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DESIGN AND IMPLEMENTATION OF THE AEROBATIC FUEL SYSTEM OF THE M60 ENGINE

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Abstract

The paper deals with the specific modification of the M60 two-stroke engine so that the engine can be used in aerobatic conditions. In the introduction of the paper, the basic theory concerning piston two-stroke engines, the principle of operation of this engine, and the analysis of individual fuel systems is first discussed, with a focus on fuel injection systems and their components. Furthermore, the preparation of the fuel mixture is characterized together with the factors affecting it and also the basic characteristics of the engine control unit. In this way, the reader will gain the knowledge necessary for a better understanding of the following chapters. The motivation is to find a way to modify the non-aerobatic engine for the needs of aerobatic flight, and this modification includes a number of important advantages over the original fuel system design mentioned in the paper. At the core of the paper, we discuss the design of the fuel system, including important modifications, and also the practical implementation of this fuel system on the engine mentioned above. At the end of the paper, we evaluate the results of the work achieved by changing and modifying the fuel system on the M60 engine, including the achievement of the set objectives.

Keywords

Piston engine, Carburettor, Direct injection, Indirect injection, Mixture preparation, Two-stroke engine, Intake manifold, Fuel system,

1. INTRODUCTION

Technical developments have enabled advances in all areas of aviation, leading to developments in reciprocating internal combustion engines as well. The high demands associated with aerobatics have also been transferred to the technical advances in aircraft engine fuel systems. It is this topic that is addressed in our paper, which aims to design and implement an aerobatic fuel system for the M60 engine.

In addition to the main objectives, sub-objectives are also elaborated in the paper, which enables progress towards the fulfilment of the main objectives. Motivation for us is the work on the piston engine, the practical implementation including the design and the possibility of creative thinking. The aim of the work is to rebuild the original fuel system, which did not meet the requirements for aerobatic flight, and to design a new one that would meet the requirements.

The paper discusses the problems of individual fuel systems, including important components. Attention is also given to the preparation of the fuel mixture and the factors affecting it. The described issues are important for further elaboration of the work. The main part of the work consists of the preparation of the design of the aerobatic fuel system as well as the actual practical implementation of the M60 engine. The paper describes the solution of problems and complications that occurred during the implementation.

2. OPERATING PRINCIPLE OF A TWO-STROKE ENGINE

More four-stroke engines than two-stroke engines can be found in today's aircraft piston engines. This does not mean that two-stroke piston engines have disappeared completely. The choice of the four-stroke engine in the aviation sphere is linked to the advantages such an engine brings. Considering the objectives and the nature of this paper, it is the issue of two-stroke engines that will be discussed in this chapter.

2.1. Two-stroke engine cycle

The two-stroke piston engine, as the name implies, operates in two periods, so the piston performs exactly two strokes. Unlike a four-stroke engine, the entire working cycle is completed in one turn of the crankshaft, but the cycle is still made up of intake, compression, ignition combined with expansion and finally exhaust. These four processes happen in just two strokes of the piston. [1]

2.2. Basic characteristics of the M60 engine

The M60 engine was designed and manufactured in the 1990s by Aeromot Brno. It is a reciprocating two-stroke four-cylinder engine with opposed cylinders with a power of 58 kW (kilowatt), i.e. 80 HP (horsepower). The fuel system consists of a pair of diaphragm pumps that provide fuel delivery from the tank. The pumps supply fuel to two float carburettors which are mounted on top of the engine near the diaphragm pumps. Each carburettor delivers fuel through a common intake manifold to the two cylinders. There are a total of two throttle valves in both intake manifolds below the carburettors, which are operated manually by means of a common throttle rod. Flushing and filling of the cylinders are handled by a sleeve valve through the inlet and exhaust ports. With a power output of 58 kW, the engine operates at 2250 rpm (revolutions per minute) - propeller speed. However, the recommended cruise power is 40 kW and 2000 rpm. [2]

3. FUEL SYSTEMS

Fuel systems are a complex system of delivering fuel from the tank to the engine cylinder so that the engine runs continuously and efficiently over a specified speed range. Efficient engine operation depends on the proper preparation of the fuel mixture. [3]

The preparation of the fuel mixture is provided by special equipment. With these devices, the required amount of air and fuel is supplied to the cylinder so that the engine runs continuously under specified conditions. There are several types of fuel mixture preparation equipment, which we will describe next. [3]

3.1. Carburettor

A carburettor is a device for preparing a mixture of air and fuel. It is an evolutionarily older type of mixture preparation device that is less frequently used nowadays and is being replaced by more modern injection devices. However, the carburettor still appears in small engines with lower power outputs as it is a cheaper and simpler mixture preparation device. [4]

3.1.1. Diaphragm carburettor

In principle, the diaphragm carburettor is no different from other carburettors. The difference lies only in the mechanism for maintaining the fuel level in the fuel chamber by means of a diaphragm. This diaphragm is flexible and folds due to the pressure difference. The diaphragm is connected to the needle valve by a lever mechanism. In the event of a vacuum in the fuel chamber caused by the fuel being drawn into the mixing chamber, the diaphragm will fold to the fuel chamber side due to the pressure difference in the fuel and air chambers. The deflection of the diaphragm is transmitted via a lever mechanism to the needle valve which begins to discharge fuel into the fuel chamber. This causes the pressure in the fuel chamber to rise, the chamber pressures equalize, the diaphragm returns to its neutral position and the needle valve closes due to the action of the spring. When the carburettor is working, the diaphragm is continually moving, and the valve accordingly lets through the necessary amount of fuel. [5]

Such a diaphragm carburettor can also be used for aerobatic purposes, however, it is not used much nowadays. It can still be found on older aerobatic aircraft. Thanks to the diaphragm mechanism, the fuel supply to the fuel chamber and the operation of the carburettor are ensured, independently of the engine or carburettor position. [6]

3.2. Fuel injection system

Due to the more demanding requirements placed on engine economy, fuel injection is nowadays used, which allows for more even fuel dispersion, a more homogeneous mixture, better fuel metering and reduced fuel consumption. There is also no need to worry about carburettor priming and the necessary carburettor heating. The injection also puts less strain on the environment, as combustion is more perfect, resulting in less harmful substances in the exhaust gases. [1, 7]

As we focus on aircraft piston engines, it is important for us to ensure smooth operation of the engine, even when changing its position. However, this requirement cannot be met in piston engines with a conventional float carburettor (the exception is the use of a diaphragm carburettor). On the contrary, the fuel injection system allows the engine to run continuously even when the engine is repositioned, but there are other conditions that must be met. [6]

3.2.1. Direct fuel injection

If the fuel is injected directly into the cylinder, we speak of direct injection. This solution is very efficient in terms of performance as the fuel is sprayed directly into the combustion chamber and there are no hydraulic losses. On the other hand, direct injection requires an elaborate system to inject the fuel under high pressure. This pressure is needed to best disperse the fuel in the air in the combustion chamber. However, such a solution is considerably expensive and difficult to maintain. [7, 8, 9]

3.2.2. Single-point fuel injection

Single point fuel injection is the first option to inject fuel into the intake manifold. Fuel is injected into the intake manifold from a single point via an injection nozzle. The location of the injection nozzle corresponds to the location of the carburettor, which means that the fuel is injected upstream of the throttle body into the air stream, with the injection nozzle positioned perpendicular to the base of the throttle body. The fuel is injected intermittently based on engine speed and pressure in the intake manifold downstream of the throttle body. In addition to these two quantities, other quantities such as the amount of air intake and the position of the throttle valve may be used. The amount of fuel injected is controlled by the time the injection nozzle is open and also by the fuel pressure. The fuel pressure supplied by the fuel pump must be constant. [9, 10]

The prepared fuel/air mixture flows through the throttle valve through the intake manifold to the intake valve. The intake valve then passes this mixture into the combustion chamber. On two-stroke engines, the prepared mixture enters the crankcase via a check valve in the intake manifold. As the name implies, this type of fuel injection means that the mixture is prepared equally for all cylinders with one common intake manifold. [1]

3.2.3. Multi-point fuel injection

The second option for indirect injection is multipoint fuel injection. This type is slightly more complex compared to single-point injection because each cylinder has one injection nozzle. The difference also lies in the location of the injection nozzles, which inject the fuel in front of the intake valve, i.e. behind the throttle body. Also different is the intake manifold, which is branched according to the number of cylinders in the engine and includes a fuel ramp that feeds fuel under pressure towards the injection nozzles that are located on it. The fuel is injected continuously or intermittently. The advantage of this type is better fuel mixture formation and uniform filling of the individual cylinders of the engine. [9]

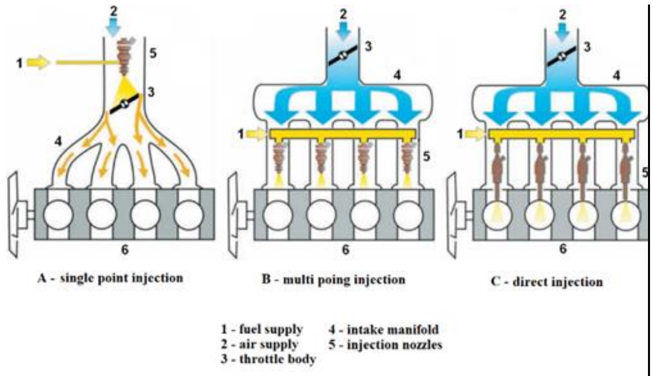

Figure 1: Comparison of different types of injection [11]

Fuel can be injected intermittently, in which case we speak of timed injection or electronically controlled fuel injection. The fuel pump feeds the fuel through a fuel ramp that distributes it to the injection nozzles and creates positive pressure. In this case, however, it is already electromagnetically controlled injection nozzles that can inject a precisely defined amount of fuel at precisely defined time intervals. The instruction to open and close the injection nozzle comes from the engine control unit, based on data such as the pressure in the intake manifold downstream of the throttle body, the engine speed or the intake air temperature. There are three types of timed injection into the intake manifold. Simultaneous, group and sequential injection. [9, 10]

3.2.4. <u>Simultaneous fuel injection</u>

The simultaneous injection is a type of injection where all injection nozzles inject fuel at the same time. Thus, for all cylinders, fuel is injected simultaneously, during each revolution of the crankshaft. Thus, fuel is injected exactly twice in one working cycle, with the injection rate being half of the total amount of fuel required. The injection also takes place when the intake valves are closed. The injected fuel remains in the intake channel until the intake valve is opened. [10]

3.2.5. <u>Group fuel injection</u>

Group injection consists of combining the injection nozzles into two groups. The number of injection nozzles within one group depends on the number of cylinders of the engine. In the case of a four-cylinder engine, there are two groups of two injection nozzles, in the case of a six-cylinder engine there are two groups of three nozzles. The injection nozzles within one group are connected in parallel and therefore open simultaneously. Within one group, fuel is injected into the cylinders whose operating cycles are consecutive. Injection into the intake manifold takes place once per complete working cycle and the injection nozzle opening time corresponds to the required amount of fuel. [9, 10]

3.2.6. <u>Sequential fuel injection</u>

In sequential injection, fuel is injected only into those cylinders which subsequently undergo an intake stroke. The injection nozzles operate individually depending on the position of the crankshaft and camshaft. The crankshaft position signal is not sufficient because the injection is linked to the opening of the intake valve, which opens only once during two turns of the crankshaft. The control unit is, therefore, unable to distinguish whether an intake or an expansion stroke is taking place. For this reason, the position of the camshaft must also be sensed, by which the control unit can already distinguish which stroke is involved. The length of the fuel injection corresponds to the required amount of fuel. Compared to the previous two injection types, this type of injection is the most complex, but at the same time the most sophisticated in terms of mixture formation, performance, consumption and exhaust gas ecology. [10, 12]

3.3. Injection system components

Compared to carburetted piston engines, fuel injected engines are more complex. Whether it's fuel injection into the combustion chamber or the intake manifold, both of these systems require equipment to ensure the continuous operation of the engine. In particular, we are talking about injection nozzles and fuel pumps. [10]

3.3.1. <u>Injection nozzle</u>

The injection nozzle is the end component of injection systems. It may be located in the intake manifold above or below the throttle body or in the immediate vicinity of the combustion chamber. It depends on which injection system it is part of. The closer it is placed to the combustion chamber, the more pressure must be applied to atomise the injected fuel, as it is necessary to form a homogeneous mixture. Control of the injection nozzles can be provided mechanically or electromagnetically. [15]

The mechanically operated injection nozzle is opened and closed by fuel pressure. The fuel pressure is provided by the fuel injection pump. The opening of the nozzle occurs when the fuel pressure causes the spring to be compressed, which extends the nozzle needle and allows fuel injection. The extended needle returns to the nozzle seat when the pressure drops. The mechanically operated injection nozzle can be used for continuous fuel injection. [15]

The electromagnetically actuated injection nozzle is more represented nowadays. Its opening and closing are controlled by the engine control unit by an electrical signal. Structurally, this type of nozzle is more complex than the mechanically actuated injection nozzle. It usually consists of a nozzle body with an internal solenoid winding, an electrical supply and a needle mounted on the seat. Unless an electrical signal is applied to the injection nozzle, the needle remains seated in the seat pressed by a spring and the fuel passage is closed. If an electrical signal is applied to the solenoid winding, the needle is raised and fuel flows through the gap in the seat. [10]

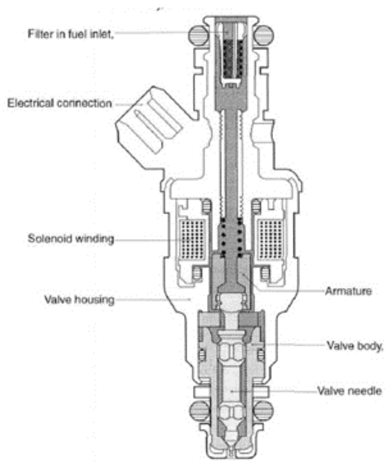

Figure 2: electromagnetically controlled injection nozzle [14]

3.3.2. The fuel pump

Fuel pumps work by delivering fuel from the tanks to the engine. They are therefore a very important part of fuel systems. For piston engines with a carburettor, diaphragm pumps have usually been used. These are pumps with a mechanical drive from the engine itself, which were used to deliver fuel from the tanks to the carburettors. [15]

In addition to mechanical pumps, there are also electric pumps. They differ from each other with regard to the required pressure of the fuel to be supplied and there are therefore several types. Typically, electric pumps are used to supply fuel to indirect injection nozzles. [15]

The design of the electric fuel pump consists of three parts. The connecting lid includes the electrical connection, the check valve and the fuel inlet. The check valve maintains the fuel pressure even after the pump has been switched off. This prevents the formation of bubbles due to increased fuel temperature. The pump's electric motor consists of a system of permanent magnets and armature, which are designed for the required amount of fuel to be conveyed at the specified system pressure. The third part is called the pump part. Both the electric motor and the pump section are housed in a common casing through which the fuel flows. The fuel flow provides their cooling. The main part of the pump section consists of an impeller on the shaft of the electric motor. By rotating the impeller, fuel is drawn from the tank and the necessary pressure is built up. Exceeding the maximum pressure is regulated by a special valve at the pump outlet. [10]

Depending on the type of injection system and its fuel pressure requirement, electric fuel pumps are divided into single-stage or two-stage. Alternatively, two single-stage fuel pumps can be used in succession. The pumps may also differ from each other in their pump section. They are divided into positive displacement and vane pumps. [10]

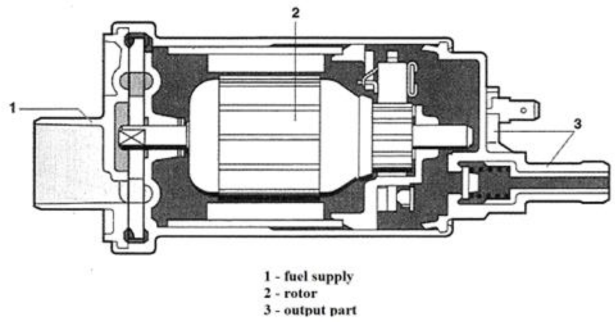

Figure 3: Fuel pump driven by electric motor [10]

4. MIXTURE PREPARATION

In the preparation of the fuel mixture, we start from the basic theory of combustion. During combustion, the chemical energy of the fuel is converted into heat energy. Combustion of the fuel requires oxygen, which is supplied to the combustion chamber in the form of air. This mixture of fuel and air must be in the correct ratio for the fuel to be completely burned. The ratio of air to fuel is determined by calculation, according to the type of fuel that is used. In the case of spark-ignition internal combustion engines, 14,7 kg (kilogram) of air is required to completely burn 1 kg of fuel. Diesel engines are based on a different ratio. [10]

4.1. The stoichiometric mixture

A stoichiometric mixture is a term for a mixture for which a specified ratio is observed. For spark-ignition engines this ratio is 1:14,7. As long as the fuel/air ratio is maintained and the mixture is properly mixed in the combustion chamber, the fuel contained in the mixture can be perfectly burned. During combustion, the hydrocarbons contained in the fuel and the oxygen in the air are converted into carbon dioxide and water vapour. [10]

4.2. Excess air coefficient

The excess air coefficient is used in the preparation of the fuel-air mixture composition. This coefficient expresses the ratio of the amount of air actually supplied to the theoretical amount of air required to burn a certain amount of fuel perfectly. The coefficient is denoted by the Greek letter λ (lambda) and is equal to one for a stoichiometric mixture - $\lambda=1$. It is very important in the preparation of a fuel mixture and by it we can determine whether the prepared mixture is correct, lean or rich. If the mass of air drawn in is greater than the theoretical value, the coefficient of excess air is greater than one ($\lambda>1$). We refer to such a mixture as poor. Conversely, if the mass of entrained air is less than the theoretical value, the air excess coefficient is less than one ($\lambda<1$). We refer to such a mixture as rich because it has excess fuel. [10, 13]

4.3. Measuring the amount of intake air

There are several ways to measure the amount of air intake and this is done with fuel injection systems to create the correct mixture. The amount of air can be measured directly or indirectly. [10]

4.3.1. *Indirect measurement of air quantity*

In indirect air measurement, the amount of air itself is not measured, but is replaced by another parameter that determines the amount of fuel injected. This parameter can be, for example, the position of the throttle valve or the pressure in the intake manifold. In order to achieve the optimum mixture, multiple parameters are sensed. [10, 13]

4.3.2. *Direct measurement of air quantity*

Not only optimisation, but also stringent emission standards have required more precise ways of measuring the amount of air. Direct measurement of air quantity consists of either measuring the volume of air or its mass. Air quantity meters are located in the intake manifold. [10, 13]

4.3.3. *Influence of other parameters on fuel dosage*

Fuel dosing is primarily based on the amount of air. From their ratio the composition of the mixture is determined. However, other parameters such as engine speed, engine temperature or engine load also influence the fuel dosage. These parameters are also taken into account by the engine control unit to ensure optimum engine operation, correct consumption and exhaust emissions. [10, 13]

5. ENGINE CONTROL UNIT

The Engine Control Unit (ECU) is an electronic control unit that represents a complex system for controlling individual components or engine systems. [16]

A. Input data of the engine control unit

- Crankshaft sensor,
- Intake manifold pressure sensor,
- Throttle position sensor,
- Air quantity sensor,
- Lambda sensor and others. [17]

B. Engine control unit functions

- Electronic fuel injection,
- Mixture preparation,
- Ignition system including timing and advance ignition,
- Real-time monitoring and others. [18, 19]

C. ECU MASTER Ignition engine control unit

The MASTER Ignition ECU is a versatile control unit that can be used in several areas. The MAP sensor version of the control unit has an integrated intake manifold pressure sensor. The ECU MASTER unit's ECU functions allow programming of ignition advance control and injection timing for spark ignition engines with both induction and capacitive ignition. The included software program allows real-time monitoring and adjustment of individual engine parameters. We are talking about e.g. engine speed, intake manifold pressure, ignition advance, injection time, measured temperatures and other parameters or values. Adjustment using the software device consists of arbitrary ignition and injection settings The control unit has a number of inputs and outputs that can be used to monitor given parameters and adjust certain functions. [20]

6. OBJECTIVES

A. The main objectives

- Design of aerobatic fuel system for the M60 engine,
- Implementation of an aerobatic fuel system for the M60 engine.

B. Sub-objectives

- A brief introduction to the issue,
- Selection and summary of selected literature sources,
- Analysis of fuel systems,
- Characteristics of individual fuel systems,
- Comparison of selected fuel systems,
- Analysis of factors influencing mixture preparation,
- Characteristics of the engine control unit,
- Elimination of complications arising during implementation,
- Precision during implementation,
- Chronological photo documentation,
- Testing of the new fuel system.

7. DESIGN OF AEROBATIC FUEL SYSTEM FOR THE M60 ENGINE

Since the original fuel system of the M60 engine did not meet the requirement for aerobatic flight, it was necessary and our goal to design a new fuel system for this engine so that the requirement mentioned above was met.

7.1. Fuel system diagram

The fuel system is the supply of fuel from external tanks located e.g. in the wings towards the engine. It consists not only of the tanks themselves, but also of the pipe system through which the fuel flows towards the fuel injection pump. Usually the fuel system is also made up of a number of valves which provide, for example, venting or defueling. The requirement for fuel purity is also very important. For this reason, the fuel system also includes the fuel filter itself, or a system of several fuel filters, which trap unwanted impurities in the fuel as it travels to the combustion chamber. In particular, the injection nozzles of not only direct injection but also indirect injection are susceptible to fuel purity. [4]

7.2. The principle of operation

Such a theoretical design represents fuel delivery from two fuel tanks located in the wings of the aircraft. From these tanks the fuel is conveyed to the central fuel tank using a pair of diaphragm pumps, which originally served to supply fuel to the carburettors. Each diaphragm pump would draw fuel from its own tank. Before entering these pumps, the fuel would be filtered through a fuel filter so as not to damage the diaphragm pump itself and at the same time not to clog the lines or the central fuel tank. The central fuel tank would contain the fuel injection pump itself, or its suction basket, which would be located exactly in the centre of this tank. This would ensure the condition of continuous refuelling even when the position of this tank is changed. The fuel injection pump would supply fuel under pressure to the fuel ramp. Prior to entering the fuel ramp, the fuel would be filtered in a fuel filter so as not to clog the injection nozzles. Injection nozzles mounted in the fuel ramp would inject the required amount of fuel into the intake manifold ahead of the throttle body, based on instructions from the control unit. A mixture of fuel and air would be formed in the intake manifold. This mixture would enter through the intake duct towards the crankcase of the piston engine. The engine control unit is also an important part of this design. Although the control unit is not a direct part of the fuel system, it is essential to its operation. This control unit makes it possible to control the fuel injection electronically through the injection nozzles, based on the vacuum in the intake manifold and the engine speed.

7.3. Central fuel tank

The central fuel tank is a very important component of the aerobatic fuel system because it allows fuel to be pumped into the engine even when the engine position is changed.

A suitable option for us was a plastic round tank often used in the automotive industry as an expansion tank for the coolant mixture.

7.4. Fuel injection pump

The fuel injection pump is an important part of the aerobatic fuel system. It allows fuel to be pumped from the central fuel tank to the fuel ramp. In addition, it delivers fuel to the injection nozzles at a certain pressure so that this fuel can then be sprayed through the injection nozzles.

7.5. Indirect injection design for the M60 engine

The design of the fuel injection system was first created in AutoCad Inventor. AutoCad Inventor allowed us to create a 3D design of the fuel injection system, which made it easier to make further decisions before we made a non-reversible practical implementation.

7.5.1. <u>Intake manifold design</u>

For further use of the engine we count with the original throttle bodies. Based on the given dimensions and shape of the throttle body, we have designed an intake manifold consisting of a base of the same shape as the throttle body and a circular line. The intake manifold was shaped as follows (Figure 4), with the inlet portion being the fresh air drawn in from the propeller as shown by the arrows in the figures. The inlet duct situated in this way was a suitable option for us, especially because of the direct inlet of fresh air.

Figure 4: Intake manifold design

7.5.2. <u>Fuel injection design</u>

The next stage was the design of the injection system. This consisted of a single point injection system consisting of a pair of injection nozzles mounted in the intake manifold on one side and in the fuel ramp on the other side.

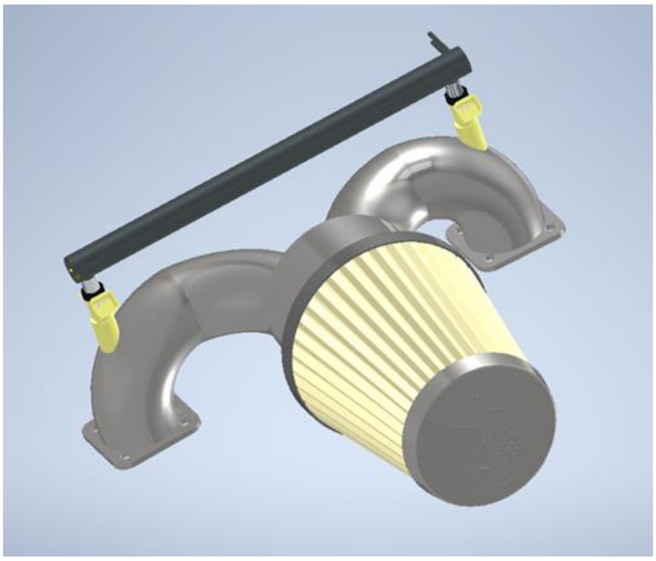

Figure 5: Design of the fuel ramp and injection nozzles in the intake manifold - front view [author]

8. IMPLEMENTATION OF THE FUEL SYSTEM

After a thorough elaboration of the design of the new fuel system, we started the actual practical implementation of the individual parts of the fuel system. Thus, we started from the design itself, which is described in the previous chapter. During the practical implementation, we encountered a number of complications that we had to resolve over time so that specific problems did not cause further problems, e.g. in the assembly of the individual components of the fuel system. The complications that arose during the implementation are described in the individual subchapters to which they relate. The manufacture of the components and the implementation of the fuel system is described chronologically, as we actually proceeded, step by step:

- Production of the intake manifold,
- Choosing the right material for the intake manifold,
- Production of the intake manifold base,

- Connection of the base to the knee pipe

Figure 6: manufactured intake manifold [author]

8.1. Installation of the intake manifold and subsequent modification of the design

We mounted the fabricated pair of intake manifolds on the throttle bodies instead of the carburettors. This was just a test fitting without the correct gaskets, so that we could assess whether the proposed alternative would be correct. However, this step showed us that the original design would have to be partially modified. Although the direction of the intake manifolds was suitable and had no obstruction, the intake basket in the original design would have been too large and could not be fitted, due to the upward protrusion of the propeller reducer. For this reason, the original design had to be modified.

8.2. Modification of the original design

The second alternative was to change the direction of the intake manifold. It was necessary to turn the intake manifold 180°, i.e. backwards. In addition, it was no longer possible to use one common air filter, as the distance between the intake manifold was too great. For this reason, we were inspired by the first alternative, to use just two smaller air filters. This modification of the design also brought one advantage. It was no longer necessary to deal with the complications associated with making a flange to hold the air filter common to both intake manifolds as originally designed.

Figure 7: Modification of the original design associated with a 180° rotation of the intake manifold [author]

8.3. Injection system

The fuel supply and injection into the intake manifold is provided by a number of components. These components did not need to be fabricated, such as the intake manifold, because they are components that we obtained by disassembling some automotive fuel systems. However, it was necessary to adapt them to our M60 engine according to the specified design.

- Fuel ramps and their modifications.

8.4. Injection nozzle inlet modification in the intake manifold

According to the established design, the intake manifold needed to be further modified. This modification consisted the creation of a suitable fitting for the injection nozzle in the intake manifold. Our aim was to create a perpendicular fit to the base of the intake manifold and at the same time to position this fit at the centre of the cross-section of the base so that the injection nozzle could inject fuel directly onto the throttle body. This modification summarized several steps:

- Manufacture of injection nozzle neck,
- Drilling a hole in the intake manifold,
- Inserting the neck into the intake manifold.

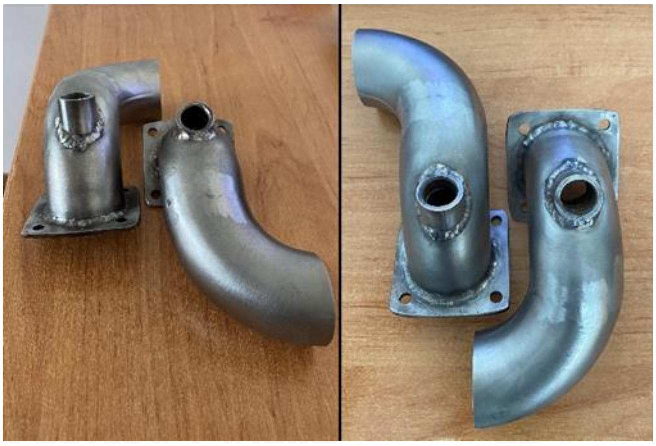

Figure 8: Modified intake manifolds [author]

8.5. Central fuel tank and its modifications

Based on the requirements we had already established for the central fuel tank in the design, we decided to purchase an expansion tank for the refrigerant mixture. When selecting the tank, we made sure that the inlet diameter was large enough so that we could insert the fuel injection pump into the tank and also remove it easily. The expansion tank from the Ford Transit we eventually purchased met these requirements. Along with the tank, a pressure cap was purchased for this tank up to a pressure of 1.45 BAR.

Following modifications:

- Adjustment of the inlet opening,
- Adjustment of the pressure cap.

8.6. Installation of individual fuel system components

The manufactured components were then mounted on the M60 engine. We started with fitting the intake manifolds to the throttle bodies. Because of the good tightness of the joint between these components, we had to use gaskets. The gaskets were made from purchased clingerite with a thickness of 0.5 mm. We cut the exact shape according to the original gasket. The holes were punched using a set of punchers. The intake manifolds were secured against the throttle bodies via 4 bolts along with spring washers and nuts. Air filters were fitted to the inlets of the intake manifolds and secured with clamps.

Injection nozzles were inserted into the throats of the intake manifolds along with a fuel ramp. We decided to use the fuel ramp and injection nozzles from a Fiat Punto. Wiring was run from the engine control unit towards the injection nozzles. The second fuel ramp and its injection nozzles from the Skoda Felicia remain part of the project as a backup component.

The central fuel tank was bolted to the engine stand. In total, this tank has four holes. Two holes of the same diameter are used to feed fuel from a pair of diaphragm pumps via fuel lines. We have not used the third hole yet and have blinded it for tightness. However, it could later be used to accommodate a bleeder valve. The fourth hole is located in the throat of the main bore and was used to create a fuel return line. In the event that the central fuel tank became full, fuel would leak back into the main tank through this hole via the fuel line.

8.7. Testing individual parts of the fuel system

Individual components have been tested and tried to see if they work properly.

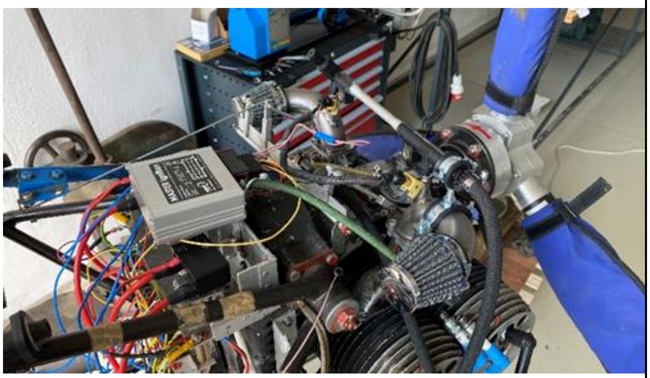

Figure 9: Complete implementation of the fuel system. [author]

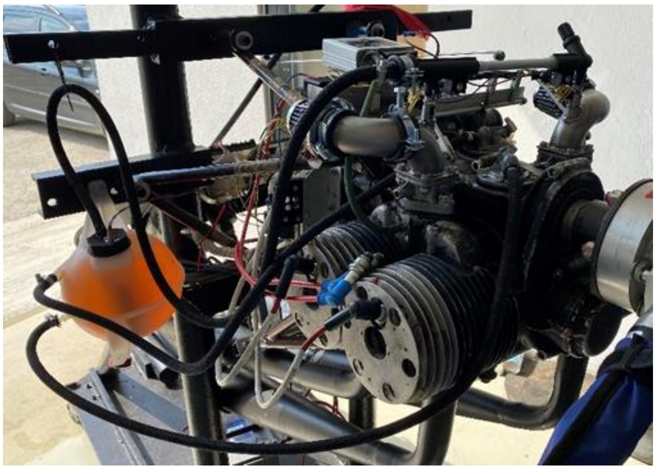

Figure 10: Complete implementation of the fuel system II. [author]

9. CONCLUSION

This paper has dealt with the design and practical implementation of an aerobatic fuel system for the M60 engine. The practical implementation was based on the developed design. In the theoretical part of the paper the problems of individual fuel systems were described, as well as the individual components of these systems.

In the introductory chapters, the basic characteristics of two-stroke engines were treated, including a brief description of the M60 engine. Subsequently, the issue of fuel systems, their distribution and comparison was treated. The mentioned fuel systems were discussed in detail and compared with each other by the method of comparison. As part of the treatment of the problem, the individual components of the fuel systems were described, and their various alternatives were considered. The alternatives were processed in the form of description, characterization and comparison. Attention was paid to the preparation of the fuel mixture. The factors influencing the formation of the fuel-air mixture and the possibilities of forming the fuel-air mixture have been discussed. The various methods have been described and categorized within the chapter. The theoretical part included the treatment of the characteristics of the engine control unit. The functions, advantages and disadvantages that the engine control unit brings were described. At the end of the chapter, the purchased engine control unit ECU MASTER was described.

The practical part was implemented on two levels. The first part was devoted to the design of the acrobatic fuel system. Within the design, the fuel system was described, including a schematic that discusses the fuel delivery from the tanks to the combustion chamber. Furthermore, the individual components that form part of the new fuel system were described. The design of the injection system was created in the software program AUTOCAD Inventor, which allowed the visualisation of the individual components of the fuel system. The created design became a necessary basis for further continuation in the practical part. The second part of the practical part consisted of the actual implementation of the fuel system. The realisation consisted of the creation of the individual components of the fuel system. The formation, modifications and complications that occurred during the practical part have been described within the chapters to which they relate. The manufactured, modified or purchased components were then fitted to the engine in the correct design. At the end of the practical part, the testing of the individual components was described. This established the functionality of both the individual components and the entire fuel system of the M60 engine.

We can consider that the task, together with the main objectives set, has been fulfilled. In the same way, we managed to meet the sub-objectives and respond to the complications that arose during the practical part. The incorporation of the new fuel system together with the engine control unit creates new space for its possible optimization or suggestions for additional components that would improve the engine's performance.

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