SIMULATION OF COMMON RAIL FOR HYDROGEN ENGINE IN AUTOMOBILE APPLICATION

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ABSTRACT

This project is about to develop common rail model for hydrogen engine. The objective of the project is firstly to develop simulation model for common rail hydrogen engine. Secondly to simulate common rail hydrogen engine for determining the best parameters. Thirdly to improve the efficiency of the common rail. This project is conducted in five stages, which is develop a simple common rail system, change the simulation analysis from using gasoline as its fuel to hydrogen gas, change the rail diameter of common rail, change the rail pressure and lastly, change the injector hole diameter. Performance output is evaluated in five criteria, which are the pressure in pipe, speed of sound in pipe, mass flow rate in pipe, pressure in injector connecter and mass flow rate in injector connector. From the simulation analysis, it can conclude that common rail model have been developed with suitable parameter for hydrogen gas as the fuel. Even though the exact dimension of parameters is not state clearly, it s already give the range value of dimension to get the best parameters. Therefore, it is suggested that Parameter Identification Technique is utilized in this project to determine the more accurate dimension for common rail in hydrogen engine.

ABSTRAK

Projek ini berkisar tentang penghasilan model common rail untuk enjin hidrogen. Objektif projek ini ialah pertama sekali untuk menghasilkan model simulasi common rail untuk enjin hidrogen. Kedua ialah untuk menjalankan simulasi terhadap common rail untuk enjin hidgoren untuk mendapatkan parameter yang terbaik. Ketiga ialah untuk meningkatkan kecekapan sistem common rail. Projek ini dijalankan dalam 5 peringkat, iaitu peringkat menghasilkan sistem common rail yang ringkas, menukarkan analisis simulasi daripada menggunakan minyak petrol kepada gas hidrogen, menukarkan diameter saluran common rail, menukarkan tekanan dalam saluran common rail dan akhir sekali, menukarkan diameter pemancut. Pembandingan prestasi keluaran dilakukan berdasarkan kriteria seperti tekanan dalam saluran utama, halaju bunyi dalam saluran utama, kadar pengaliran jisim dalam salur utama, tekanan dalam penyambung pemancut dan kadar pengaliran jisim dalam penyambung pemancut. Menerusi keputusan keluaran simulasi, disimpulkan bahawa model common rail dengan menggunakan gas hidgoren sebagai bahan bakar dapat dihasilkan dengan menggunakan parameter yang sesuai. Walaupun dimensi yang paling tepat tidak dapat dinyatakan dengan jelas, ianya telah memberikan nilai anggaran dimensi untuk mendapatkan parameter yang terbaik. Oleh itu, dicadangkan agar teknik mengenalpasti parameter di dalam projek ini dapat dibangunkan untuk mendapatkan dimensi yang lebih tepat untuk common rail dalam enjin hidgoren.

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LIST OF SYMBOLS

Q	-	Volume Flow Rate
C_f	-	Flow Coefficient
A	-	Area
P_u	-	Upstream Pressure
P_d	-	Downstream Pressure
ß	-	Bulk Modulus (Flexibility)
V	-	Volume
$\dot{V}$	-	Volume Flow Rate
ρ	-	Density

LIST OF ABBREVIATIONS

ECU	-	Engine Control Unit
ASCL	-	Advanced Continuous Simulation Language
'def'	-	default
'ign'	-	ignore

CHAPTER 1

INTRODUCTION

1.1 PROJECT INTRODUCTION

Common rail direct fuel injection is a modern variant of direct fuel injection system for petrol and diesel engines. The term "common rail" refers to the fact that all of the fuel injectors are supplied by a common fuel rail which is nothing more than a pressure accumulator where the fuel is stored at high pressure. On diesel engines, it features a high-pressure (over 1,000 bar) fuel rail feeding individual solenoid valves, as opposed to low-pressure fuel pump feeding unit injectors (Pumpe Duse or pump nozzles), or high-pressure fuel line to mechanical valves controlled by cams on the camshaft. Third-generation common rail diesels now feature piezoelectric injectors for increased precision, with fuel pressures up to 1,800 bars. In petrol engines, it is utilised in gasoline direct injection engine technology.

The injection pressure can even be generated independently of engine revs and the injected fuel quantity can be freely selected within limits. A prerequisite for this decoupling of pressure generation and injection in common rail systems is the high-pressure accumulator, which consists of the rail and the high pressure fuel lines to the

nozzles. The key component of the system is the solenoid valve controlled injector. In order to control the opening and closing time of the needle, a small chamber of pressurised fuel is present at the top of the needle. This volume is connected to the rail through a small orifice that assures that same pressure between the nozzle and the chamber when the valve is closed. At the same time, a small solenoid balance valve is in operation in this area that can open at an accurately specified time, thus creating a pressure drop. This will result in a negative net force on the valve needle, and the injection is initiated. As soon as the solenoid closes, the pressure in this chamber will increase again resulting in the closure of the needle. Shaping the injection rate, obtaining pilot injection and multiple injections are done by controlling the nozzle needle movement.

1.2 PROBLEM STATEMENT

In the later years, the common rail injection system with electronic controls has been promoted as the future standard in fuel injection systems for engines. Among the advantages claimed with respect to the common rail concept are injection rate shaping, variable timing and duration of the injection, in addition to variable injection pressure, enabling high injection pressure even at low engine loads.

The common rail that already use today is only suitable for fuel as its working fluid. From the experimental test, the pressure, injection rate shaping, variable timing and duration of the injection, in addition to variable injection pressure are available for fuel although for gasoline or diesel.

Fossil fuel that depleting out today need to be change with other alternative fuel. The hazardous emissions of fossil fuel which can destroy the environment also need to change with other fuel that produce only a little to no hazardous emissions.

When we use hydrogen engine, we need to convert or redesign some part of common rail, so that it will suitable use in hydrogen engine. It is cause of the fuel that use is hydrogen gas. We need to ensure that it can work as the future standard in fuel injection systems for hydrogen engines. It should also consider the injection rate shaping, variable timing and duration of the injection, in addition to variable injection pressure, enabling high injection pressure even at low engine loads.

1.3 PROJECT OBJECTIVES

1.3.1 To develop simulation model for common rail hydrogen engine.

1.3.2 Simulate common rail hydrogen engine for determining the best parameters.

1.3.3 To improve the efficiency of the common rail.

1.4 PROJECT SCOPES

1.4.1 Develop and simulate computational model that suitable for optimization process of parameters studies by using GT-Fuel commercial code.

1.4.2 Optimize the parameter studies: Rail diameter, injection pressure, and injector hole diameter.

1.4.3 The model will be suitable for normal engine operation (3000 rpm) and perform good condition.

1.5 PROJECT ORGANISATION

This thesis consists of five (5) chapters.

Chapter 1: Introduction- This chapter is the introductions about the project that will be develop. It consist the introduction, problem statement, objective, scope, and thesis organization.

Chapter 2: Literature Review- This chapter will explain the case study of the project. There are two (2) general structure of this study, the technique that has been use and the former system that are already created.

Chapter 3: Methodology- This chapter will discuss more close on the overall work flow in the development of the project. It will justify the technique along with the equipment and the software.

Chapter 4: Results and discussion- This chapter will explain and discuss all of the results from the simulation analysis.

Chapter 5: Recommendation and conclusion- This chapter is the last parts of this thesis that will be summarizing the project that will be develop.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This chapter discusses about common rail system, explanation about it, ruled-based system and some of related works that implement expert systems. It also describes, summarize, evaluate and clarify the research that has been done for the benefit of this project. The aim of this research is to study on the strength and weaknesses of other systems and obtain a clearer view of the method used in the development process.

2.2 RELATED WORK

The common rail system prototype was developed in the late 1960s by Robert Huber of Switzerland and the technology further developed by Dr. Marco Ganser at the Swiss Federal Institute of Technology in Zurich, later of Ganser-Hydromag AG (est.1995) in Oberägeri. In the mid-1990s Dr. Shohei Itoh and Masahiko Miyaki of the Denso Corporation, a Japanese automotive parts manufacturer, developed the common rail fuel system for heavy duty vehicles and turned it into practical use on their ECD-U2 common-rail system mounted on the Hino Rising Ranger truck and sold for general use in 1995. Denso claims the first commercial high pressure common rail system in 1995.

Modern common rail systems, whilst working on the same principle, are governed by an engine control unit (ECU) which opens each injector electronically rather than mechanically. This was extensively prototyped in the 1990s with collaboration between Magneti Marelli, Centro Ricerche Fiat and Elasis. After research and development by the Fiat Group the design was acquired by the German company Robert Bosch GmbH for completion of development and refinement for mass-production. In hindsight the sale appeared to be a tactical error for Fiat as the new technology proved to be highly profitable. The company had little choice but to sell, however, as it was in a poor financial state at the time and lacked the resources to complete development on its own. In 1997 they extended its use for passenger cars. The first passenger car that used the common rail system was the 1997 model Alfa Romeo 156 1.9 JTD, and later on that same year Mercedes-Benz C 220 CDI.

Common rail engines have been used in marine and locomotive applications for some time. The Cooper-Bessemer GN-8 (circa 1942) is an example of a hydraulically operated common rail diesel engine, also known as a modified common rail.

The engines are suitable for all types of road cars with diesel engines, ranging from city cars such as the Fiat Nuova Panda to executive cars such as the Volvo S80.

2.3 PRINCIPLE OF COMMON RAIL

Solenoid or piezoelectric valves make possible fine electronic control over the fuel injection time and quantity, and the higher pressure that the common rail technology makes available provides better fuel atomisation. In order to lower engine noise the engine's electronic control unit can inject a small amount of diesel just before the main injection event ("pilot" injection), thus reducing its explosiveness and vibration, as well as optimising injection timing and quantity for variations in fuel quality, cold starting, and so on. Some advanced common rail fuel systems perform as many as five injections per stroke.

Common rail engines require no heating up time and produce lower engine noise and emissions than older systems. Figure 2.1 shows the schematic diagram of common rail system.

Diesel engines have historically used various forms of fuel injection. Two common types include the unit injection system and the distributor/inline pump systems. While these older systems provided accurate fuel quantity and injection timing control they were limited by several factors as described below:

2.3.1 They were cam driven and injection pressure was proportional to engine speed. This typically meant that the highest injection pressure could only be achieved at the highest engine speed and the maximum achievable injection pressure decreased as engine speed decreased. This relationship is true with all pumps, even those used on common rail systems; with the unit or distributor systems, however, the injection pressure is tied to the instantaneous pressure of a single pumping event with no accumulator and thus the relationship is more prominent and troublesome.

2.3.2 They were limited on the number of and timing of injection events that could be commanded during a single combustion event. While multiple injection events is possible with these older systems, it is much more difficult and costly to achieve.

2.3.3 For the typical distributor/inline system the start of injection occurred at a pre-determined pressure (often referred to as: pop pressure) and ended at a pre-determined pressure. These characteristic results from "dummy" injectors in the cylinder head which opened and closed at pressures determined by the spring preload applied to the plunger in the injector. Once the pressure in the injector reached a pre-determined level, the plunger would lift and injection would start. In common rail systems a high pressure pump stores a reservoir of fuel at high pressure, up to and above 2,000 bars. The term "common rail" refers to the fact that all of the fuel injectors are supplied by a common fuel rail which is nothing

more than a pressure accumulator where the fuel is stored at high pressure. This accumulator supplies multiple fuel injectors with high pressure fuel. This simplifies the purpose of the high pressure pump in that it only has to maintain a commanded pressure at a target (either mechanically or electronically controlled). The fuel injectors are typically ECU-controlled. When the fuel injectors are electrically activated a hydraulic valve (consisting of a nozzle and plunger) is mechanically or hydraulically opened and fuel is sprayed into the cylinders at the desired pressure. Since the fuel pressure energy is stored remotely and the injectors are electrically actuated the injection pressure at the start and end of injection is very near the pressure in the accumulator (rail), thus producing a square injection rate. If the accumulator, pump, and plumbing are sized properly, the injection pressure and rate will be the same for each of the multiple injection events.

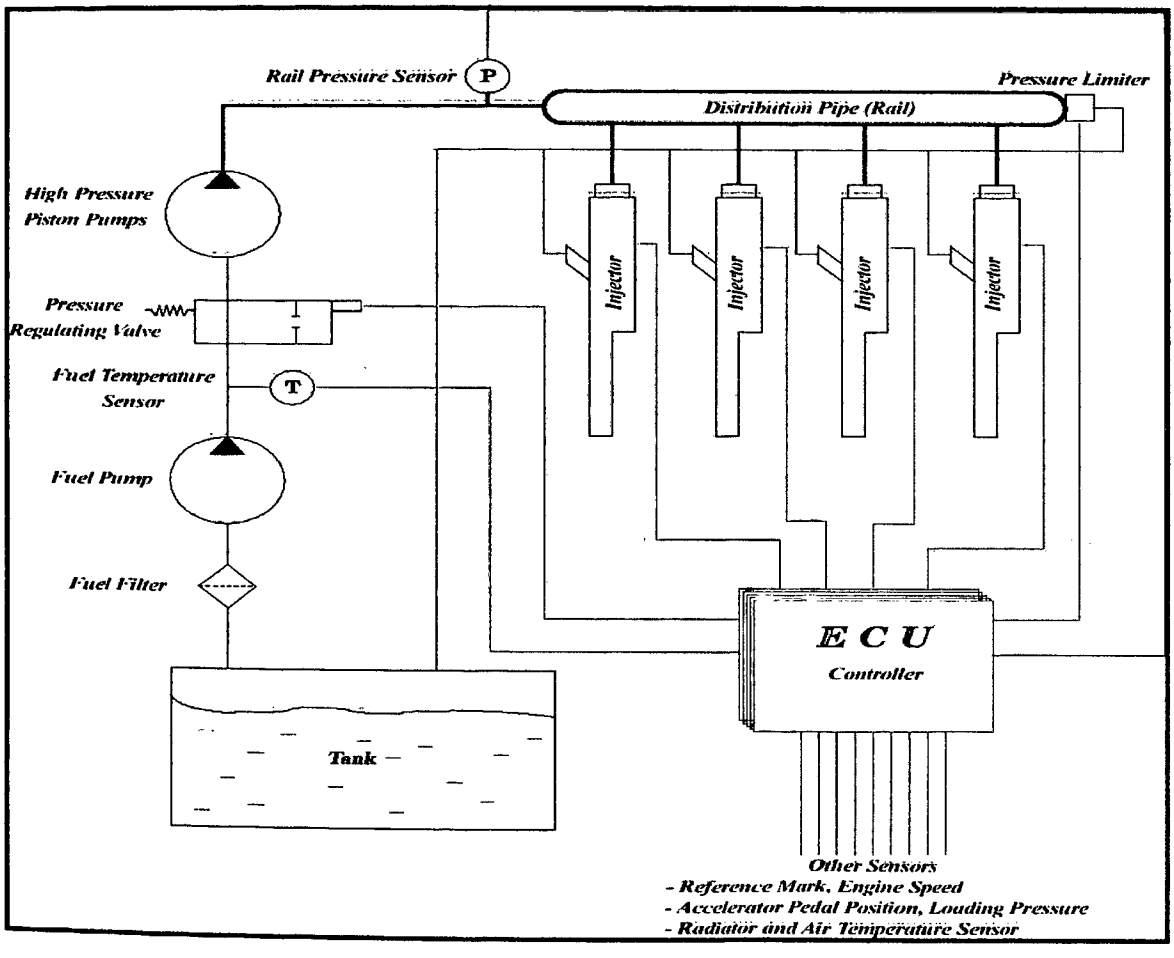

Figure 2.1: The schematic diagram of common rail system

2.4 COMMON RAIL THEORY

2.4.1 NOZZLES

Hydraulic nozzle flow is modelled using the general equation:

$$Q = C_f \cdot A \cdot \sqrt{\frac{2}{\rho} \cdot (p_u - p_d)} \tag{2.1}$$

where Cf is the flow coefficient, A is the flow area, ρ is the density and p_u and p_d are upstream and downstream pressure.

Figure 2.2 shows the nozzle is modelled as a resistor (R-element). Input to this model is upstream and downstream pressure, while the output is flow rate.

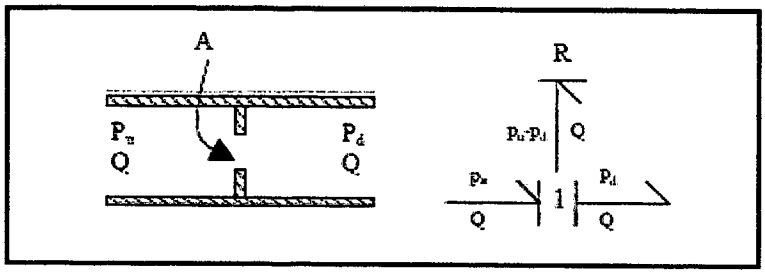

Figure 2.2: Nozzle schematic diagram

2.4.2 HYDRAULIC FLEXIBILITY OF VOLUMES

Figure 2.3 shows the hydraulic flexibility. It must be included in a model where high frequency dynamic behaviour is to be studied. The hydraulic flexibility is given by the bulk modulus of the fluid at constant temperature, defined as:

$$\beta = \rho \cdot \left(\frac{\partial p}{\partial \rho} \right)_T \tag{2.2}$$

For a constant volume element, the constitutive relation becomes:

$$p = p_0 + \frac{\beta}{V} \cdot \int (Q_u - Q_d)dt \tag{2.3}$$

and for a variable volume element like the cylinder of the fuel pump, the relation becomes:

$$p = p_0 + \int \frac{\beta}{V} \cdot (\dot{V} - Q)dt \tag{2.4}$$

The flexibility of the volume elements shown next is given by the relation:

$$C \equiv \frac{V}{\beta} \tag{2.5}$$

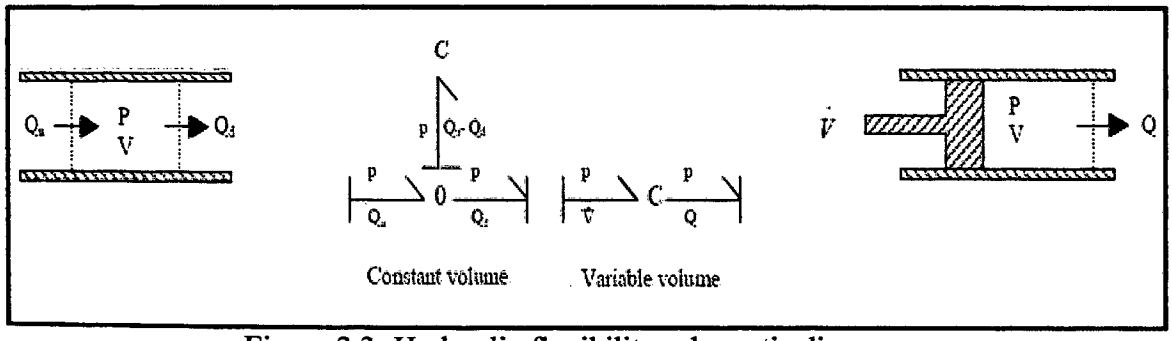

Figure 2.3: Hydraulic flexibility schematic diagram

Inputs to these models are upstream and downstream flow rate (or rate of volume change), while the output is pressure.

Fuel injection systems consist of components from several energy domains working together in a highly dynamic system. The bond graph modelling approach1 has for many years shown its excellence in representing multi-domain systems. By using bond graphs and matching software for modelling and simulation, it will be shown how

this can be a powerful tool for engineers when evaluating the performance of physical systems. Converting a bond graph model into a set of first order differential equations is a straightforward systematic process that can easily be computerised. The models presented in this paper are developed in the modelling tool MS12, generating simulation code for ACSL3 (Advanced Continuous Simulation Language).

2.5 PREVIOUS RESEARCH

2.5.1 Modelling

From a modellers point of view, fuel injection systems consist of more or less the same components, enabling the modeler to use and re-use basic sub models. This re-usability of models is crucial in an effective modelling environment. We will now present the sub-models required for assembling overall models for both the traditional injection system and the common rail injection system.

2.5.2 System Model

Figure 2.4 shows the sub models using the modelling tool MS1. The sub-models are used to assemble total models of a traditional injection system and a common rail injection system much in the same manner as building the physical system. Using bond graphs in combination with matching software enables the engineer to make changes and modifications to a model in a straightforward manner without reformulation of equations. The figure below shows the two models as they appear in MS1.

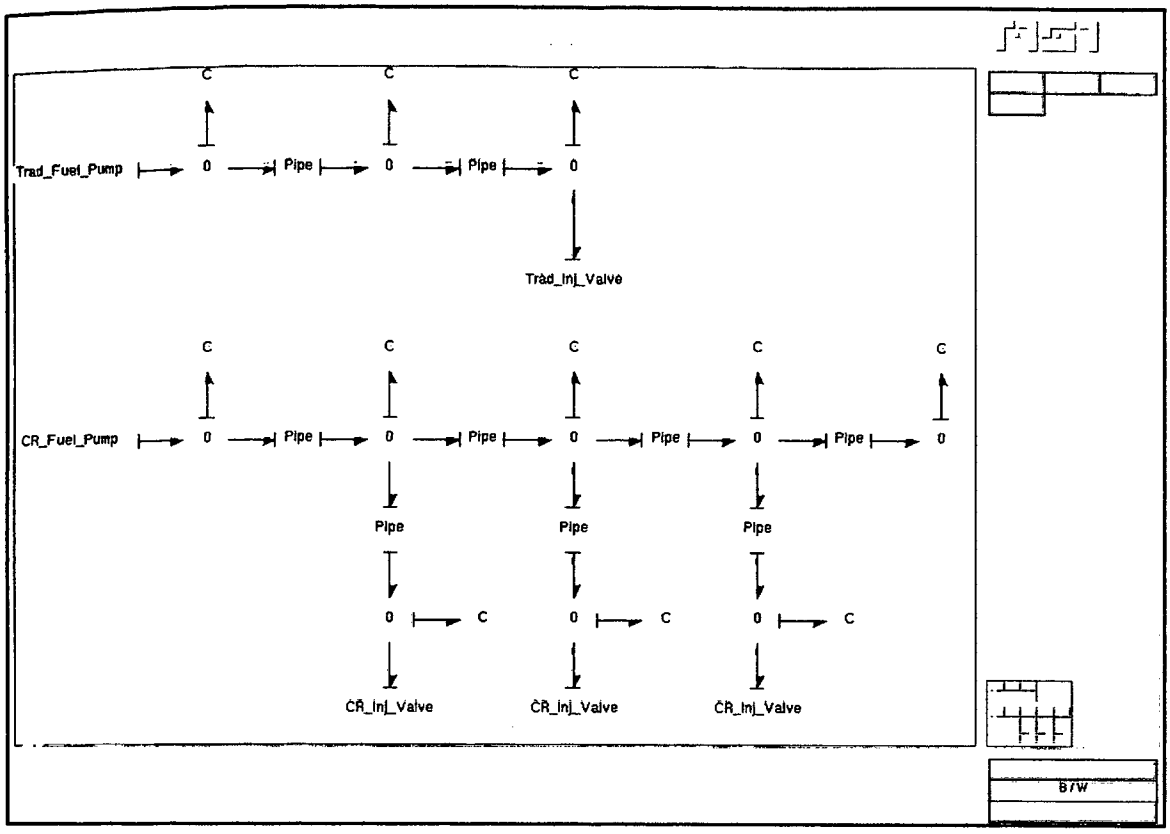

Figure 2.4: The fuel injection system models as they appear in MS1

MS1 is a modelling environment aimed at the study of dynamic systems that can be represented by ordinary differential algebraic equations. Its multi input/output possibilities provide a consistent handling of several model representations in addition to bond graphs. MS1 generates source code used for simulation in the designated solver, in our case ACSL.

2.5.3 Simulation

Figure 2.5 shows the plot of the pressure in the sac volume for both the traditional injection system and the common rail injection system. The pressure in the rail is 1000 bar.