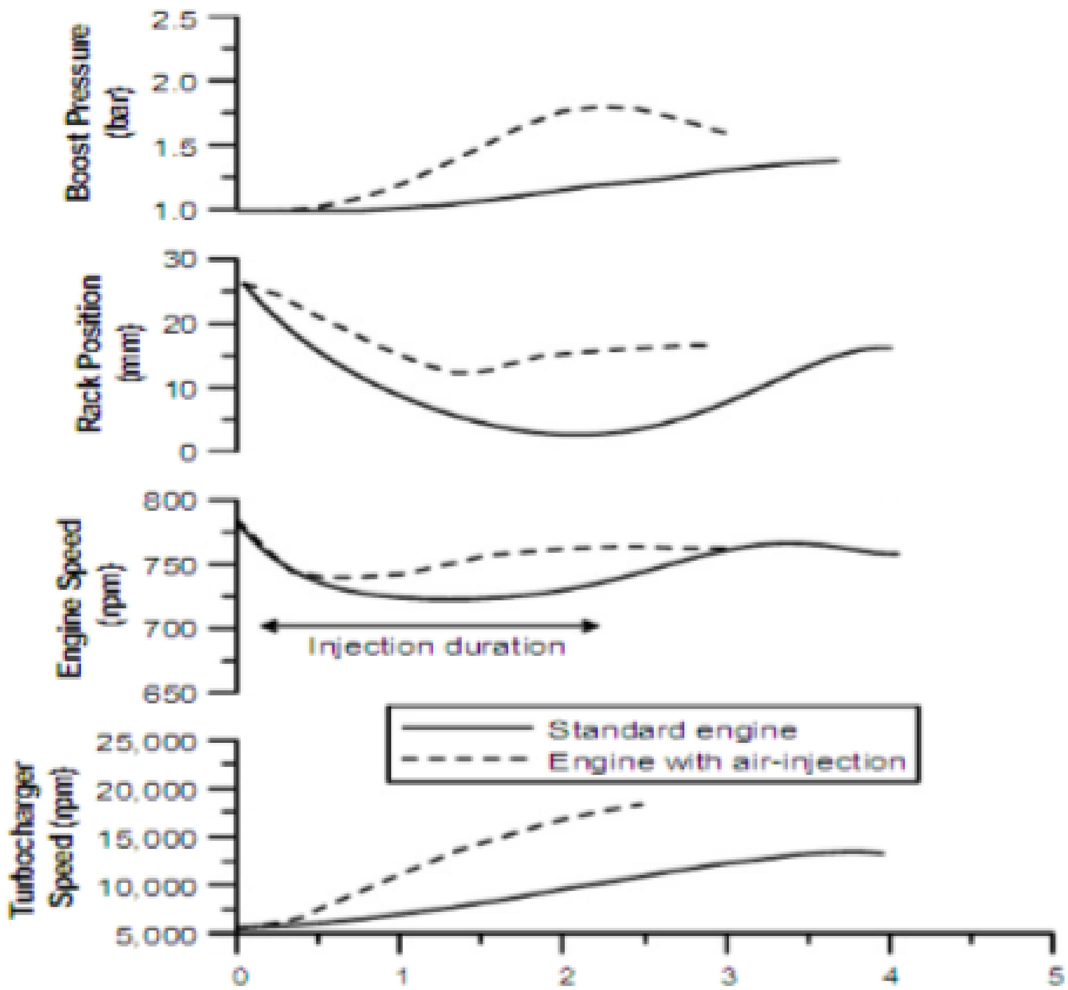

Figure 2.4 Effect of air-injection on transient response after a load step of 60% full load (medium-speed, gasoline engine at 750 rpm). [4]

2.4 Air injection system advantages.

The present project provide many advantages include:

1. A first benefit of a vehicle system that is equipped with a rate-shaped pneumatic booster system is that significant fuel efficiency increases may be obtained. The fuel savings result from the use of rate-shaped compressed air injection to improve combustion and exhaust generation to more rapidly get the engine into the engine speed range at which the engine is operating at its most efficient fuel efficiency (often referred to as the engine's "sweet spot") and thereby get the vehicle to the desired cruising speed in the least amount of time, and with the least amount of fuel consumption possible while still avoiding operational, emissions and/or equipment engineering limits.

2. An additional benefit with the system rate shaping is that the vehicle designer can avoid unnecessary compressed air use and thus decrease the size and cost of the vehicle's installed compressed air generation and storage equipment. Specifically, by injecting only the actual amount of compressed air required to obtain a desired vehicle acceleration while still maintaining compliance with operating limits, and doing so only at the actual times the compressed air is needed during the pneumatic boost event, this system can obtain a desired level of engine torque output with less compressed air than typically consumed by another pneumatic booster systems.

3. The increased precision in compressed air injection decreases the volume of compressed air required during vehicle operations, allowing the vehicle designer to reduce the size of the compressed air generation and storage components to match the lower compressed air demands. These reductions in component size and capacity provide further fuel economy benefits, both due to reduced vehicle weight and due to reduced energy loss from the vehicle's air compressor.

2.5 Air injection systems disadvantages:

While it has previously been known to inject compressed air into the intake manifold of an engine to improve boosting pressure work in this field has primarily concentrated on maximizing the amount of compressed air available to flow into the engine intake manifold, and on minimizing the response time from the initiation of the pneumatic boost event to the actual injection of compressed air so as to immediately begin to increase engine torque output and avoid undesired operator perceived delays in delivery of torque from the engine.

1. Sometimes very abrupt increase in engine torque output at the beginning of a pneumatic boost event injection resulting from very rapid compressed air injection. Such sharp engine torque output transients may also be experienced at the subsequent termination of compressed air injection this transient can create significant discomfort to the vehicle operator and passengers.

2. In the rush to quickly boost engine torque output until the turbocharger has built up sufficient pressure, regulatory limits such as pollution emissions limits may be exceeded. The sudden application of excessive pneumatic boost also has the potential to impose sudden loads on the engine components. For example, sudden application of excessive pneumatic boost can apply a large amount of torque to the vehicle drivetrain which may approach engine, transmission and/or drive axle stress limits.

3. Excessive pneumatic boost may also generate a sudden high volume, high pressure flow of exhaust gases from the engine which can cause the speed of the turbocharger turbine-compressor assembly to rise to high levels. Similarly, sudden compressed air injection and accompanying increased exhaust gas flow can create the potential for over-pressuring the engine's intake air intercooler and its associated piping.

After knowing the advantages and disadvantages of air injection We decide to choose this method because it doesn't exceed the inertia as the other methods do, and it need acceptable budget which is suitable for us.

CHAPTER THREE

ENGINE ACCELERATION IMPROVEMENT SYSTEM

Contents:

3.1 The effect of inertia on vehicle dynamics

Newton second law show the vehicle mass acted upon by an unbalanced force F experiences an acceleration a that has the same direction as the force and a magnitude that is directly proportional to the force.

From Newton second low:

$$F_x = m \times a_x \qquad 3.1$$

F_x: $forces\ in\ x\ direction$

m: mass of the vehicle

a_x: acceleration in x direction

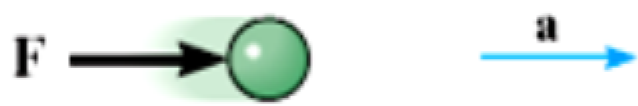

Figure 3.1 Accelerated motion [5].

we can see that at the beginning of the vehicle the only factor that affect on the vehicle dynamics is the mass.

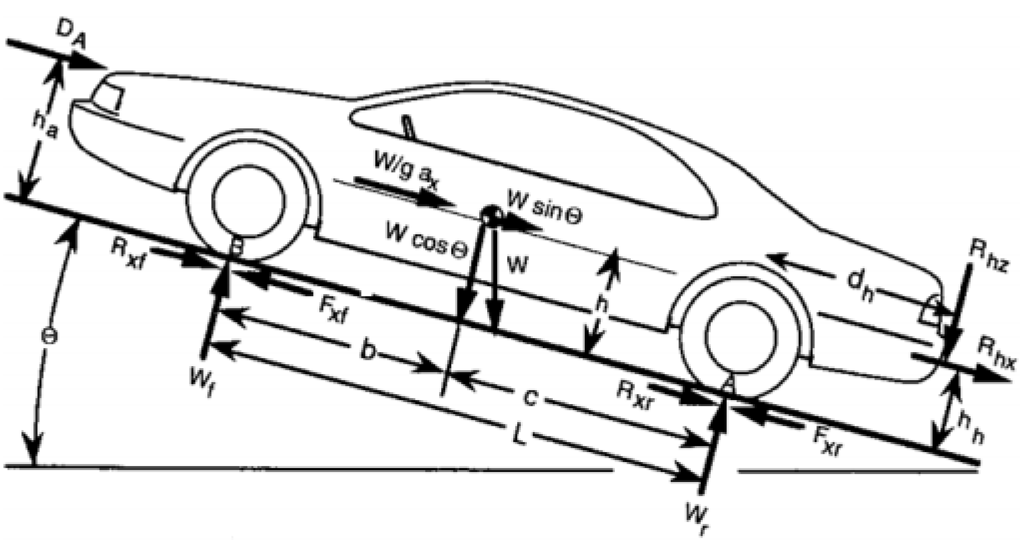

Figure 3.2 Forces acting on two-axle vehicle [5].

$F_e = m\ddot{x} + R_x + F_{aero}$ *3.2*

R_x: is the rolling resistance force.

F_{aero}: is the aerodynamic drag force.

F_e: engine force.

Since the attractive force that the engine is produce bigger than (R_x and F_{aero}) , so we need the air boosting just when we change the velocity and accelerate.

$$Work(w) = F \times l\ (N.m) \qquad 3.3$$

$$Power(p)\ cylinder = w/t = F \times l/t(w) = p_{w \times} \eta_e = T_e \times w_e \qquad 3.4$$

$$T_w = F1_x \times r \qquad 3.5$$

$$m\ddot{x} = F_x - F_{rl} \qquad 3.6$$

$$F_x = m\ddot{x} + F_{rl} \qquad 3.7$$

F: force, L: stroke length, p_w: wheels power, t: time, η_e: engine efficiency,

T_w: wheels torque, w_e: engine speed, F_x: tractive force, r: radius of wheels,

F_{rl}: road load force , T_e: engine torque

Since it is not desired to change the engine geometry we can rise the cylinder pressure by increasing the amount of inflow air to combustion chamber for allowing to burn more fuel.

$$\int P\,dv = w \qquad 3.8$$

$$W_i/V_d = mep \qquad 3.9$$

$$P = (M \times R \times T)/V \qquad 3.10$$

Where:

mep: mean effective pressure

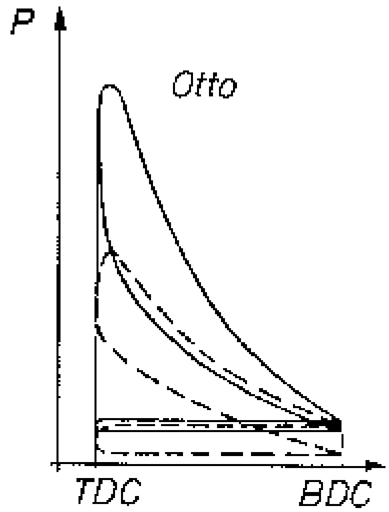

Figure 3.3 Essential theory on internal combustion engines.

3.2 Engine Torque Calculation for Desired Acceleration

The wheel speed $\omega_w$is proportional to the engine speed$\omega_e$and related through the gear ratio R as follows:

$$\omega_w = R\omega_e \qquad 3.11$$

and the transmission shaft speed is equal to the engine speed: $\omega_t = \omega_e$

The longitudinal vehicle velocity is approximated by:

$$\dot{x} = r_{eff} \times \omega_e \qquad 3.12$$

Where:

r_{eff} : is the effective tire radius.

$$\ddot{x} = r_{eff} \times R \times \dot{\omega_e} \qquad 3.13$$

R: is the gear ratio.

The longitudinal vehicle equation is:

$$m\ddot{x} = F_x - R_x - F_{aero} \qquad 3.14$$

Where:

F_x: is the the total longitudinal tire force from all tires.

We can write the equation as:

$$m\,\dot{\omega}_e r_{eff} = F_x - R_x - F_{aero} \qquad 3.15$$

Hence

$$F_x = m\, r_{eff}\dot{\omega}_e + R_x + F_{aero} \qquad 3.16$$

$$I_w\dot{\omega}_w = T_{wheel} r_{eff} - (F_x)$$

$$= T_{wheel} - mRr_{eff}^{\ 2} \times \dot{\omega}_e - r_{eff} \times R_x - r_{eff} \times F_{aero} \qquad 3.17$$

the torque at the wheels required to produce the desired acceleration is:

$$T_{wheel} = I_w \times R \times \dot{\omega}_e + mr_{eff}^{\ 2}\dot{\omega}_e + r_{eff} \times F_{aero} + r_{eff} \times R_x \qquad 3.18$$

$$I_t\,\omega\dot{t} = T_t - RT_{wheel} = T_t - I_w \times R^2 \times \dot{\omega}_e - M \times \dot{R}^2 \times r_{eff}^{\ 2} \times \dot{\omega}_e - R \times r_{eff} \times F_{aero} - R \times r_{eff} \times R_x$$

3.19

Since $\omega_t = \omega_e$ and $T_p = \mathrm{T_t}$ we have ,

$$I_t\dot{\omega}_e = T_p - I_w \times R^2 \times \dot{\omega}_e - m \times R^2 \times r_{eff}^{\ 2} \times \dot{\omega}_e - R \times r_{eff} \times F_{aero} - R \times r_{eff} \times R_x \qquad 3.20$$

$\mathrm{T_p}$: *is the pump torque.*

the pump torque load on the engine is:

$$T_p = (I_t + I_w \times R^2 + m \times R^2 \times r_{eff}^{\ 2})\dot{\omega}_e + R \times r_{eff} \times F_{aero} + R \times r_{eff} \times R_x \qquad 3.21$$

$$I_e\dot{\omega}_e = T_{net} - T_p$$

$$= T_{net} - (I_t + I_w R^2 + m \times R^2 \times r_{eff}^{\ 2})\dot{\omega}_e - R \times r_{eff} \times F_{aero} - R \times r_{eff} \times \mathrm{R_x} \qquad 3.22$$

Hence

$$I_e\dot{\omega}_e = T_{net} - (I_t + I_w R^2 + m \times R^2 \times {r_{eff}}^2)\dot{\omega}_e - R \times r_{eff} \times F_{aero} - R \times r_{eff} \times R_X \quad 3.23$$

<u>Or</u>

$$J_e\dot{\omega}_e = T_{net} - R \times r_{eff} \times F_{aero} - R \times r_{eff} \times R_x \quad 3.24$$

<u>Where</u>

$$J_e = I_e + I_t + R^2 I_w + m \times R^2 \times {r_{eff}}^2 \quad 3.25$$

$$F_{aero} = C_a\left(R \times r_{eff} \times \omega_e\right)^2 \quad 3.26$$

$$\dot{\omega}_e = (T_{net} - C_a \times R^3 \times {r_{eff}}^3 \times {\omega_e}^2 - R(r_{eff} \times R_x))/J_e \quad 3.27$$

where:

$$J_e = I_e + I_t + (m{r_{eff}}^2 + I_w)R^2 \quad 3.28$$

J_e: is the effective inertia reflected on the engine side.

$$(T_{net}) = (J_e/Rr_{eff})\,\ddot{x}_{des} + \{C_a * R^3 \times {r_{eff}}^3 \times {\omega_e}^2) + R(r_{eff} \times R_x)\} \quad 3.29$$

Where:

$\ddot{x}_{des}$: is the desired acceleration.

then the acceleration of the car is equal to the desired acceleration defined by the upper level controller i.e. $\ddot{x}_{des} = \ddot{x}$

3.3 The mean value engine model (MVEM)

The mean value engine model: is how to control the design for the internal combustion engines.

The intake manifold need inflow from the boost valve which is modeled as a compressible flow restriction. A pressure valve is connected to the boost valve and there is a throttle to allow the backflow out of the intake manifold.

At first when there is no dynamics are considered and the pressure tank remains constant the throttle is assumed to have no leakage and fully closed.

The torque generation is modeled using the Willans approximation. For a stoichiometric operated engine the mean effective pressure mep is calculated by equation 3.30 [1] :

$$P_{me} = \eta_W \times (w_e) \times \eta_{ign} \times (u_{ign}) \times LH/(V_d \times \phi_0) \times 4\pi \times (\dot{m}\ \beta)/w_e - P_{me} \qquad 3.30$$

Where:

η_W: is an efficiency term depending on the engine speed w_e.

LH: is the lower heating value of the fuel.

V_d: is the engine displacement

ϕ_0: is the stoichiometric air-to-fuel mass ratio.

$\dot{m}\ \beta$: represents the air mass flow from the intake into the engine.

η_{ign}: represents the ignition efficiency depending on the retardation u_{ign} of the ignition angle from the ignition angle that yields the maximum brake torque (MBT ignition angle).

The engine is approximated as a volumetric pump. A typical formulation for the air mass flow through a four-stroke engine in equation 3.31 [1]:

$$\dot{m}\ \beta = \lambda l \times P_{imp}/(R \times \Theta_{im}) \times V_d \times w_e/(4\pi) \qquad 3.31$$

Where:

λl: denotes the volumetric efficiency of the engine.

P_{imp}: is the intake manifold pressure.

R: is the gas constant of air.

Θ_{im}: is the intake manifold temperature.

V_d : is the engine displacement.

3.4 System dynamics

When the boost valve is opened, air flows into the intake manifold and the pressure rises. If the throttle is open, the pressure downstream of the compressor also rises and possibly drives the compressor into surge. If the throttle remains closed, there is no outflow from the manifold downstream of the compressor, and surge can also occur. However, to prevent surge, an additional valve called over stream valve is installed, which connects the outlet of the compressor with its inlet.

$$d/dt\,(P_{imp}) = K.R/(v_{im}).(\dot{m}_{bv}.\Theta_t - \dot{m}\,\beta\,.\Theta_{im}) \qquad 3.32$$

$$d/dt(P_{imp}) = K.\ R.\ \Theta_t/(v_{im}).\dot{m}_{bv} - \kappa.\ \lambda l.\ V_d.\ P_{imp}/(v_{im}.4\ \pi).w_e \qquad 3.33$$

Where:

K: represents the heat capacity ratio of air.

v_{im}:is the volume of the intake manifold.

$\dot{m}_{bv}$: is the mass flow through the boost valve.

Θ_t: is the tank temperature.

We can raise the torque of the engine without changing the engine geometry , just by adding air.

CHAPTER FOUR

MODELING AND CALCULATIONS

CONTENT:

4.1 Introduction

Mean Value Engine Model (MVEM) is the basis of control design for advanced internal combustion engines. The engine performance transient process usually takes a few cycles. The MVEM provides an adequate accurate description of the engine dynamics with reasonable approximation by ignoring the heat loss and sub-cycle events. MVEM is very important for engine system control development, especially when the modern engine becomes more and more complicated when equipped with throttle and after-treatment systems. Usually the MVEM is developed based on data from engine tests, which is a costly and time consuming process. In this chapter, the air path MVEM modeling method is discussed for a gasoline engine. Simulation is applied to demonstrate the effectiveness of this new method. This approach could be used to get the MVEM for control design even before the prototype engine is available. It reduces the cost, risk and labor compared with the test data based approach. This MVEM model can be built in modules and the parameters can be validated for a specific engine. These advantages make it applicable to a wide range of engines.

4.2 Intake manifolds

The intake and exhaust manifolds are modeled as open thermodynamic systems, where the mass of gas can increase or decrease with time (so-called filling and emptying model). The two governing equations for such systems are the Conservation of Mass and the Conservation of Energy. Considering the adiabatic conditions and assuming an ideal gas with constant specific heats, the rate mass flow change inside this control volume can be given by the continuity equation given by:

$$\frac{dm_{im}}{dt} = \dot{m}_{\iota} - \dot{m}_{o} \qquad 4.1$$

Where:

m_{im} is the intake manifold mass content , $\dot{m}_{\iota}$ is the input mass flow to the intake manifold , and $\dot{m}_{o}$ is the out flow to the engine cylinder. For an ideal gas, the mass in this case can be expressed as follows:

$$m_{im} = \frac{p_{im}V_{im}}{RT_{im}} \qquad 4.2$$

Where:

p_{im} and T_{im} is the pressure and temperature of the intake manifold respectively , and R is the gas constant of the intake manifold mixture , while V_{im} is the intake manifold volume . Accordingly, the pressure rate of change inside the intake manifold is modeled as:

$$\frac{dp_{im}}{dt} = \frac{RT_{im}}{V_{im}}(\dot{m}_{\iota} - \dot{m}_{o}) \qquad 4.3$$

The total mass flow into the intake manifold depends on the pressure difference between the source and the intake manifold, and the accumulated masses in the manifold are:

$$\dot{m}_{\iota} = \dot{m}_{com} + \dot{m}_{at} + \dot{m}_{egr} \qquad 4.4$$

Where: $\dot{m}_{com}$is the mass flow rate from the compressor, $\dot{m}_{at}$ is the mass flow rate from the air tank, $and\ \dot{m}_{egr}$ is the re-circulated exhaust gas mass flow, which is equal to zero in this project , because during acceleration the re-circulated exhaust gas valve is completely closed.

For the purpose of this modeling, it is sufficiently accurate to adopt subsonic flow through restriction modeling to account for the flow for the intake manifold. For subsonic flow the mass flow rate from the air tank to the intake displacement can be expressed as:

$$\dot{m}_{at} = \frac{c_V A_V p_t}{\sqrt{RT_r}} \sqrt[\gamma]{\frac{p_{im}}{p_t}}^{\,2} \sqrt{\left(\frac{2\gamma}{\gamma-1}\left[1 - \sqrt[\frac{\gamma}{\gamma-1}]{\frac{p_{im}}{p_t}}\right]\right)} \qquad 4.5$$

Where: C_V is the coefficient of discharge of the compressed air , A_V is the flow area of the injector valve, p_t is the pressure of the air in the tank, and γ is the air specific heat ratio.

The air flow into the intake manifold from the compressor($\dot{m}_{com}$) is determined from the compressor power equation

$$\dot{m}_{com} = \frac{\eta_{comp.}}{C_p T_a} * \frac{P_c}{\left[\sqrt[\frac{\gamma}{\gamma-1}]{\frac{p_c}{p_a}} - 1\right]} \qquad 4.6$$

The compressor efficiency ($\eta_{comp.}$) cannot be measured directly and has to be calculated based on the pressure and temperature ratios across the compressor.

$$\eta_{comp.} = \frac{\left[\sqrt[\frac{\gamma}{\gamma-1}]{\frac{p_c}{p_a}} - 1\right]}{\left[\sqrt[\frac{\gamma}{\gamma-1}]{\frac{T_c}{T_a}} - 1\right]} \qquad 4.7$$

Where: P_c is the compressor power and p_c and T_c is the air pressure and temperature developed by the compressor respectively, p_a and T_a is pressure and temperature of ambient air respectively, C_p is the specific heat of ambient air, and Ɣ is the air specific heat ration.

4.3 Air- charging model

Air charging from the intake manifold to the cylinder is a highly nonlinear process depending on the volumetric efficiency η_{vol}, engine speed N_e and intake manifold states of T_{im} and p_{im} which describes the engine pumping process as:

$$\dot{m}_o = \eta_{vol} \frac{p_{im}}{T_{im} R_{im}} * \frac{N_e V_d}{120} \qquad 4.8$$

Where: V_d is the displacement volume , the volumetric efficiency is mainly a function of engine speed, intake manifold pressure.

4.4 exhaust manifold

To model the conditions in the exhaust manifold, the temperature of the mass flow from the cylinder into the exhaust manifold is necessary. It is a function of fuel flow, air flow into the cylinders, and engine speed

$$T_{ex} = f(m_f, m_{air}, N_e)$$

The exhaust pressure dynamic are modeled as in the intake manifold

$$\dot{p}_{ex} = \frac{R_{ex T_{ex}}}{V_{ex}}\left(\dot{m}_{ex} - \dot{m}_{turbo} - \dot{m}_{wg}\right) \qquad 4.9$$

Where: p_{ex} is the pressure , T_{ex} is the temperature, and R_{ex} is the gas constant of the intake manifold , while V_{ex} is the manifold volume and $\dot{m}_{ex}$ exhaust mass flow rate , which consist of fuel and air flow rate into the cylinder , $\dot{m}_{turbo}$ and $\dot{m}_{wg}$ are turbine flow rates and waste gate flow rates respectively. The waste gate openings used to adjust the bypass flow as $\dot{m}_{wg}$, in order to control the exhaust manifold pressure. The engine air density is indirectly adjusted through the turbocharger power by the exhaust manifold pressure.

4.5 calculations:

When the throttle close

$$\dot{m}_o = \dot{m}_{eng.} \times \frac{\Delta t}{\tau c} + \dot{m}_{mani.} \qquad 4.10$$

$$\dot{m}_{eng.} = \frac{v_d \times pt}{R \times T} \qquad 4.11$$

$$\dot{m}_{mani.} = \frac{v_m \times pt}{R \times T} \qquad 4.12$$

$$\dot{m}_o = \left[v_{d} \times \frac{\Delta t}{\tau c} + v_m\right] \times \frac{pt}{RT} \qquad 4.13$$

$$= \left[1600 \times \frac{30}{60} + 2400\right] \times \frac{10\text{^}-6 \times 600 \times 10\text{^}-4}{287 \times 294}$$

= 22.754×10^-10 kg/sec

$$\Delta\, m = 1.5 \times \dot{m}_0 \qquad 4.14$$

= 34.1 ×10^-10 kg

$$\Delta\, \dot{m} = \frac{\Delta\, m}{\Delta t} = \frac{34.1 \times 10\text{^}-10}{30 \times 10\text{^}-3} \qquad 4.15$$

= 1.136×10^-3 kg/sec

Where: $\dot{m}_o$ is the out flow to the engine cyliondor ,
$\dot{m}_{eng.}$ is the mass flow rate inside the engine ,
$\dot{m}_{mani.}$ is the mass flow rate inside the intake manifold, Δt is the operating time $= 30 \times 10\text{^} - 3$, τt is the taw for one cycle $= 60 \times 10^{-3}$at 1000 RPM.

C_0=0.15 for the solenoid valve , A_v= 0.003175m for solenoid valve , R = 287 J/KG×K , T_0= 294 K , γ= 1.4 , Pt= 600 ×10^-4 mpa

And using this equation:

$$\dot{m}_{th} = \frac{C_0 A_V p_0}{\sqrt{RT_r}} \sqrt[\gamma]{\frac{p_{im}}{p_0}} \sqrt[2]{\left(\frac{2\gamma}{\gamma-1}\left[1-\sqrt[\frac{\gamma}{\gamma-1}]{\frac{p_{im}}{p_0}}\right]\right)}$$

From this equation we can calculate p_0

$p_0 = 0.1086$ mpa

$p_0 = 1.086$ bar

Where p_0 is the pressure of the air injected .

$$\%error = \frac{\dot{m}_o}{\frac{p_0 \times v\ tank}{R \times T}} \qquad 4.16$$

$$= \frac{22.758\times10\text{^}-10}{\frac{0.108\times40\times10\text{^}-3}{287\times294}}$$

$= 0.0289$

We suppose that no air provided from intake manifold, so the only provider of the air is our system, and this percentage should be less than 0.1.

CHAPTER FIVE

SYSTEM OPERATION

CONTENT:

5.1 Introduction

Vehicles exhibit a weak point of poor drivability under transient running conditions. Reduced air flow in the combustion chamber while fuel is injected causes inadequate air fuel ratio (i.e. rich mixture). The result is an increased formation of emissions such as CO, NOx which contribute to environmental pollution.

Air injection increases the air flow during the transient phase reducing the harmful emissions. Experimental work has shown that injecting air into the manifold greatly improves the transient response of engine power.

5.2 System Components

System components include air compressor , pressure regulator, solenoid valve , air tank and figure 5.1 show this.

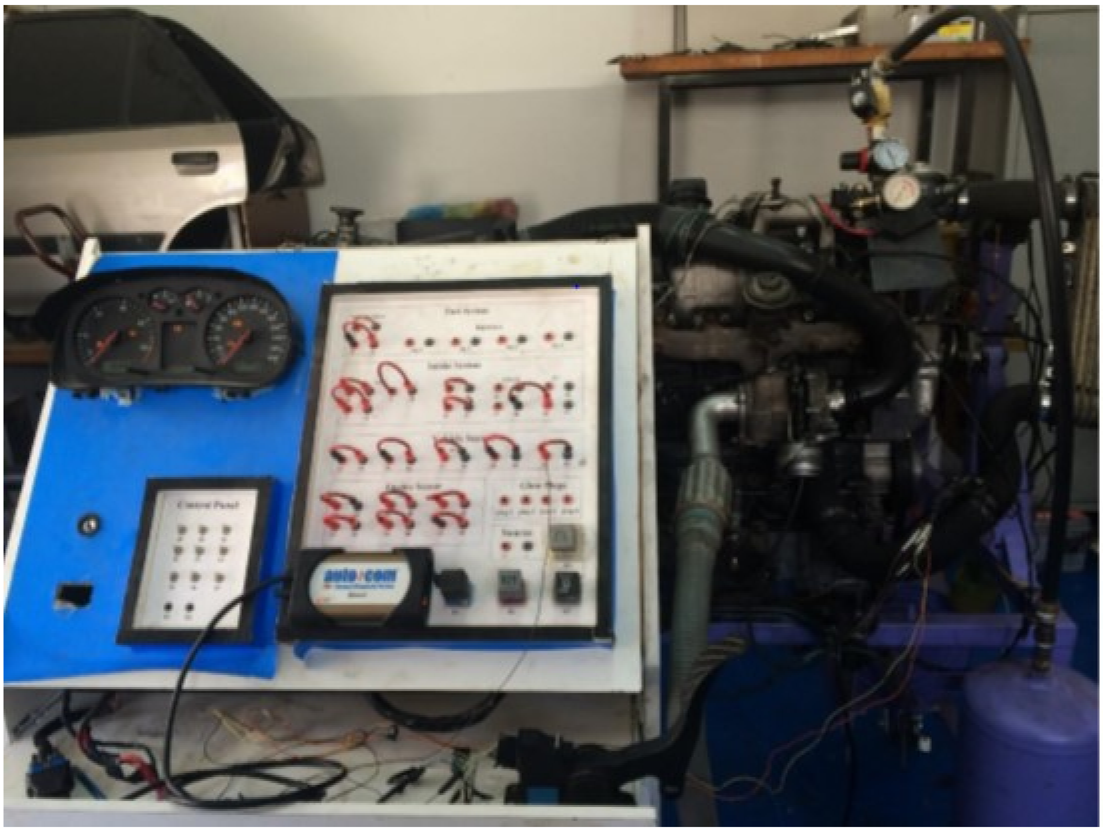

Figure 5.1 system components

5.2.1 The air injection unit

The air injection unit consists of:

1. Air compressor.

2. High-pressure air tank with mechanical pressure sensor.

3. Air injection unit (Pressure regulator, solenoid valve).

5.2.1.1 Air compressor

The compressor that is used is the compressor for the A/C system that used in the vehicle, which allow charging the air inside the tank under high pressure.

Figure 5.2 air compressor

5.2.1.2 High-pressure air tank with mechanical pressure sensor

It can accumulate the air under pressure of 1.2 bar and its volume is 40 liter , including mechanical pressure sensor and pressure gage where the mechanical pressure sensor is used to regulate the pressure in the tank by connecting and disconnecting the voltage to the compressor.

FIGURE5.3 Air tank

5.2.1.3 Air injection unit (pressure regulator, solenoid valve)

a. Air pressure regulator

Its function to reduce the pressure coming from the high-pressure air storage tank (1.2 bar) to the desired pressure in the intake manifold.

FIGURE 5.4 manual Pressure regulator

b. Air injection solenoid valve

Its function is to pass the pressurized air from the tank to the intake manifold when it needed in the transient period.

FIGURE 5.5 Solenoid valve

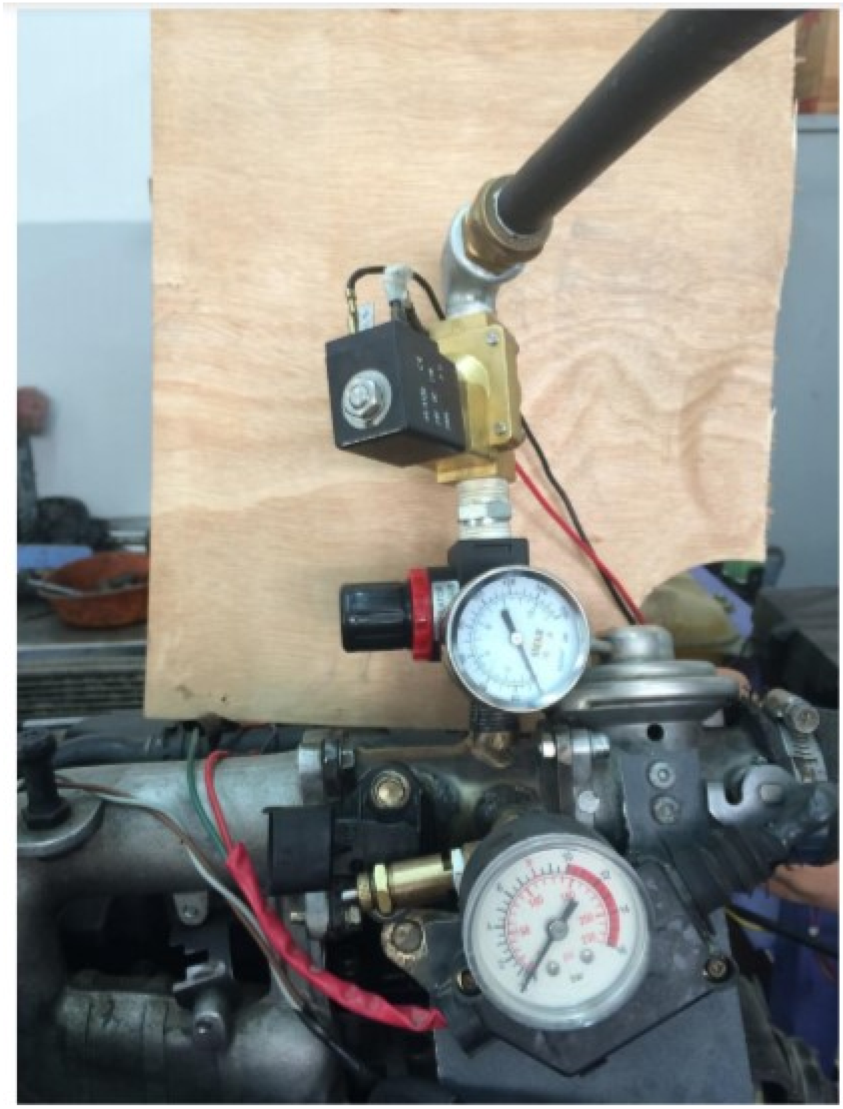

Figure5.6 pressure regulator and solenoid valve

CHAPTER 6

RESULTS

CONTENT:

6.1 results

6.1 RESULTS

The project was applied on a gasoline engine. The engine has the following specifications:

Table 6.1 engine specification

Engine type	4 stroke gasoline
stroke	83.6
bore	78
Number of cylinders	4
Combustion ratio	Indirect injection
Compression ratio	9

The results in our project comes after using multi scan device to:

- Measure mass flow rate at different rpm before connect the project.
- Measure mass flow rate at different rpm after connect the project.
- Measure fuel injection duration at different rpm before connect the project.
- Measure fuel injection duration at different rpm after connect the project.

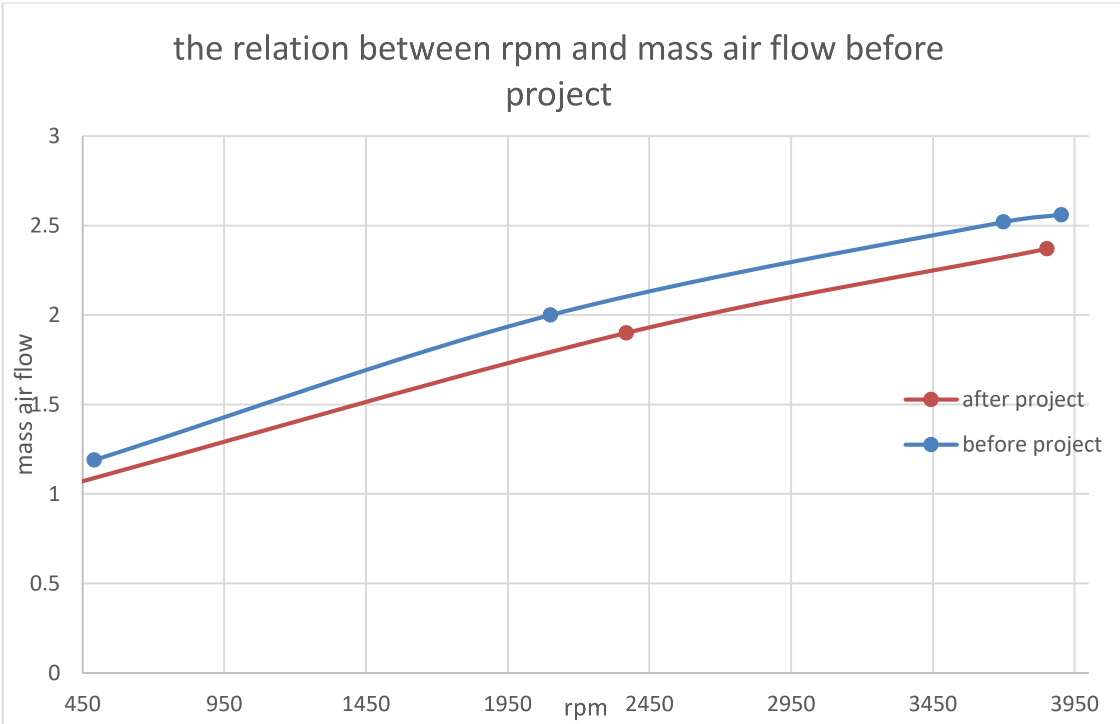

FIGURE 6.1: the relationship between rpm and mass air flow before and after project

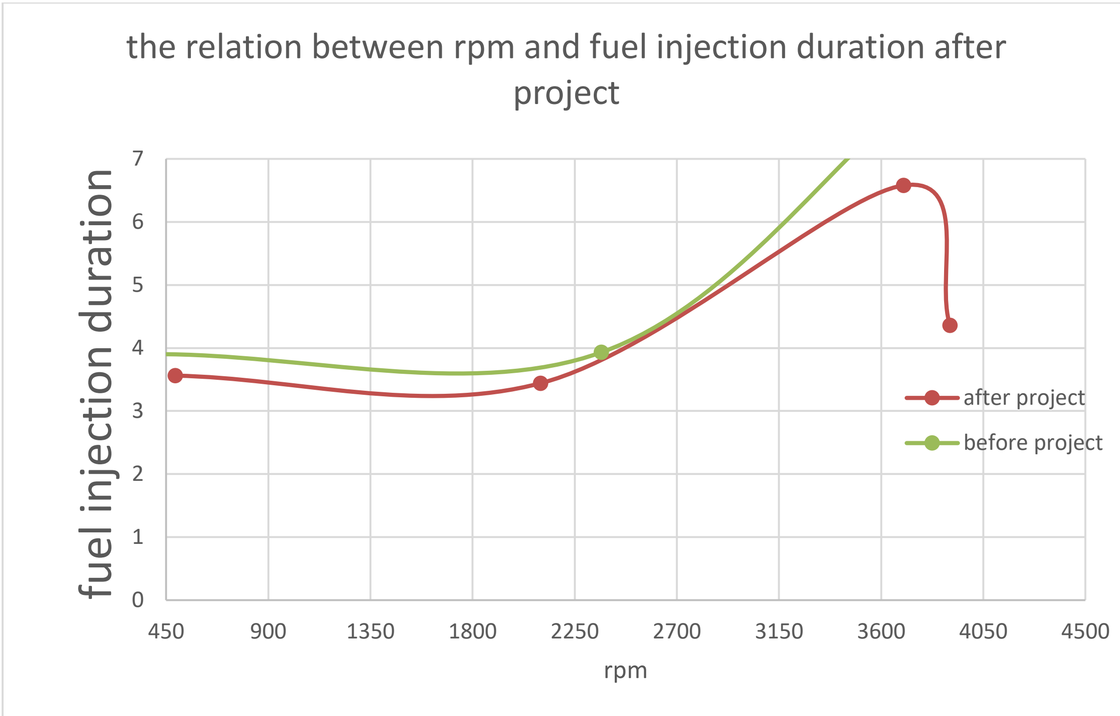

FIGURE 6.2: the relationship between rpm and fuel injection duration before and after project.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

Content:

7.1 Conclusions

This project presented modeling technique and experimental results of a transient turbocharged engine system. The initial results show that this is a promising area to reduce emissions and improving performance of internal combustion engines during transient operation.

The obtained results show that:

1. Significant improvement to the transient response of the compressor outlet which should reduce the formation of $CO_2$and NO_X.

2. Larger Injection pressures have an increased effect on the boosting pressure response.

3. Overall engine performance has been improved.

4. High injection pressures improve acceleration performance.

7.2 Recommendations

The obtained results are promotion and need further study for potential improvement of engine transient response and emission model.

Engine development is a multi-disciplinary area and has the interaction and cooperation at multiple levels and aspects. This research discusses the co-design and integration of detail modeling and control design. Some proposed methods are not finished and some ideas need further development for verification and application.

Following are potential topics:

1. This project is more effective in the large trucks, because we do not need more space to put the air tank, because in the trucks there is already air tank in the brake.
2. This project is more effective in the direct injection Spark and Compression Ignition Engine, because in the direct injection we can increase the amount of air injected , because in the direct injection the air enter into the combustion chamber directly , and this will make the project more economical , because we do not need to increase the amount of fuel when increase the amount of air .

References:

[1] Norbert Z, Christoph O, Leno G, intake manifold boosting of turbocharged spark – ignition engine. 2013, pages: 1746-1763.

[2] Filipi Z ,Wang Y, AssanisD. Effect of variable geometry turbine (VGT) on diesel engine and vehicle system transient response. SAE paper No. 2001-01-1247, 2001.

[3] Zellbeck H, Friedrich J, Berger C. Electrically assisted turbocharging as a new boosting concept. 1999, pages: 386–391.

[4] Rakopoulos, C.D., Giakoumis, E.G. (2009). Diesel Engine Transient Operation Principles of Operation and Simulation Analysis. National Technical University of Athens, School of Mechanical Engineering. Springer-Verlag London Limited. 390 pp.

[5] Thomas D. Gillespie, Fundamentals of vehicle dynamics, published by: society of automotive engineering, INC. 1992, ISBN-13: 978-1560911999, pages: 519.