FORMULA SAE – POWER TRAIN

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ABSTRACT

This paper contains an outline of the design project at hand, a brief overview of the decision making processes used in the project, a summary of the work undertaken thus far, and an analysis of future requirements. The section under completed work will be divided up into design, construction and testing, and theoretical results and calculations.

KEYWORDS: Engine Development, Intake system, Fuel system, Rear Axle, System Parameters

1. INTRODUCTION.

The Society of Automotive Engineers (SAE) has for some time been running a design and build competition between tertiary institutions. This event, known as the Formula SAE competition, involves the design and construction of a high-performance racing vehicle by students as a part of their design projects. While the event has been running successfully in the United States for a number of years, it was introduced in 2000 into Australia as the Formula SAE Australasia competition.

As a result of the events' increasing popularity, the University of Adelaide's Department of Mechanical Engineering has decided to place an entry into the 2001 competition. It was envisaged that the competition would form part of the final year design project for Mechanical and Mechatronic Engineering students. At initial meetings of the participating students and project supervisors it was decide that the three groups would be formed in order to break down the design responsibilities into sensible sections. This resulted in the formation of a chassis/body group, suspension group and a power-train group.

The power-train group is ultimately responsible for the cooling system, the fuel system, the air intake system, the exhaust, the rear axle, and the overall modification and testing of the engine. The design and construction of these elements has formed the backbone of our work for the past 6 months.

2. DESIGN AND CONSTRUCTION.

The initial decision-making processes were devised to give the optimum solution to our design problems, given our considerable constraints. The various systems were divided up amongst the group members and considered separately. A problem statement and design criteria were established for each system, then a brainstorming session was undertaken to produce multiple possible solutions to each problem. After researching the positive and negative aspects of each solution, a concept selection matrix was drawn up according to the design criteria, and from a points weighting system, tempered with common sense and intuition, the final design for each separate system was arrived at.

2.1 COOLING SYSTEM

The function of the cooling system is to minimise the heat stress exerted on the combustion chamber, thus ensuring a lubricant film is maintained on the cylinder walls, the cylinder head, pistons, exhaust/intake valves, and camshaft. The lubricant must be sufficiently cooled to maintain the desirable viscosity under operating conditions. The failure of the cooling system will result in the thermal fatigue of rotating components, the generation of large quantities of heat due to the increase in friction causing pre-ignition of the fuel. The heat that is to be removed by the cooling water from the cylinder head ranges from 20 to 35 percent of the energy input for a four-stroke automotive engine. The cooling system must be lightweight and cost-effective and designed to operate efficiently without adversely affecting the fluid flow (aerodynamics) over the vehicle (minimal drag).

After consideration of various designs, the final decision was to locate the radiator in the side ferring of the race vehicle. This is the typical position of the water-cooler for most open-wheelers, including Formula 1 and Formula Holden. This location is ideal since cool air is continually following through the core of the radiator, hence maximising the efficiency, whilst not causing huge amounts of drag.

2.2 INTAKE SYSTEM

The sub-functions of the air/fuel intake system are to ensure adequate flow of air and fuel/air mixture to the engines inlets. For our particular design the intake will need to optimise the flow of air and fuel through a 20mm circular restrictor [2]. The system must also ensure that the air fuel ratio being delivered is as close to stoichiometric as possible for all engine speeds and throttle settings.

The chosen intake system diverges into four separate ducts. This design was chosen because it mimicked the exhaust system, thereby enabling an easier manufacturing and testing process, as both would have already been set up for the exhaust. The dimensions of the intake will be slightly different to the exhaust, to allow for both the different airflow requirements and the space available.

In the current working design, a single carburettor is placed above the restrictor. Below the restrictor, fuel and air will be delivered to the engine through a tune-length piping network. Should there be time, a fuel injection system will be implemented, replacing the single carburettor, as the use of computerised control will result in greater efficiency and performance over all engine speeds and loading conditions.

2.3 EXHAUST

The expansion chamber in an engine harnesses sound waves to draw fresh charge into the chamber and pressure release the used mix. We can therefore think of an engine's exhaust port as a sound generator. Each time the exhaust port is opened, the pulse of exhaust gases rushing out the port creates a positive pressure wave, at the same frequency as the engine rpm. (Therefore the expansion chamber length is decided by the maximum / optimum rpm the engine will reach).

Although an analysis was carried out to determine the best exhaust, Team Honda had already provided us with a high-performance exhaust system. This consists of a muffler and megaphone exhaust, which corresponded with the simplest and most economical of our designs. At some future date, an oxygen sensor will be mounted on the exhaust at the point where all four flows converge. This will assist in ensuring correct mixture is provided, and is a necessary requirement for the intended fuel injection system.

2.4 Fuel System

The function of the fuel system is to provide a constant supply of fuel to the engine whilst ensuring the safety of the driver and all persons. An appropriate fuel pump, regulator and filters were provided by Bosch Automotive, including components for the proposed fuel injection system. Many concepts were designed and some even got as far as detailed CAD drawings, however the manufacturability of some of the designs was called into question, so the fuel tank design is still in the preliminary stages.

2.5 Rear Axle

The function of the rear axle is to transfer the torque from the engine/gearbox through the wheels to the road surface. This provides the car with a forward motion. The rear axle also transmits the braking torque through the wheels to the road to stop the car. When the car turns a corner the outside wheel turns more revolutions than the inside wheel. The rear axle can include a differential of various designs to allow this to happen.

The final design includes a Zexel Torsion limited slip differential as used by Audi and Hummer. The brake disc will be mounted directly to one side of the differential and the drive sprocket to the other side. The differential will be supported by two bearings. It will also contain four universal joints so that fully independent suspension can be used.

2.6 Part Design

Although various sponsors supplied us with many components of the power-train system, a great many specialised parts needed to be designed and constructed in-house. These include:

- The housing for the differential
- Various bearing housings
- The dynamometer rig for engine testing
- The engine mounting (for the car itself)
- The fuel rail and fuel tank
- The intake piping and manifold (including air box and restrictor)
- Sprockets and shafts for the rear axle

3. Calculations and Theoretical Results

3.1 Gear Ratio Design

Team Honda provided the gearbox with the engine as one unit, so the internal gear ratios of the gearbox were fixed [1]. However some analysis needed to be undertaken in order to determine the best final drive ratio, as the front and rear sprocket size must be optimised for both acceleration and economy.

Before the arrival of the gearbox, the testing procedure for the engine needed to be determined. In order to simplify this process, an initial analysis of the approximate gear ratios was undertaken, using appropriate assumptions and estimations. The overall gear ratio for the entire gearbox was calculated from the required road speed and estimated engine speed. The top gear ratio was estimated from approximate loading and torque requirements, and these two figures were then used to generate the internal gearbox ratios and the overall gear ratios for the engine. In order to get a more accurate estimation of the torque requirements, a torque calculation spreadsheet was produced, which enabled us to assess the total axle torque, the rear axle torque, the drive pinion torque and the torque from the wheel slip. This gave us some idea of the strains on the gearbox.

3.2 ENGINE MOUNTING FORCE ANALYSIS

Most of the force and element analysis was undertaken by the chassis subgroup. However when the engine mountings were designed, it became vital to undertake a reaction force analysis to determine whether the mountings could withstand the stresses applied by the engine and rear axle. Some estimations were required, but the final design is adequate to withstand all applied stresses. Further analysis will be required in order to determine the crash capabilities of the mountings.

3.3 INTAKE FLOW ANALYSIS

Because of the 20mm restrictor required by the SAE rules [2], the area around the restrictor must be designed to provide the maximum possible flow, so as to make the best use of all available air. Using the principles of fluid mechanics, the design of the intake system must be optimised. We wish to maximise flow rate and minimise turbulence, stagnation and separation of the flow, whilst keeping within the given spatial constraints. The reason for maximisation of the airflow is to increase the power provided to the engine by fuel combustion. Another important consideration was the equal distribution of the vaporised fuel and air mixture; this ultimately led to the development of a conical plenum and tuned length runners. This system enables the fuel and air mixture to be equally divided amongst the four cylinders, ensuring the maximum performance and efficiency of the engine.

3.4 CALCULATION OF DIFFERENTIAL BEARING LOADS

It is vital to make and appropriate choice of bearing for the given loading conditions. If the bearing chosen is not strong enough to withstand the applied forces, then it or its housing may fail. On the other hand, weight is a primary concern for the car as a whole, so if the bearing selected is larger than required, it will add unnecessary weight to the car. Hence a compromise between weight and strength has been assessed and a decision has been made concerning these two important parameters.

3.5 FUEL TANK VOLUME ANALYSIS

Because of the restrictions placed upon the car by SAE, it is important that the total volume of the fuel present, not only in the fuel tank, but in the fuel lines and hoses connected to the tank, is known at all times. An extensive analysis of the fuel volume was carried out using an excel spreadsheet, which is capable of being modified as the fuel tank design changes.

4. **TESTING**

4.1 ENGINE TESTING

The engine is currently undergoing comprehensive testing and analysing for all possible conditions and stresses, to ensure the behaviour of the engine can be predicted accurately. Specifically, the testing will measure and maximize the performance of the engine over a range of speeds; assess and optimise the gear ratios; and determine the slowest engine speed maintainable at full open throttle (in order to maximise fuel economy).

4.2 RESULTS

The results of this project can be seen in the finished designs and constructions of the power-train components.

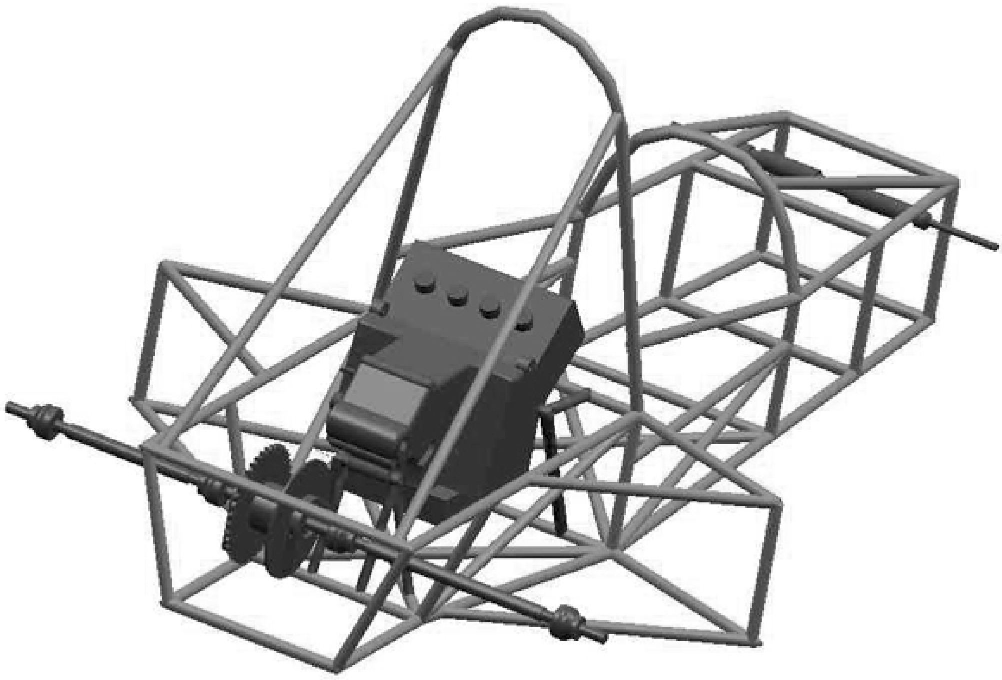

Figure 1

5. **CONCLUSION**

Although much of the project has already been accomplished, there remains a large amount of work that is yet to be undertaken. Over the next few weeks, the testing of the engine will be completed, as will the construction of the engine mounts, rear axle and the fuel tank. After the engine is running satisfactorily with a single carburettor then should time permit, a fuel injection system will be implemented. When construction of the power-train, chassis and suspension has been completed, the car will be field tested, then raced at the Formula SAE Australasia Competition, to be held in early December.

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- Adelaide University, Department of Mechanical Engineering
- Jap Motorcycle Dismantlers
- Everlast Mufflers
- Zexel Torsion

7. REFERENCES

[1] Honda, Giken, Kogyo, Kabushiki, Kaisha, "Honda Shop Manual CBR600Fx", Honda Motor Company Ltd., (1998)

[2] Society of Automotive Engineers, "Formula SAE Rules", Society of Automotive Engineers USA, (2001)

8. APPENDICES

No appendices will be attached to this report, due to space restrictions.