ANALISIS ALIRAN CAS DI DALAM PANCARONGGA EKZOS SEBUAH KERETA

(ANALYSIS OF CHARGE FLOW IN EXHAUST MANIFOLD OF A CAR)

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ACKNOWLEDGMENT

Assalamualaikum

Alhamdulillah, first of all, I am grateful to Allah, upon His bless, I am able to complete my Final Year Project.

I would like to specially thank my parents for their support all the time, morally and financially. Without them, I would not have been able to complete my studies here.

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Thank You

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ABSTRAK

Ramai yang tidak mengetahui dan mengabaikan fungsi sistem ekzos. Dalam minda mereka, sistem ekzos hanyalah sebuah sistem yang berfungsi untuk mengalirkan asap ekzos yang terhasil melalui pembakaran bahan api di dalam enjin. Sebaliknya, sistem ekzos juga mempunyai peranan yang penting dalam meningkatkan prestasi sesebuah enjin.

Analisis ini bertujuan untuk menganalisa sifat-sifat aliran di dalam pancarongga ekzos. Analisis dimulakan dengan membina model geometri pancarongga ekzos menggunakan perisian I-DEAS. Kemudian, jejaring bagi model tersebut dibuat menggunakan perisian GAMBIT. Akhir sekali, dengan menggunakan perisian FLUENT, analisis sifat-sifat aliran dijalankan dengan memasukkan keadaan-keadaan sempadan, bahan dan parameter lain yang diperlukan.

Keputusan analisis ini ialah profail halaju, suhu dan tekanan di dalam pancarongga ekzos. Melalui kajian ini, beberapa kaedah dalam meningkatkan prestasi rekabentuk pancarongga ekzos telah dikemukakan.

ABSTRACT

Many do not know and disregard the function of the exhaust system. In their mind, the exhaust system is just a system to dispose the exhaust gases; the result of the combustion process, out of the engine. In fact, the exhaust system also plays an important part in improving the engine's performance.

This analysis is dedicated to analyze the flow characteristics inside the exhaust manifold. The analysis is started by modeling the geometry of the exhaust manifold using I-DEAS. Then, the model is meshed using GAMBIT. Finally, the analysis is carried out using FLUENT after determining the boundary conditions, materials and other parameters needed for simulation.

The results of this analysis are the velocity, temperature and pressure profile inside the exhaust manifold. Through this research, some ways of improving the design of the exhaust manifold has been found.

CHAPTER 1
INTRODUCTION

1.1 Evolution of the Internal-Combustion Engine

The first person to experiment with an internal-combustion engine was the Dutch physicist Christian Huygens, about 1680. But no effective gasoline-powered engine was developed until 1859, when the French engineer J. J. Étienne Lenoir built a double-acting, spark-ignition engine that could be operated continuously. In 1862 Alphonse Beau de Rochas, a French scientist patented but did not build a four-stroke engine; sixteen years later, when Nikolaus A. Otto built a successful four-stroke engine, it became known as the “Otto cycle.” The first successful two-stroke engine was completed in the same year by Sir Dougald Clerk, in a form which (simplified somewhat by Joseph Day in 1891) remains in use today. George Brayton, an American engineer, had developed a two-stroke kerosene engine in 1873, but it was too large and too slow to be commercially successful.

In 1885 Gottlieb Daimler constructed what is generally recognized as the prototype of the modern gas engine: small and fast, with a vertical cylinder, it used gasoline injected through a carburetor. In 1889 Daimler introduced a four-stroke engine with mushroom-shaped valves and two cylinders arranged in a V, having a much higher power-to-weight ratio; with the exception of electric starting, which would not be introduced until 1924, most modern gasoline engines are descended from Daimler’s engines.

Basically, an internal combustion engine is any engine that uses the explosive combustion of fuel to push a piston within a cylinder - the piston's movement turns a crankshaft that then turns the car wheels via a chain or a drive shaft. The different types of fuel commonly used for car combustion engines are gasoline (or petrol), diesel, and kerosene.

As an engine plays the main role in producing mechanical power for the system it was involved with, it is comprised of subsystems such as the fuel system, the intake or induction system, the exhaust system, the cooling system and the lubricating system.

The purpose of the exhaust system is to control the emissions and exhaust produced by the engine. The idea is to turn the harmful pollutants your car produces into harmless ones that don't ruin the environment. These pollutants include hydrocarbons (unburned), carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, phosphorus, lead and other metals. Although emissions control systems vary between manufacturers and vehicles, they all have the same goal and use many of the same methods.

The exhaust system comprises the following component:

1. Exhaust manifold and header
2. Manifold to exhaust pipe gaskets
3. Exhaust pipe
4. Exhaust pipe hangers
5. The EGR valve
6. PCV valve
7. The air pump
8. The catalytic converter
9. Muffler
10. Tailpipe

The exhaust manifold, usually constructed of cast iron, is a pipe that conducts the exhaust gases from the combustion chambers to the exhaust pipe. It has smooth curves in it for improving the flow of exhaust. The exhaust manifold is bolted to the cylinder head, and has entrances for the air that is injected into it. It is usually located under the intake manifold.

In this research, the charge flow inside the exhaust manifold is going to be analyzed theoretically and also using some engineering computer software such as Fluent, Gambit and I-DEAS. It was hoped that through this research, some ways of improving the design of the exhaust manifold can be found.

1.2 Objective

The objective of this research is to analyze the charge flow inside the exhaust manifold of a commercial car four-stroke spark ignition engine using modern computer simulation. Computer Aided Design (CAD) and Computational Fluid Dynamics (CFD) software will be used starting from the construction of the manifold and finally, analyze the flow inside the manifold.

Decades ago, the method of designing and evaluate the unsteady flow of gas in the exhaust manifolds was by using mathematical equation. Engineers found it very difficult to solve one problem in a short time. Sometimes, information gathered through physical testing was not enough or did not satisfy for use with equation. This makes it really tough for them to come up with a better design.

Subsequently, Computational Fluid Dynamics (CFD) provides easiness and timeliness testing or simulation of gas flow in the exhaust manifold. From one-dimensional flow through multi-dimensional flow, CFD surely in some cases eliminate physical testing. Through CFD information of the flow at some instances inside the exhaust manifold can be known quickly and that really help in detecting problem in the design and also solving it.

In this project, modern approach will be used in determining the nature of flow in the exhaust manifold. Computer Aided Design (CAD) software for example, I-DEAS will be used to construct the exhaust manifold and finally, simulation of the flow inside will be done by CFD software that is FLUENT.

CHAPTER 2
LITERATURE REVIEW

2.1 Internal Combustion Engine

The reciprocating internal combustion engine must be by far the most common form of engine or prime mover. As with most engines, the usual aim is to achieve a high output with a high efficiency. The two main types of internal combustion engine are: spark ignition (SI) engines, where the fuel is ignited by a spark; and compression ignition (CI) engines, where the rise in temperature and pressure during compression is sufficient to cause spontaneous ignition of the fuel. The spark ignition engine is also referred as the petrol, gasoline or gas engine from its typical fuels, and the Otto engine, after the inventor. The compression engine is also referred to as Diesel or oil engine; the fuel is also named after the inventor.

During each crankshaft revolution there are two strokes of the piston, and both types of engine can be designed to operate in either four strokes or two strokes of the piston. The four-stroke operating cycle can be explained by reference to figure 2.1.

1. The induction stroke. The inlet valve is open, and the piston travels down the cylinder, drawing in a charge of air. In the case of a spark ignition engine the fuel is usually pre-mixed with the air.

2. The compression stroke. Both valves are closed, and the piston travels up the cylinder. As the piston approaches top dead centre (tdc), ignition occurs. In the case of compression ignition engines, the fuel is injected towards the end of the compression stroke.

3. The expansion, power or working stroke. Combustion propagates throughout the charge, raising the temperature, and forcing the piston down. At the end of the

power stroke the exhaust valve opens, and the irreversible expansion of the exhaust gases is termed 'blow-down'.

4. The exhaust stroke. The exhaust valve remains open, and as the piston travels up the cylinder the remaining gases are expelled. At the end of the exhaust stroke, when the exhaust valve closes some exhaust gas residuals will be left; these will dilute the next charge.

The four-stroke cycle is sometimes summarized as 'suck, squeeze, bang and blow'. Since the cycle is completed only once every two revolutions the valve gear (and fuel injection equipment) have to be driven by mechanisms operating at half engine speed. Some of the power from the expansion stroke is stored is a flywheel, to provide the energy for the other three strokes.

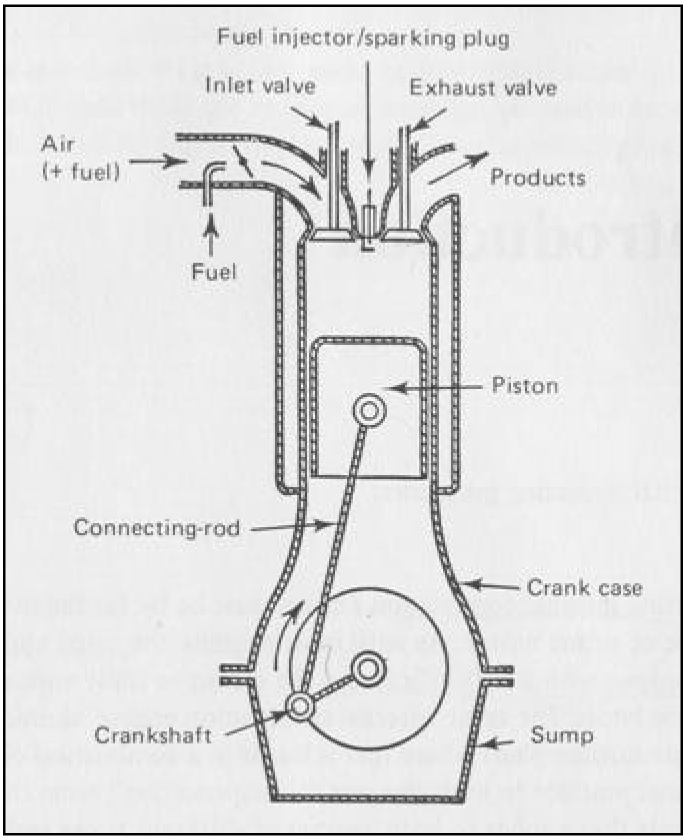

Figure 2.1: A four-stroke engine

The two-stroke cycle eliminates the separate induction and exhaust strokes; and the operation can be explained with the reference to figure 2.2.

1. The compression stroke. The piston travels up the cylinder, so compressing the trapped charge. If the fuel is not pre-mixed, the fuel is injected towards the end of the compression stroke; ignition should again occur before top dead centre. Simultaneously, the underside of the piston is drawing in a charge through a spring-loaded non-return inlet valve.

2. The power stroke. The burning mixture raises the temperature and pressure in the cylinder, and forces the piston down. The downward motion of the piston also compresses the charge in the crankcase. As the piston approaches the end of its stroke the exhaust port is uncovered and blow down occurs. When the piston is at the bottom dead centre the transfer port is also uncovered, and the compressed charge in the crankcase expands into the cylinder. Some of the remaining exhaust gases are displaced by the fresh charge; because of the flow mechanism this is called 'loop scavenging'. As the piston travels up the cylinder, first the transfer port is closed by the piston, and then the exhaust port is closed.

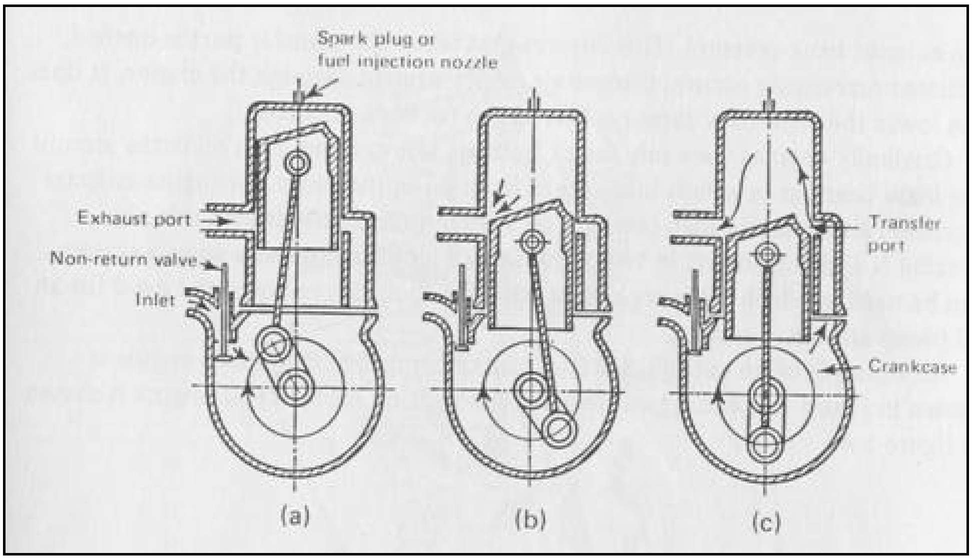

Figure 2.2: A two-stroke engine

For a given size engine operating at a particular speed, the two-stroke engine will be more powerful than a four-stroke engine since the two-stroke engine has twice as many power strokes per unit time. Unfortunately the efficiency is likely to be lower than that of a four-stroke engine.

2.2 Components of an exhaust system

Commonly, the exhaust system consists of the following components.

1. Exhaust Manifold and Header

The exhaust manifold, usually constructed of cast iron, is a pipe that conducts the exhaust gases from the combustion chambers to the exhaust pipe. It has smooth curves in it for improving the flow of exhaust. The exhaust manifold is bolted to the cylinder head, and has entrances for the air that is injected into it. It is usually located under or opposite the intake manifold.

A header is a different type of manifold; it is made of separate equal-length tubes. Four tube headers will slightly out perform three tube and Ram Air manifolds, and the three tube headers and RA units are a little better than stock manifolds.

2. Manifold to Exhaust Pipe Gaskets

There are several types of gaskets that connect the exhaust pipe to the manifold. One is a flat surface gasket. Another type uses a ball and socket with springs to maintain pressure. This type allows some flexibility without breakage of the seal or the manifold. A third type is the full ball connector type, which also allows a little flexibility.

3. Exhaust Pipe

The exhaust pipe is the bent-up or convoluted pipes that connect the entire exhaust system together. Some are shaped to go over the rear axle, allowing the rear axle to move up and down without bumping into the exhaust pipe; some are shaped to bend around under the floor of the car, connecting the catalytic converter with the muffler.

Exhaust pipes are usually made out of stainless steel, since the high heat conditions involved with the muffler system will cause rust. Exhaust pipes are classified by their diameter, with wider diameters being preferred for increased performance. In addition to width, the actual design of the exhaust pipe has a tremendous effect on performance. The more bends, kinks, and rough edges inside the pipe, the greater the internal friction on the exhaust gasses and the less efficient the exhaust system.

Therefore, performance exhaust system usually feature exhaust pipes that are smoothly bent, smooth on the inside, and have as fewest bends as possible to reduce the friction inside the pipe. Uniform diameter head-pipes of adequate size will improve performance over carelessly bent or badly crimped pipes. Mandrel bent pipes provide the best available performance.

4. Exhaust Pipe Hangers

Hangers hold the exhaust system in place. They give the system flexibility and reduce the noise level. The hanger system consists of rubber rings, tubes and clamps.

5. The EGR Valve

The Exhaust Gas Recirculation (EGR) valve is used to send some of the exhaust gas back into the cylinders to reduce combustion temperature. Why? Nitrous oxides form when the combustion temperature gets above 2,500 degrees F. This happens, because at such temperatures, the nitrogen in the air mixes with the oxygen to create nitrous oxides.

Nitrous oxide combines with the hydrocarbons in the air to create smog, definitely not a good thing. Therefore, the purpose of the EGR valve is to re-circulate some of the exhaust gas back through the intake manifold to the cylinders, which lowers the combustion temperature. Lowering the combustion temperature lowers the amount of nitrous oxide produced. Consequently, less of it comes out the tail pipe.

There are two types of EGR valves. One operates through the use of a vacuum, and the other operated through the use of pressure. Both types allow the exhaust gas in to lower the combustion temperature when it gets too high.

6. PCV Valve

The process of combustion forms several gases and vapors; many of them quite corrosive. Some of these gases get past the piston rings and into the crankcase. If left in the crankcase, these substances would cause all kinds of bad things (rust, corrosion, and formation of sludge), so they have to be removed. The PCV system uses a hose connected between the engine and the intake manifold to draw these gases out of the engine's crankcase and back into the cylinders to burn with the regular fuel. The only problem to solve is how to keep these gases from going in any case into the manifold and upsetting the required air-fuel ratio. The solution to this problem is the PCV valve.

The PCV valve controls the release of crankcase gases and vapors to the intake manifold. The valve is kept closed by spring action when the engine is at rest. When the engine is running normally, the low vacuum it creates allows the valve to open and release crankcase vapors and gases into the intake manifold for burning. If the engine is idling or slowing down, the vacuum level rises and pulls the valve plunger into the valve opening. This partially blocks off the opening so that only a small amount of vapors and gases can be drawn into the intake manifold.

One really comforting feature of the PCV valve is its behavior in the event of a backfire. If the car backfires in the manifold, the pressure makes the spring close the valve completely. With the valve closed, there is no chance that the flame can move into the crankcase and cause an explosion.

7. The Air Pump

The air pump sends (or pumps) compressed air into the exhaust manifold and in some cases to the catalytic converter. The oxygen in the pressurized air helps to burn quite a bit of any unburned hydrocarbons (fuel) and thereby converts the poisonous carbon monoxide into good old carbon dioxide.

A belt from the engine drives the air pump. It has little vanes (thin, flat, curved fins) that draw the air into the compression chamber. Here, the air is compressed and sent off to the exhaust manifold where it speeds up the emissions burning process. Stainless steel nozzles are used to shoot the air into the exhaust manifold, because they will not burn. Some engines use a pulse air injection system. This system uses pulses of exhaust gas to operate an air pump that delivers air into the exhaust system.

8. The Catalytic Converter

To further help reduce harmful emissions, modern cars (those built after 1977) have a catalytic converter in the exhaust system. The catalytic converter is installed in the exhaust line, between the exhaust manifold and the muffler. Basically, the harmful gases enter the catalytic converter, a kind of stainless steel container, which is lined with chemicals (catalysts - which are chemicals that cause a reaction between other chemicals without being affected itself) such as aluminum oxide, platinum and palladium. These chemicals cause the carbon monoxide and hydrocarbons to change into water vapor and carbon dioxide. Some converters have a third lining of chemicals, platinum and rhodium, that reduce nitrogen oxides (three-way, dual bed converter). Therefore, the pollutants are changed from harmful gases to harmless ones before they are let into the environment through the muffler and tail pipe.

The materials within a catalytic converter vary between cars. Catalytic converters are designed to do different things, depending on the design of the converter. Some catalytic converters use what is called an "oxidation" catalyst; this usually consists of ceramic beads coated with platinum to reduce hydrocarbons and carbon monoxide. Through the catalytic action, the hydrocarbons and carbon monoxide are "burned" to create water vapor and carbon dioxide. This type of catalytic converter needs an input of oxygen, so oxygen is usually injected into the cylinder head, or directly into the exhaust header or manifold.

Newer catalytic converters have a two part design. The front half is a "three-way" catalyst, which burns various pollutants, and reduces hydrocarbons, carbon monoxide, and oxides of nitrogen into water, carbon dioxide and nitrogen. These converters require exact fuel air mixtures in order to maintain efficient exhaust reduction. The rear section of these converters is the normal oxidation catalyst that further reduces hydrocarbons and carbon monoxide. Air from the air pump is injected into the center of these converters. Here the air is allowed to mix with the exhaust before it passes into the oxidation catalyst, where it burns off its toxic chemicals and reduces emissions.

The reason that leaded gas cannot be used in an engine with a catalytic converter is that the lead coats the chemicals in the converter. This makes them unable to do the job anymore, since the chemical lining can't come in contact with the pollutants. At first, this was a big disappointment, because lead acted as a lubricant and helped to reduce wear on some of the engine parts. Luckily for the engines and the environment, car manufacturers soon got around the problem by making tougher parts and coating them with special metal.

9. Mufflers

Exhaust gases leave the engine under extremely high pressure. If these gases escaped directly from the engine the noise would be tremendous. For this reason, the exhaust manifold sends the gases to a muffler, which is located between the catalytic converter (if present) or exhaust manifold and the tail pipe. The muffler quiets the noise of the exhaust by "muffling" the sound waves created by the opening and closing of the exhaust valves. When an exhaust valve opens, it discharges the burned gases at high pressures into the exhaust pipe, which is at low pressure. This type of action creates sound waves that travel through the flowing gas, moving much faster than the gas itself (up to 1400 m.p.h.), that the muffler must silence. It generally does this by converting the sound wave energy into heat by passing the exhaust gas and its accompanying wave pattern, through perforated chambers of varied sizes. Passing into the perforations and reflectors within the chamber forces the sound waves to dissipate their energy. The pressure of the gases is reduced when they pass through the muffler, so they go out of the tail pipe quietly.

There are two types of muffler design. A Reverse-Flow muffler is oval-shaped and has multiple pipes. Four chambers and a double jacket are used to accomplish muffling of the exhaust noise. Exhaust gases are directed to the third chamber, forced forward to the first chamber, from where they travel the length of the muffler and are exhausted into the tail pipe. A Straight Through Muffler has a central tube, perforated with several openings which lead into an outside chamber packed with a sound absorbing (or insulating) material. As the exhaust gases expand from the perforated inner pipe into the outer chamber, they come in contact with the insulator and escape to the atmosphere under constant pressure. Because of this, the expanding chamber tends to equalize or spread the pressure peaks throughout the exhaust from each individual cylinder of the engine. This type of muffler is designed for the purpose of reducing back pressure and, consequently, makes slightly more noise.

Since a muffler cannot reduce the noise of the engine by itself, some exhaust systems also have a resonator. Resonators are like little mufflers, and are usually the "straight through" type. They are added at the end of the exhaust system to take care of any noise that has made it through the muffler.

10. The Tailpipe

The tailpipe is a long metal tube attached to the muffler. It sticks out from under the body of the car, generally at the rear, in order to discharge the exhaust gases from the muffler of your engine into the air outside the car. Tailpipes are not as critical of irregularities in construction due to the cooling of the exhaust and resulting lower gas volume. However, severe crimps or wrinkles should be avoided, and mandrel bent pipes should be used when practical and possible.

2.3 Exhaust manifolds

Made of cast iron or tubular steel, the exhaust manifold mounts to the exhaust side of the cylinder head. An exhaust manifold gasket is used at the connection to ensure a good seal. Engines with their cylinders arranged in-line usually have one exhaust manifold. Engines with V-type cylinder arrangements, like the V6 and V8, have two separate exhaust manifolds, one mounted to each cylinder head.

The purpose of exhaust manifold is to route the exhaust gases leaving the cylinder head to the exhaust system. As such, the manifold also serves as a connection point for the exhaust pipe. It has smooth curves in it for improving the flow of exhaust.

Depending on engine configuration and the number of exhaust manifolds, there may be two exhaust pipe connections. Depending on the year, make and emissions equipment installed on the vehicle, the exhaust manifold may also serve as a mounting location for hardware of the air injection system or for an oxygen sensor. Also, some exhaust manifolds may still include a heat riser valve, controlled by a temperature-sensitive spring. This valve is designed to help divert hot exhaust gas through a separate passage in the intake manifold to aid in better warm-up derivability.

Although not commonly replaced with other exhaust system parts, exhaust manifolds should be checked periodically to ensure they are tight, free from cracks, and that the exhaust pipe mounts are secure. A “ticking” noise during acceleration or the sound or smell of leaking exhaust could indicate a leak at the manifold or its connections. However, don’t rely on the sense of smell as a conclusive means of determining if there’s an exhaust leak. Carbon monoxide has no odor. If there any problem with the exhaust system, have it inspected immediately by a professional technician. Another symptom of a potential exhaust leak is a failed emissions test. A leak not only lets exhaust gas out, it also allows oxygen to enter the exhaust stream, which can be detected during an emissions test.

Modern exhaust systems need to do four things:

1. Remove the exhaust gases from the engine as efficiently as possible,
2. Reduce the noise of the exhaust pulses to acceptable levels,
3. Reduce harmful emissions in the gases, and
4. Direct the poisonous gases away from the passenger compartment.

Any series of pipes can direct the exhaust away from the passenger compartment, so this is the simple part. Getting those gases out efficiently is a challenge.

2.4 Manifold design

The pressure pulses in the exhaust system are much greater than those in the inlet system, since in a naturally aspirated engine the pressures in the inlet have to be less than about 1 bar.

In designing the exhaust system for a multi-cylinder engine, advantage should be taken of the pulsed nature of the flow. The system should avoid sending pulses from the separate cylinders into the same pipe at the same time, since this will lead to increased flow losses. However, it is sensible to have two or three cylinders that are out of phase ultimately feeding into the same pipe. When there is a junction, a compression wave will also reflect an expansion wave back; this is shown in figure 2.3.

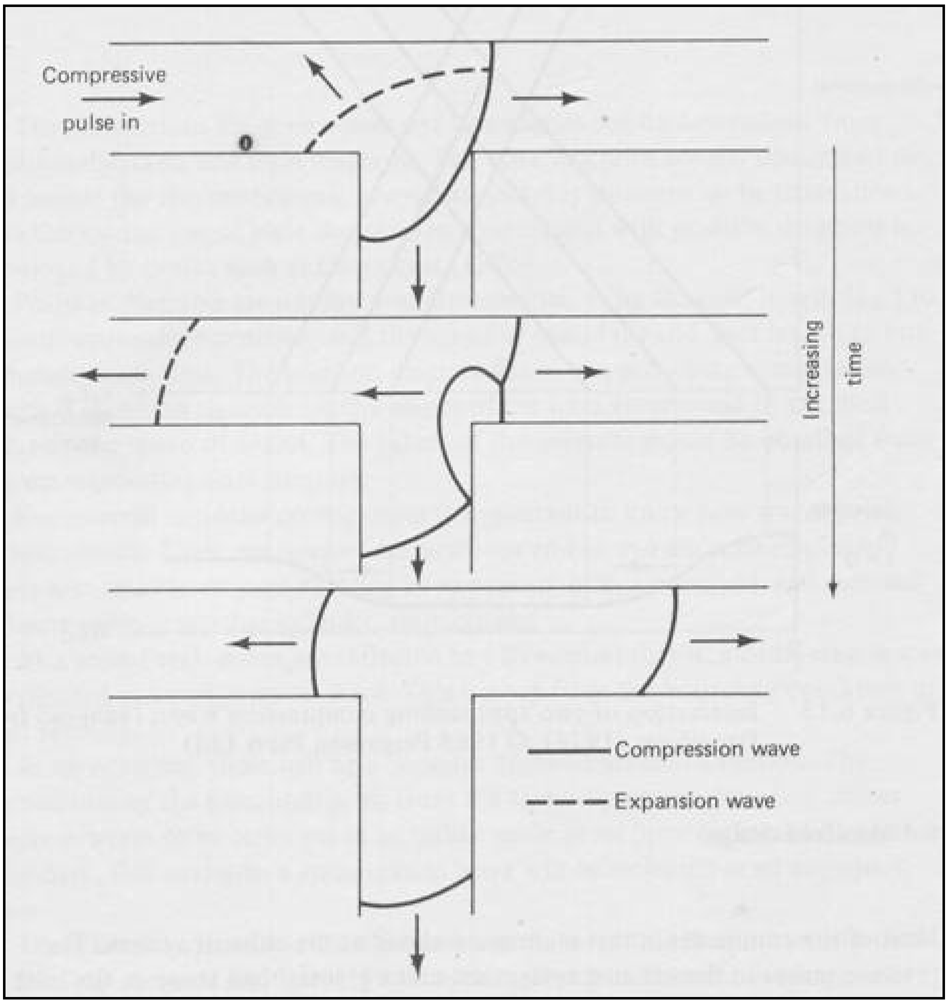

Figure 2.3: Pulsed flow at a junction

If the expansion wave returns to the exhaust valve at the end of the exhaust valve opening, then it will help to scavenge the combustion products; if the inlet valve is also open then it will help to draw in the next charge. Obviously the cancellation of compression and expansion waves must be avoided.

There are number of arrangements of exhaust manifolds that can be used for basic four-cylinder engines. These range from connecting all the cylinders into one manifold, shown in figure 2.4 in which two cylinders are connected initially and then the common pipes are joined downstream, to the more highly tuned 'banana-bunch' manifold in which all cylinders are brought together at one junction.

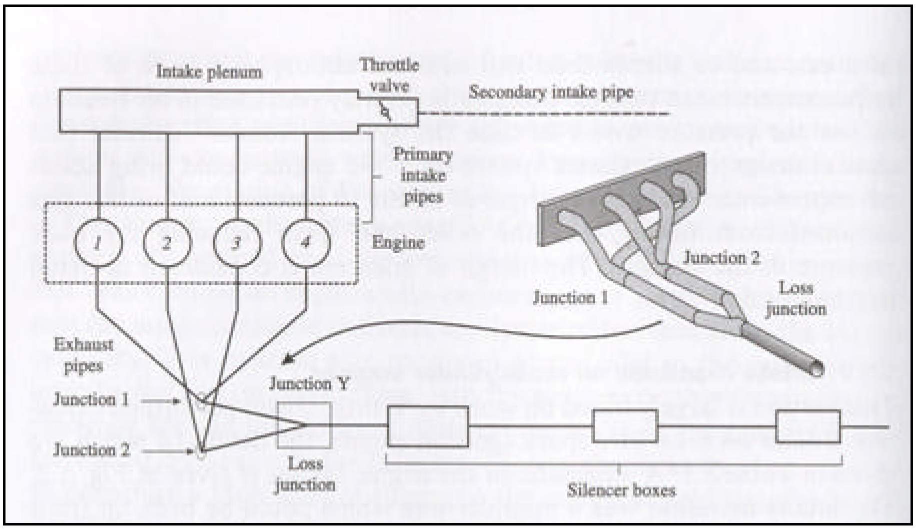

Figure 2.4: Schematic diagram of four-cylinder engine, showing inlet and exhaust manifolds

The pipe length from each exhaust port to its first junction is the same, and the pipes will be curved to accommodate the specified lengths within the given distances. The length adopted will influence the engine speed at which maximum benefit is obtained. The manifold is such that for the given firing order (cylinders 1 – 3 – 4 – 2), the pressure pulses will be out of phase.

The aim of this type of manifold is to try to separate the exhaust flows of cylinders which are liable to interfere with each other, and to produce beneficial wave reflections to assist the scavenging of the cylinders; this requires the establishment of two primary sub-manifolds connecting cylinder 1 and 4, and cylinder 2 and 3. It is possible to understand the operation of this type of manifold by considering the passage of the blow down pulse from cylinder 1. This pulse leaves the cylinder and travels down the pipe until it meets junction 1, where it 'sees' a sudden enlargement because the pipe area effectively doubles at the confluence of the pipes. Hence, a reaction wave is transmitted back cylinder 1, and this can assist the scavenging. In addition, smaller pressure waves are transmitted into the other two pipes, one going towards junction ‘Y’, and the other towards cylinder 4. If the pressure wave reaches cylinder 4 when the exhaust valve is closed then it will not interfere with the flow through the cylinder. This is likely to be the case because the wave travel time is about 80º crank angle for this engine speed of 3500 rpm, and the phasing between cylinders 1 and 4 is 360º. The wave traveling towards junction ‘Y’ will be reflected back towards cylinder 1 as a rarefaction wave. However, it will also be transmitted through that junction, albeit with reduced amplitude, towards cylinders 2 and 3 where it will interfere with the scavenging process of the cylinder which fires 180º after cylinder 1. Since these manifolds are ‘symmetrical’ each cylinder interferes with those that fire after it in similar ways.

2.5 General design considerations

Intake and exhaust manifolds have a major effect on engine performance and emissions of noise and pollutants. If the air/fuel ratio is maintained constant the potential for energy release in the combustion process, which is manifested as the indicated mean effective pressure (and ultimately the torque generated by the engine), is related to the quantity of air entering the cylinders. The majority of engines used in automobile applications is naturally aspirated and operate on the four-stroke cycle, in which distinct strokes of the piston are used to induce the air and exhaust it. These strokes enable the engine to pump gas through itself and they can be significantly affected by the design of the intake and exhaust systems. Two-stroke engines, which do not have discrete suction and exhaust strokes, rely almost entirely on the operation of the exhaust gas dynamics to purge the cylinder of combustion products and the manifolds of these engines have a dramatic effect on their performance. Successful design of the exhaust system in turbocharged engines helps ensure that sufficient energy is available at the turbine, over the operating spectrum of the engine, to drive the compressor at a condition which will produce the required boost ratio.

2.6 Induction and exhaust process

In reciprocating internal combustion engines the induction and exhaust processes are non-steady flow processes. For many purposes, such as cycle analysis, the flows can be assumed to be steady. This is quite a reasonable assumption, especially for multi-cylinder engines with some form of silencing in the induction and exhaust passages. However, there are many cases for which the flow has to be treated as non-steady, and it is necessary to understand the properties of pulsed flows and how these can interact. Pulsed flows are very important in the charging and emptying of the combustion chambers, and in the interactions that cam be occur in the inlet and exhaust manifolds. This is particularly the case for two-stroke engines where there are no separate exhaust and induction strokes. An understanding of pulsed flows is also needed if the optimum performance is to be obtained from a turbocharger. In naturally aspirated engines it is also important to design the inlet and exhaust manifolds fro pulsed flows if optimum performance and efficiency are to be attained. However, inlet and exhaust manifolds designs are often determined by considerations of cost, ease of manufacture, space and ease of assembly, as opposed to optimizing the flow.

There is usually some form of silencing on both the inlet and exhaust passages. Again, careful design is needed if large pressure drops are to be avoided.

2.7 Flows in the manifold systems of engines

A schematic of a typical conventional modern spark-ignition engine is shown in figure 2.5.

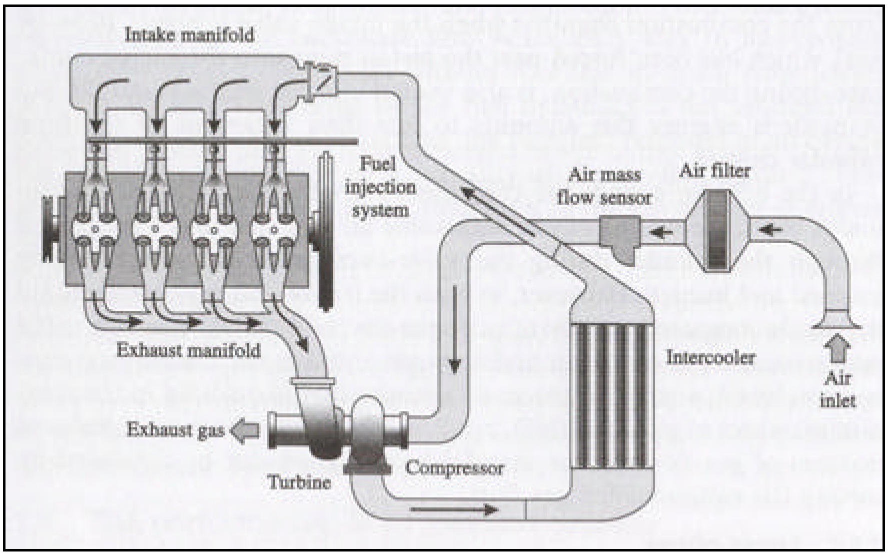

Figure 2.5: Schematic diagram of modern turbocharged, intercooled, fuel-injected spark-ignition engine

Air is drawn into the intake manifold and passes through a filter before being regulated by a throttle valve. Further downstream the fuel, and possibly recirculated exhaust gas, is added to the air stream. When the intake valves are open this mixture passes into the cylinder where it is burned. The combustion products later enter the exhaust system when the exhaust valve opens. On many modern engines, a fraction of the exhaust gas is recirculated (EGR) to the intake manifold to bring about the reduction in the combustion temperatures and the rest progresses through the emissions control devices and silencers, and thence in to the atmosphere. These processes mean that all three phases of matter can be found inside the exhaust systems.

- Gaseous phase

In the exhaust system the constituents are mainly combustion products, but these will be mixed with some air and fuel that have passed through the cylinder during the valve-overlap period without being trapped and burned. However, the gas is composed mainly of nitrogen (over 70 percent) as this is the major constituent of the air and it passes through the combustion process unaltered, except for the small amount that is oxidized in the creation of oxides of nitrogen (NO_x) pollutants. Hence, the most significant features of gas flows in the manifolds of engines can be simulated by solving the equations for gas flow.

- Liquid phase

Any water vapour generated in the in the combustion process by the oxidation of the hydrogen in the fuel is usually found in vapour phase in warm engines, due to its low partial pressure and the relatively high temperature of the exhaust pipes. However, on starting it may condense as it encounters the relatively cool walls of the exhaust system towards the tailpipe end but this has negligible effect on the operation of the engine.

- Solid phase

Solid material usually only occurs in engine exhaust manifolds in the form of particles generated during the combustion process. This matter, in the form of submicron scale soot, is more abundant in the exhaust streams of diesel engines than in spark-ignition engines and has little effect on the gas flow.

2.8 Engine emissions

The term 'engine emissions' refers primarily to pollutants in the engine exhaust. Examples of pollutants are carbon monoxide (CO), various oxides of nitrogen (NO_x) and unburnt hydrocarbons (HC). These emissions are worse from the spark ignition engine than from compression ignition engine. Emissions from compression ignition engines are primarily soot, and odour associated with certain hydrocarbons. Recently concern has been expressed about possible carcinogens in the exhaust but it is not clear if these come from the diesel fuel or the combustion process.

The concentrations of CO and NO_x are greater than those predicted by equilibrium thermodynamics. The rate of the forward reaction is different from the backward reaction, and there is insufficient time for equilibrium to be attained. Emissions of CO, NO_x and HC vary between different engines and are dependent on such variables as ignition timing, load, speed and, in particular, fuel/air ratio.

Carbon monoxide (CO) is most concentrated with fuel-rich mixture, as there will be incomplete combustion. With lean mixtures, CO is always present owing to dissociation, but the concentration reduces with reducing combustion temperatures. Hydrocarbon (HC) emissions are reduced by excess air (fuel-lean mixtures) until the reduced flammability of the mixtures causes a net increase in HC emissions. These emissions originate from the flame quench layer – where the flame is extinguished by cold boundaries; regions like piston ring grooves can be important. The outer edge of the quench regions can also contribute to the CO and aldehyde emissions.

The formation of NO_x is more complex since it is dependant on a series of reactions such as the Zeldovich mechanism:

$$O_2 \Leftrightarrow 2O$$

$$O + N_2 \Leftrightarrow NO + N$$

$$N + O_2 \Leftrightarrow NO + O$$

Chemical kinetics show that the formation of NO and other oxides of nitrogen increase very strongly with increasing flame temperature. This would imply that the highest concentration of NO_x should be for slightly rich mixtures, those that have the highest flame temperature. However, NO_x formation will also be influenced by the flame speed. Lower flame speeds with lean mixtures provide a longer time for NO_x to form. Similarly NO_x emissions increased with reduce engine speed.

Emissions of HC and CO can be reduced by operating with lean mixtures; this has the disadvantage of reducing the engine power output. It is also difficult to ensure uniform mixture distribution to each cylinder in multi-cylinder engines. Alternatively, exhaust gas catalytic reactors or thermal reactors can complete the oxidation process; if necessary extra air can be admitted.

The ways of reducing NO_x emissions are more varied. If either the flame temperature or speed is reduced, the NO_x emissions will also be reduced. Retarding the ignition is very effective as this reduces the peak pressure and temperature, but it has an adverse effect on power output and economy. Another approach is to increase the concentration of residuals in the cylinder by exhaust gas recirculation (EGR). EGR lowers both flame temperature and speed, so giving useful reductions in NOx. Between 5 to 10 per cent EGR is likely to halve NO_x emissions. However, EGR lowers the efficiency and reduces the lean combustion limit. Catalysts cam be used to reduce the NO_x to oxygen and nitrogen but this is difficult to arrange if CO and HC are being oxidized. Such systems have complex arrangements and require very close to stoichiometric mixtures of fuels with no tetraethyl lead. Compression ignition engines have fewer gaseous emissions than spark ignition engines, but compression ignition engines have greater particulate emissions. The equivalence ratio in a diesel engine is always less than unity (fuel lean), and this account for the low CO emissions, about 0.1 per cent by volume. Hydrocarbon emission (unburnt fuel) is also less, but rises towards the emission level of spark ignition engines as the engine load (bmep) rises.

The emissions of NO_x are about half those for spark ignition engines. This result might at first, seem to contradict the pattern in spark ignition engines, for which NO_x emissions are worst for an equivalence ratio of about 0.9. In diffusion flames, fuel is diffusing towards the oxidant, and the oxidant diffuses towards the fuel. The equivalence ratio varies continuously, from the high values at the fuel droplet to values less than unity in the surrounding gases. The flame position can be defined for mathematical purposes as where the equivalence ratio is unity. However, the reaction zone will extend each side of the stoichiometric region to wherever the mixture is within the flammability limits. This will have an averaging effect on NO_x production. In addition, radiation from the reaction zone is significant, and NO_x production is strongly temperature-dependent. A common method to reduce NO_x emissions is to retard the injection timing, but this has adverse effects on fuel consumption and smoke emissions. Retarding the injection timing may be beneficial because this reduces the delay period and consequently the uncontrolled combustion period.

The most serious emission from compression ignition engines is smoke, with the characteristic grey or black of soot (carbon) particles. Smoke from compression ignition engines originates from carbon particles formed by cracking (splitting) of large hydrocarbon molecules on the fuel-rich side of the reaction zone. The carbon particles can grow by agglomeration until they reach the fuel-lean zone, where they can be oxidized. The final rate of soot release depends on the difference between the rate of formation and the rate of oxidation. The maximum fuel injected (and consequently power output) is limited so that the exhaust smoke is just visible. Smoke output can be reduced by advancing the injection timing or by injecting finer fuel spray, the latter being obtained by higher injection pressures and finer nozzles. Smoke form a compression ignition engine implies a poorly calibrated injected pump or faulty injectors.

2.9 Gas dynamics and its effect on the performance of engines

At present the most popular methods for evaluating the performance of internal combustion engines are based on one-dimensional gas dynamics simulation. These treat the intake and exhaust manifolds as pipe networks, and evaluate the unsteady flows in these by assuming the flows therein can be represented by a single, average, velocity at any cross-section. These neglects the effects of turbulence and viscosity in the pipes, which establish the velocity profile across the flow: the effects of fluid friction can be included in the calculations by means of a friction factor. Such an approach is satisfactory for most of the flows encountered in the pipework of internal combustion engines, although it becomes less appropriate if the pipe curvature is high. Where such a simplified approach is limited is when the flow in the manifold exhibits multi-dimensional patterns, for example in pipe junction. It is possible to overcome these difficulties by applying empirically based loss coefficients, but this then means that the method is not wholly predictive. Despite these possible limitations, one-dimensional simulation programs provide a powerful tool to evaluate the performance of engines, and most of the initial designs of complex manifold systems are performed using such programs.

2.10 Improving the exhaust systems

A well designed exhaust system is one of the cheapest ways of increasing engine efficiency, and therefore increasing engine power. Remember that on a four stroke engine; only one stroke out of the four does any work - the power stroke. The other three strokes - intake, compression and exhaust - all absorb some of the power that was made on the power stroke. If we can minimize the amount of power that is lost by these idle strokes, we will have more power available to drive the wheels, which is what the engine is supposed to be doing. To know why there is a worthwhile gain to be had from fitting a good performance exhaust system, we will start by carefully looking at the factory fitted system.

A V-8 engine requires two exhaust manifolds and either one or two mufflers and often accompanying resonators. If one muffler is used, the exhaust pipe from one manifold meets the other one in the form of a "Y". This is also known as a "Y-split" exhaust. Most V8s use what is called a Dual Exhaust system. A Dual Exhaust system requires two exhaust manifolds and two mufflers. Each side of the exhaust system is completely separate from the other. The advantage of a dual exhaust system is that the engine exhausts more freely, thereby lowering the back pressure which is inherent in an exhaust system. With a dual exhaust system, a sizable increase in engine horsepower can be obtained because the "breathing" capacity of the engine is improved, leaving less exhaust gases in the engine at the end of each exhaust stroke. This, in turn, leaves more room for an extra intake of the air-fuel mixture.

The purpose of the exhaust system is to control the emissions and exhaust produced by the engine. The idea is to turn the harmful pollutants your car produces into harmless ones that don't ruin the environment. These pollutants include hydrocarbons (unburned), carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, phosphorus, lead and other metals. Although emissions control systems vary between manufacturers and vehicles, they all have the same goal and use many of the same methods.