Exhaust system for the ljmu

The FS event is held every year at Silverstone in the UK. The event was set up by the Institute of Mechanical Engineers (IMechE). Universities from around the world come to Silverstone to enter their cars in the event. Each team that enters FS is solely made up of students. There are a number of different classes which the car can be entered. These are Class 1, Class 1A and Class 2.

LJMU is entering in to Class 1. Class 1 consists of a number of different events which can be broken down in to two categories, Static Events and Dynamic Events.

The Static Events include, a presentation, Engineering Design and Cost Analysis.

The Dynamic Events include an acceleration test, a skip-pad test, an autocross race and an Endurance race which includes a fuel economy test.

The final exhaust design will be used in the 2011 LJMU FS car. For the exhaust to be used it must fully comply with the FS rules and regulations. The LJMU FS car is a group project and so it will be vital to the success of the exhaust system and the final car that communication is maintained.

Formula Student 2010

LJMU competed in its first FS Class 1 event in 2010 and finished in 21st place. This was a great achievement for the university. Feedback was given to the university after the event from the FS judges. The feedback received was useful and has given areas of improvements for the car. One of the pieces of feedback was criticising the fact that the exhaust system didn’t have a Lambda sensor to measure the levels of oxygen the in exhaust gas. This will be one area of improvement for FS 2011.

Time Management

To complete this project within the strict time limits a Gantt chart has been created. This can be seen in APPENDIX REFERENCE. Within the time 4 stages will be completed. There are analysis, design, verification and manufacture.

FS Rules and Regulations

To successfully create an exhaust system a number of rules need to be met. The rules and regulations were written by the Formula Society of Automotive Engineers (FSAE). These rules are in place to maintain a level playing field throughout the teams and to also ensure that safety standards are kept. The FS rules can be interpreted in different ways and so create different and interesting designs.

To summarise a few rules, the exhaust has to exist within an area of 450 mm behind the centreline of the rear axle and 600 mm above the ground, the driver must be protected against heat and fumes and the sound must not exceed 100dBA.

The engine size is also limited by FS rules. The rules state that an engine no bigger than 610cc can be used for the competition. The used for the engine must also pass through a 20mm restrictor.

The full list of rules and break down which are relevant to this project can be found in ARTICLE 10: Exhaust System and Noise Control seen in APPENDIX REFERENCE.

Design Restrictions

As the exhaust will get very hot during running it is important that the exhaust pipes don't come in to contact or come too close to other engine peripherals such as electrical cables and fuel line. The driver will also be protected by a firewall in case of a fire or excess heat from the engine. As the fuels system, intake system and other peripherals have yet to be decided assumptions must be made in the routing of the exhaust system. The decision has been made to mount the engine front facing. This will mean that the exhaust ports are facing towards the front of the car and the intake ports are facing the back of the car. This decision has been made to simplify the design of the drive train to minimalize power lost and reduce the risk of failure.

The design is also impacted by 20mm restrictor on the air intake which will also affect the exhaust system.

Ricardo WAVE

Ricardo WAVE Build will be used to fully model the exhaust system. Ricardo WAVE is an ISO 1D/3D engine and gas dynamics simulation package. WAVE is used in a number of different industry sectors all involved in simulating engine performance. It used from creating an initial design to the modifying an existing design without having to manufacture any components. WAVE only produces theoretical engine performance data and will need to be verified with experimental data.

Ricardo WAVE is a sponsor in the FS event and so all FS teams have access to the software.

Learning Ricardo WAVE

Within the WAVE help file there is a list of tutorials which cover setting up and running an engine model. The tutorials range from beginner to advanced. The beginner spark ignition (SI) tutorial takes the user through the initial setup of an in-line, 4-cylinder 1. 6L engine. Two WAVE tutorials have been completed these are the Introductory SI Tutorial and the Intermediate Concentric Silencer Tutorial.

Going through the tutorials helped to give an idea of the different parameters that would need to be collected from the Honda CBR600RR engine. The tutorials also guide the user through the analysis of the model and how a change in the design affects output.

Engine Selection

The engine selection is partly governed by the FS rules and regulations as stated earlier. Due to the restrictions a decision was made to go for a reliable, powerful engine which is light weight. This lead to the Honda CBR600RR-4. The Honda is a 600cc performance motorcycle engine and so its power to weight ratio is high, which makes it perfect for the FS car. LJMU have used this engine for the past 2 years. The specification of the Honda CBR600-3 will be referenced to as the engine specification has not changed between 2003 and 2004.

The CBR600RR engine is an 16-valve, in-line four cylinders, four stroke, with double overhead camshafts (DOHC) (Coombs, 2006). The Engine uses Programmed Duel Storage (PGM-DS) fuel injectors, two per cylinder, one upper and one lower. The lower injectors are used to enhance reliability, above 5500rpm the upper injectors are triggered and are used to improve top end horsepower (Torrance, 2003).

A full specification of the standard CBR600RR can be found in APPENDIX REFERENCE.

There are a number of different modifications that will take place on the engine by the FS event in 2011 and so the specification is subject to change. Changes that are being considered are an optimal air induction system with the 20mm restrictor, design and manufacture of a shallower sump, reduction in number of gears and modification of ratios and developing an optimised engine map. All of these changes are aimed at increasing performance of the engine for the required characteristics of the competition.

Literature Review

To generate the best performance from an exhaust system knowledge of a 4 stroke SI Internal combustion (IC) engine is needed.

Four-stroke spark ignition (SI) engines

The four-stroke SI engine has four different strokes as seen in Figure 1, Four-stroke IC Engine (Encyclopaedia Britannica, 2007) The four strokes are Intake, Compression, Power and Exhaust. For each turn of the crankshaft two strokes occur.

The Intake stroke, also known as the Induction stroke, starts from Top Dead Centre (TDC). In this stroke the piston moves down, the intake value opens causing the air and fuel mixture to be drawn in to the combustion chamber.

The volume of the air/fuel mixture drawn in to the chamber is known as the volumetric efficiency.

If there is too much air in the mixture then the fuel will burn quickly increasing the pressure in the chamber too quickly leading to mechanical losses and misfiring. This is known as a lean fuel mixture and can lead damage the engine.

If there is too much fuel in the mixture then all of the fuel will not be burnt leading to inefficiencies as unburnt fuel will be expelled through the exhaust valve. This will also lower the temperature and pressure in the chamber. This is known as a rich fuel mixture.

The Compression stroke follows the induction stroke. The compression stroke starts from Bottom Dead Centre (BDC). The intake valve shuts and the piston starts to move back up the chamber. Just before the piston hits TDC the spark plug fires causing ignition.

The Power stroke is where the piston moves down the chamber due to the increase in pressure and temperature from combustion. When the piston hit BDC the exhaust valve opens.

The Exhaust stroke forces the gasses out of the combustion chamber through the exhaust valve after the Power stroke. At the end of the exhaust stroke the exhaust valve closes and the cycle starts again. Any exhaust gasses left in the chamber will contaminate the next intake of fuel and will reduce the power output.

As only one stroke generates any power (Power stroke), energy has to be stored in a flywheel to move the piston for the remaining three strokes. (Stone, 1999)

Engine Thermodynamics

An IC engine whether it is a 4 stroke or a 2 stroke is a non-cyclic process. However as the nitrogen in the fluid is virtually unchanged it can be argued that the process is cyclic. This makes calculating the thermodynamic efficiencies much easier as it can be compared to the Otto cycle.

Performance

To calculate the performance and effectiveness of the exhaust system a number of different parameters will need to be defined.

Exhaust Design

There are two main designs for exhaust systems, exhaust manifold and exhaust header. Both designs have different pros and cons depending on the different requirements.

A standard exhaust manifold can be seen in Figure 2, Standard Exhaust Manifold (Monster Autoparts) This Exhaust is made from cast iron, and so it is perfect for production vehicles as casting is inexpensive if the cast is only used on a large scale. However for a one off production exhaust system it would be expensive. Exhaust headers Figure 3 on the other hand are comparatively inexpensive to produce a one off design as no mould needs to be created and the pipes can be simply bent and cut in to shape.

Manifolds are also inefficient compared to exhaust headers. This is due to the air flow in a manifold. When the exhaust gas enters the manifold back pressure is built up. This back pressure restricts the flow for the next wave of exhaust gas. This means that the piston has to work harder to force the exhaust gas out of the cylinder leading to power loss. This back pressure can be reduced or eliminated using exhaust headers by taking advantage of the timing. This is known as exhaust pulsation.

To fully understand pulsation it is important to explain the exhaust system shown in Figure 3. This design is a 4-2-1 exhaust. Different exhaust designs can be found in APPENDIX REFERENCE. As can be seen each exhaust port has its own header. Header pipes 1 and 2 join and header pipes 3 and 4 join. These joints are known as collectors which then form the secondary headers. The 2 secondary headers then move in to the final collector and form the downpipe. The firing order of the Honda CBR600 engine is 1-2-4-3 (Coombs, 2006).

Improving Engine Performance

To improve the performance of the engine pulsation can be used. Pulsation is where

Exhaust Pulsation

Exhaust Gas Turbochargers

There are two different types of exhaust gas turbocharging. These are Pulse Turbocharging and Constant Pressure Turbocharging.

Exhaust Gas Recirculation

Exhaust Gas Recirculation (EGR) is where a small portion of the exhaust gas (5-10%) is fed through a valve back in to the inlet manifold ready for the intake stroke. This helps to decrease emissions of NOx (nitric oxcide and nitrogen dioxide) as the amount of fresh fuel drawn in to the cylinder in replaced with exhaust gas. Between 5 and 10% of EGR is likely to halve the NOx emissions (Stone, 1999).

EGR increases intake manifold pressure. The higher intake manifold pressure leads to a reduction in the charge cycle work and this lowers the fuel consumption. During EGR the peak combustion temperature is reduced due to the exhaust gas not being used during combustion which will cause less energy to be produced. (Bosch, 2007)

EGR can cause misfire and partial burns to occur as the amount of fuel in the cylinder is reduced, causing a lean mixture.

Data Collection

Engine Geometry

To create an accurate model in WAVE geometry from the CRB engine has to be collected. This was done in a number of different ways.

A list of geometry needed for WAVE can be found here APPENDIX REFERENCE.

A new head from a CRB engine was purchased and was used to collect the relevant information. A new head was purchased as the tests that were carried out on the head would require taking sections, which would destroy the head beyond repair.

DIGITISING ARM

VOLUME OF INTAKES AND EXHAUST PORTS

Rolling Road Testing

Exhaust Geometry