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THE ELECTRONIC CONTROL IGNITION AND FUEL INJECTION SYSTEM FOR FORMULA STUDENT RACER ENGINE

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1. Introduction

At the University of Maribor Formula S is very a popular project. Our Formula S team conceives, designs, fabricates and finally competes with a small formula-style racing car. Now we finish our second car for participation on the Formula Student Competition, which will be held this summer again in Great Britain. The participating cars and the teams are judged in a series of static and dynamic events. All events are scored in order to determine how well both the team and the car perform. The organizer of Formula Student prescribes the basic car requirements as well as the technical rules. The rules regarding the car frame and engine are defined so that the knowledge, creativity and imagination of the students and their mentors are challenged.

Our project Formula S offers an outstanding experience for young engineers in a meaningful engineering project as well as the opportunity to work in a dedicated team. Some interesting aspects of the Formula S project, team and racing car at University of Maribor will be briefly presented in this paper. Attention will be mainly focused on the air and fuel supply system for the engine.

2. Background of Formula S project

The Formula S project is kept alive by the Formula S team since the year 1999. The team consists of two mentors and approximately 10 students, which enter and leave the team in dependence of their study stage. The duty of the mentors, which work completely voluntarily, is to organize and to control all activities regarding the project. At the beginning of every new school year, they have to put together a new team from the best students, which have a wish to do serious work in the group. Namely, once a member of the Formula S team, the student must respect the rules and regulations of the team. All team members know in advance that the path from the ideas, Figure 1, to the final product requires a lot of time and hard work of every team member. Their motivation is the challenge of competition, good reputation and some benefits related to their study.

Another important duty of the mentors is to animate the university staff since a wide support from the faculty influences significantly the motivation of the students. Additionally, one often needs rooms and different laboratories and to some extent also some financial support.

The main financial support, however, especially in a form of needed material or parts, we obtain from our sponsors - many companies spread all over Slovenia. Clearly, the sponsors can be most efficiently animated on the basis of good previous results. Thus, it is quite important that the first (low-budget) results are as good as possible.

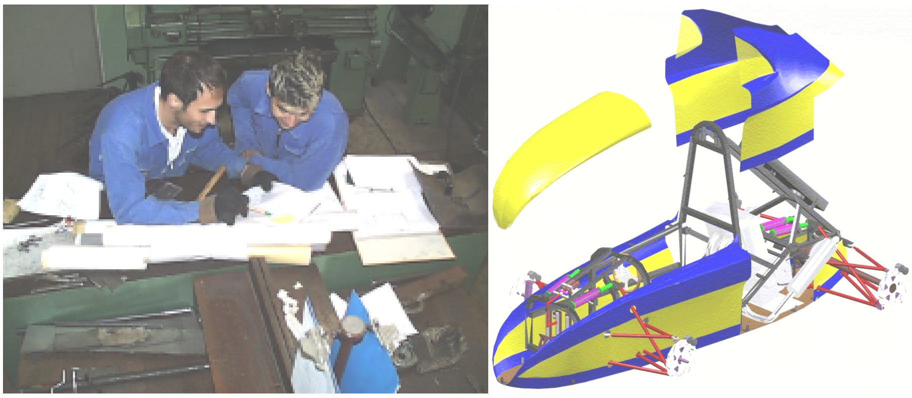

Figure 1. The birth of the idea and computer modelling

Once this is achieved, enough time has to be invested into own promotion at the faculty, at the corresponding ministry and at the companies. For example, the first price for an European team in the year 2000 we won with our first yellow-blue car, Figure 2. This good result was promptly used for promotion of our Formula S on different exhibitions. Figure 2 illustrates such an situation where the company managers admire the new design of the car.

Figure 2. Our winner Formula S in year 2000 and the prompt promotion of the new design

The new design, Figure 3, will represent a completely new car – from the engine, frame and transmission to the shell and painting. This job requires a lot of hard work, knowledge, creativity, and imagination of the students and mentors.

Figure 3. Our two Formula S cars

3. General requirements and our engine modification steps

The organizer of Formula Student determines the basic car requirements as well as the technical rules. Great importance is attached to safety of the driver. Furthermore, the competition teams also have to consider the general design requirements, chassis rules, crash protection, drivetrain and engine limitations. Some engine limitations are briefly outlined in the following.

The engine to power the car is a four-stroke piston engine with a maximal displacement of 610 cm^3. In order to limit the power capability of the engine, a single circular restrictor is required in the intake system between the throttle and the engine. All engine airflow passes through this restrictor of 20 mm diameter for gasoline-fueled cars. The only allowed sequence consists from a throttle, restrictor and engine. The car is equipped with a muffler in the exhaust system to reduce the noise to an acceptable level that is less than 113 dBA measured at the distance of 0.5 m from the end of the exhaust outlet. The engine must be operated with 94 and 100 octane-unleaded gasoline without any additives. All gasoline cars must be equipped with a fuel tank having a volume of no more than 7.57 litres.

Taking into account the above-mentioned requirements, our basic choice was made for the motorcycle Honda CBR 600 F engine. This is an inline, four cylinders, four stroke engine with integral six speed, sequential change gearbox, with displacement of 599 cm^3, with maximal power output of 69.4kW at $13200min^{-1}$ and maximal torque of 60.3Nm at $10000min^{-1}$.

To meet the imposed requirements according to the competition rules, some engine modifications of the basic Honda 600 F engine are unavoidable. A lot of this investigation related to this task falls upon the engine setup, before the engine is built into the car.

It is clear that by using a restrictor on a carburettor engine, the maximum power reduces rapidly. In our first car we could use 4 restrictors (this is allowed for a rocky (first-time) team) and 4 original carburettors from Honda and we obtained about 33kW only. From now on we have to use only one restrictor - all engine airflow must pass through one restrictor of 20 mm diameter.

In order to increase the power, we decided to replace the carburetion by a multi-point fuel injection system. This is quite a difficult task requiring:

- (i) to acquire an appropriate open Electronic Control Unit (ECU) with corresponding software so that it is possible to program it according to our requirements,
- (ii) to acquire suitable sensors that will deliver the needed engine characteristics,
- (iii) to design and finish by ourselves a suitable intake manifold, using the basic mechanism of intake manifold “tuning” and considering our requirements,
- (iv) to design and finish by ourselves an appropriate fuel supply system with some selected standard elements,
- (v) to establish the connections engine-sensors-ECU-laptop computer,
- (vi) to establish electronic control of ignition and injection parameters in dependence of instantaneous engine operating regimes.

Additionally, because of the limitations of maximal fuel tank volume, which should suffice for the whole route at the competition in England, it is also important to reduce fuel consumption as much as possible.

4. Our design of intake manifold and multipoint fuel injection system

In general, the intake runners used with multipoint fuel-injection system conduct only air; the fuel is discharged directly before the intake valves. This configuration offers greater latitude in intake manifold design. The basic mechanisms of intake manifold “tuning” are:

- (i) the geometry of the manifolds has an effect on the frequency and amplitude of the pressure waves issuing from them as noise; large plenum volumes can provide resonance effects for improved cylinder charging in certain engine-speed ranges,
- (ii) short induction runners furnish high output, but at the cost of sacrifices in low-end torque, while long induction tracts have an inverse effect.

For our construction we considered the general guidelines illustrated in Figure 4, [Bauer, 1999]. In this figure it is clearly shown, that the length of the effective intake-runner decreases with increasing the engine speed. Because of the fact, that our engine mainly operates at higher engine speeds, it is clear that the length of the induction-runners has to be as small as possible.

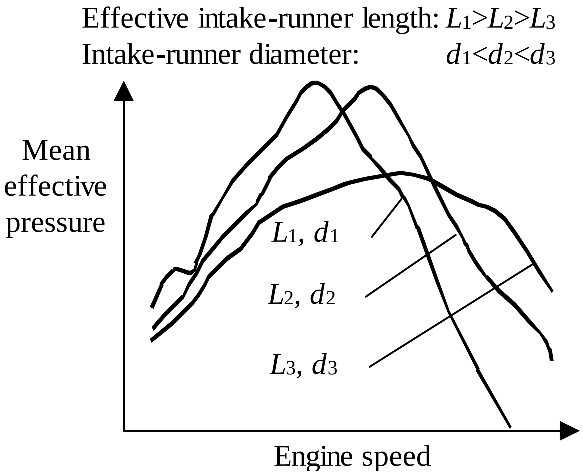

Figure 4. Mean effective pressure as a function of engine speed for 3 different lengths

Clearly, it also has to be kept in mind that intake manifold together with the engine has to be mounted into the car. At the time we have some different designs of intake manifolds, which are now in the phase of numerical investigations with AVL package BOOST and FIRE. Till today, it seems that the best results gives the intake manifold, shown in Figure 5. This intake manifold is composed from air filter, throttle, restrictor of 20mm and the corresponding intake-runners, which are the same length measured from the small "plenum" to the cylinders. Figure 5 also presents the assemblage of the intake manifold together with the engine into the frame of our second car.

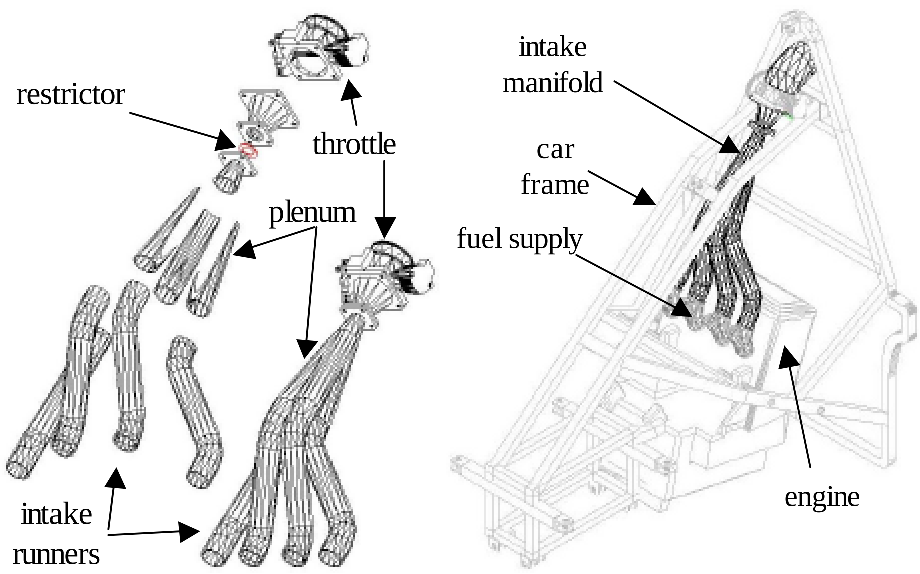

Figure 5. Our design of intake manifold

The position of fuel supply system, especially the injectors, is also evident from Figure 5. Two basic rules have to be applied when choosing the location of an injector:

- it must be aimed as straight down the center of a port as possible and
- it should discharge at a point, where air velocity is at or near it's highest.

The injector angle with respect to the inlet port should be as shallow as possible; consider 20^o the maximum.

These injectors are determined in two simple ways: on the basis of mass flow rate of air and from the desired power [Heisler, 1995].

Mass flow rate of air $\dot{m}_a$ through the intake manifold is

$$\dot{m}_a = \dot{V}_a r_a = \frac{n}{60}\frac{V_h}{2} r_a h_v \tag{1}$$

where $\dot{V}_a$ is the volume flow rate of air through the intake manifold, r_a is the air density in the intake manifold, n is the engine speed, V_h is the engine displacement and h_v is the volumetric efficiency. Knowing the mass flow rate of air, the mass flow rate of fuel can be calculated as

$$\dot{m}_f = \frac{\dot{m}_a}{14.7} \tag{2}$$

On the other hand, if we start from the simple calculation based on expected power

Pounds of fuel per hour per injector = 0.55 expected bhp/number of injectors

we obtain the necessary injector output fuel flow.

5. Engine management system

At the time we are combining a donated open Electronic Control Unit (ECU) with a new intake manifold. This Haltech E6 ECU with corresponding software enables engine management related to the multipoint fuel injection and fully electronic ignition systems, Figure 6.

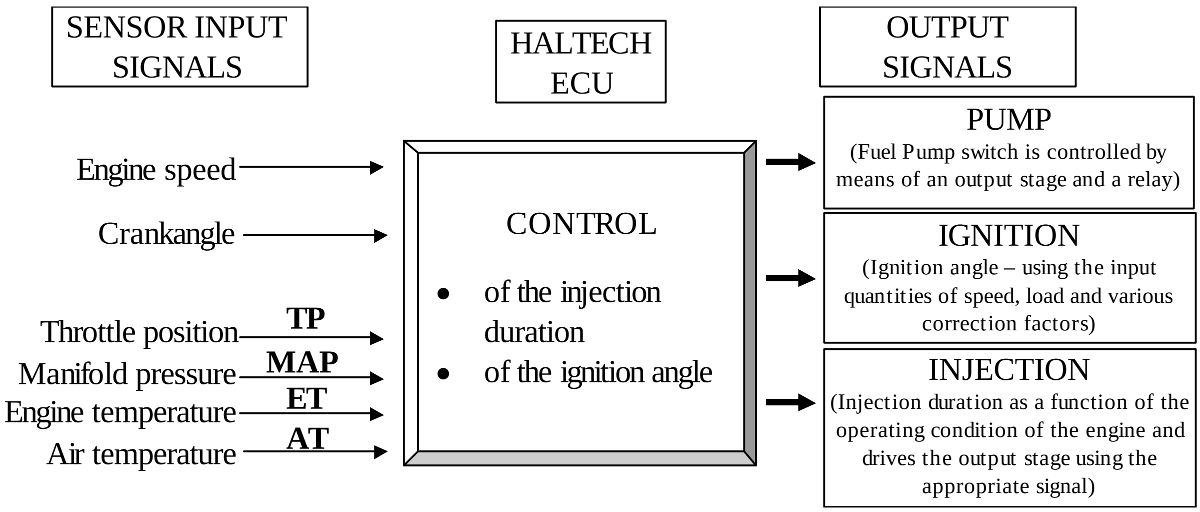

Figure 6. Engine management with Haltech E6 ECU

This control unit is an open unit so that it is possible to be programmed according to our requirements. The primary control variables are engine speed, load factor, manifold pressure and air temperature as well as engine temperature. All necessary components and sensors are dimensioned, selected or manufactured by the team and integrated on the engine together with the Haltech E6 ECU. The manifold sensor is mounted on the engine bay firewall. The coolant temperature sensor is located on a suitable position on the engine, which allows the hole and thread to be machined and which gives access to the coolant stream. The inlet air temperature sensor is designed to prevent heat soak because the sensor element protrudes into the air stream away from the manifold wall. The throttle position sensor measures the amount of throttle shaft rotation at the throttle body. The programming of the ECU is done using a laptop connected with the engine on the test stand in our laboratory.
The Haltech E6 ECU is a fully programmable fuel injection computer with outstanding possibilities allowing precise control of fuel delivery under all conditions. The E6 also doubles as a fully mappable ignition timing computer so that the user is able to fully map the ignition timing precisely through the

rev range. Consequently, the exact timing required to obtain optimum performance is applied in every rpm and load range. Many correction factors are available to the user such as cold start prime, warm-up and many more.

After all necessary connections are made and the installing software is installed, at first we have to check the engine data in order to verify whether the engine sensors behave reasonable for a stopped cold engine. Furthermore, we have to set the identification parameters to suit our Honda engine. Our main programming is related to the fuel and ignition maps to suit different manifold pressures and different engine speeds when the engine is running. All other options and correction maps are used only for correction and further improvement of the engine performance. In this way it is possible to set the cold start prime function, the fuel coolant map, the ignition coolant map, the cut off fuel on deceleration function and so on. The cold start prime function gives the engine the initial burst of fuel it needs to start at cold start. The fuel coolant map controls the addition of fuel required when the engine is not at operating temperature. The ignition coolant map controls the extra ignition timing required when the engine is not at the operating temperature. The cut off fuel on deceleration function will shut off the fuel to the engine when the engine is decelerating and is at more than idle speed control. The E6 ECU uses three correction maps to automatically compensate for changes of battery voltage and in inlet air temperature. Generally, the engine will need leaner fuel mixtures and more retard ignition as the air temperature increases.

This E6 ECU we already used with some non-optimized intake manifold and the results were rather satisfactory. Therefore, we hope that the new intake manifold will deliver even better results.

Acknowledgements

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