



INNOVATION OPTIONS FOR SELECTED SYSTEMS OF M60 ENGINE: EXHAUST SYSTEM AND ENGINE COOLING

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Abstract

Our article deals with the design and construction of a resonant exhaust system and cooling system for the M60 engine. In introductory part, the article provides the reader with a final overview of two-stroke. In the next chapter, the focus is only on the resonant exhaust system. The article of the reader informs about the basic principles of resonant exhaust systems and points out their fundamental effect on power, torque and fuel consumption. Subsequently, the article gets to the calculation of the resonant exhaust system and its execution. The final chapter deals with the cooling system and solves the design optimization of the shape of deflectors. Both in the previous chapter and in this chapter, it first deals with theoretical knowledge, design and subsequent production of deflectors.

Keywords

Two-stroke engine, Resonant exhaust system, Cooling system, Heat transfer, Optimization

1. INTRODUCTION

Today's progress has brought a new heart to the eyes of simple two-stroke engines, e.g. in the form of a control unit which controls the individual fuel and oil injection. This has significantly reduced the usability of these engines. Among other things, the engine gained a wider range of usable speeds with this system. However, our experimental M60 engine is a source of increased emissions not only due to grease lubrication, but also due to the leakage of fresh mixture into the exhaust system. This leakage was primarily solved by a resonant exhaust system, the pressure waves of which were to return the fresh mixture back to the combustion chamber.

In two-stroke engines, the exhaust system thus contributes significantly to the power, engine torque and consumption. Since the resonant exhaust system thus fundamentally affects important engine parameters, we decided to design our own exhaust system on the experimental two-stroke M60 engine. Our goal was to design a suitable exhaust system that will be used in travel mode, i.e. that we focused on a wider range of speeds used.

The next step was to design the cooling system of our air-cooled engine. By optimizing the design of the deflectors, we should improve the heat transfer from the engine heads to the surrounding atmosphere.

2. TWO-STROKE ENGINE

A two-stroke engine is a heat engine that is used to drive vehicles such as aircraft, cars, motorcycles, ships, etc., but also to drive various equipment and devices in construction, gardening, etc. It is a reciprocating internal combustion engine with non-stationary flow, which works in two such ways. The entire operating cycle takes place during one revolution of the

crankshaft in two ways. The first bar is intake and compression, the second bar is expansion and exhaust.

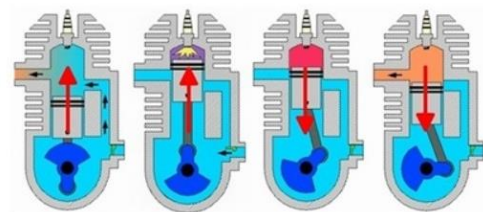


Figure 1: Engine operation. [15]

It is unique in its design simplicity, which is its great advantage. This makes it lighter and smaller and its production but also maintenance is easier. There are no valve lines in it, which are replaced in the two-stroke engine by individual channels, which are opened and closed by the moving piston itself.

The cooling of two-stroke engines is mostly air, as is the case with the M60 engine. The air-cooled engine is characterized by its ribbing, which aims to increase the area of heat transfer to the surrounding atmosphere.

3. EXHAUST SYSTEM

The exhaust system of two-stroke engines fundamentally affects the power, torque and consumption of the engine. The main requirements include: flue gas discharge into the surrounding atmosphere, ensure the required course of pressure waves and partial noise attenuation. Up to 1/3 of the engine power is involved.

The disadvantage of these exhausts is that they are not able to provide sufficient power over the entire engine speed range.

These are often tuned exhausts, with a narrow speed range at which we want to achieve the maximum possible performance. However, we can also focus on a wider range of speeds, then we choose this band at the expense of the maximum achieved power. The expansion chamber consists of different parts, each of which affects the power curve as well as the torque curve in its own way. It can consist of, for example from the elbow, the widening diffuser, the straight middle part, the tapering cone and from the outlet pipe.

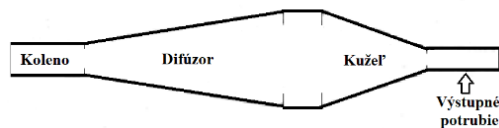


Figure 2: Parts of the exhaust system. [Source: Authors]

3.1. Principle of resonant exhaust systém

Initially, the engine burns, producing exhaust gases. The pressure in the combustion chamber is currently high and low in the exhaust pipe. As a result, the molecules will move extremely fast at the speed of sound through the resulting slit, creating a positive shock wave. The speed inside the exhaust pipe is much higher than the speed of sound in the open atmosphere [1].

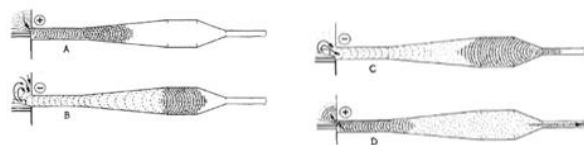


Figure 3: The course of pressure waves. [1]

The pressure wave moves in front of the gases. At first, the gases have a high velocity, but as the piston goes to the bottom dead center, the pressure drops and the gases slow down. The velocity of the gases is proportional to the pressure. However, the pressure wave continues to move at its speed of sound until it passes into the diffuse part. A positive shock wave is followed by a negative oscillation. This has a role in the resonant exhaust, slowing down the exhaust and thus reducing the amount of fresh mixture in the exhaust pipe. Also, this vacuum will reduce the pressure in the combustion chamber, which will allow a better supply of fresh mixture through the bypass channel. This wave does not push the exhaust gases back, it only takes away their energy. The negative wave helps to eliminate the positive wave [1].

The positive shock wave continues through the exhaust to the cone, where the pressure wave is partially reflected back into the engine cylinder. The wave bounces off and begins to travel back to where it must arrive before the piston closes the exhaust duct. By timing the reflected pressure wave correctly, we bring back the mixture that has left the combustion chamber together with the exhaust gases. A positive reflected pressure wave pushes the leaked mixture back. Proper timing must ensure that the bypass channel is already closed [1].

3.2. Calculation of the expansion chamber

For the correct function of the exhaust system, it is necessary to correctly dimension the individual parts. For the correct design of the exhaust system, it was necessary to find out the following data:

- The exhaust duct is open for 165 degrees
- Suction ducts are open for 152 degrees
- Exhaust elbow diameter D1 - 40mm

3.2.1. Tuned length

As the first dimension, the so-called tuned exhaust length. This length is from the inner edge of the exhaust duct (where it is covered by the piston) to the middle of the length of the tapering cone. Tuned exhaust length, calculated according to the authors [1]:

$$L_t = \frac{E_0 * V_s * 83,34}{N} \quad (1)$$

Where:

L_t – tuned exhaust length (mm)

E_0 - exhaust duct opening angle (°)

V_s – pressure wave speed (m/s) (1700 ft/sec (518m/s). [1])

N – engine speed

$$L_t = \frac{165 * 1700 * 83,34}{6000}$$

$$L_t = 46,75 \text{ in} = 1187,4 \text{ mm}$$

The calculated length of the tuned exhaust is 1187.4 mm. If we construct a rounded resonant exhaust system, this dimension will speak of the length of the center section axis.

3.2.2. Diffuser

The author proposes an optimal diffuser angle $A_1 - 8^\circ$. The choice of the diffuser angle will already significantly affect the performance curve of the motor and in this choice we must already focus on the desired result [1].

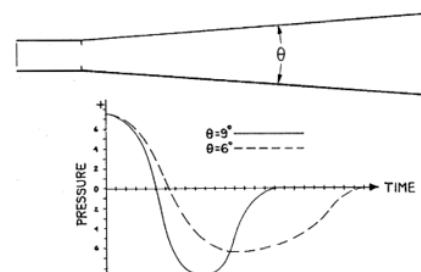


Figure 4: Diffuser. [1]

To meet our requirements, we decided to use a 6° diffuser angle. The engine has a high power, kt. we will not use. And so, at the expense of peak power, we will expand the power band.

We calculate the mean exhaust diameter according to the author [1]:

$$D_2 = \sqrt{6,25 \cdot D_1^2} \quad (2)$$

Where:

D_2 – mean exhaust diameter (mm)

D_1 – exhaust knee diameter (mm)

$D_2 = 100$ mm

$$D_2 = \sqrt{6,25 \cdot 40^2}$$

We choose the diffuser angle of 6° and the average exhaust diameter is 100 mm.

We calculate the diffuser length as follows:

$$L_4 = \left(\frac{D_2 - D_1}{2} \right) \cdot \cot(A_1/2) \quad (3)$$

Where:

L_4 – diffuser length (mm)

D_2 – mean exhaust diameter (mm)

D_1 – exhaust knee diameter (mm)

A_1 – diffuser extension angle ($^\circ$)

$$L_4 = \left(\frac{100 - 40}{2} \right) \cdot \cot(4) = 429 \text{ mm}$$

$$L_4 = 429 \text{ mm}$$

After fitting, the length of the diffuser is 429 mm.

3.2.3. Tapered cone

This part of the exhaust system tends to gradually narrow. A short cone with a large angle will increase maximum power, but the engine will lose power in the medium range. The standard exhausts of two-stroke engines do not cover the entire speed. A longer and slightly tapered cone expands the power range, and a sharper tapered cone is often a trade-off between range and maximum power [1] [2].

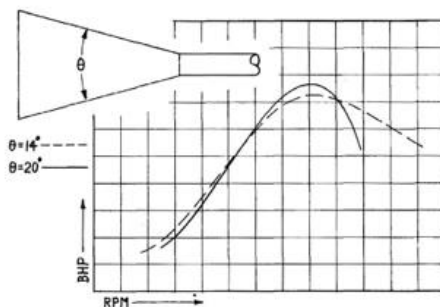


Figure 5: Tapered cone. [1]

According to the author, the angle A_2 from 14° to max. 20° . When we design a guide cone with an angle of 20° , the motor will give us high performance. However, if we exceed a given speed with this maximum power, the power will fail completely and the engine will appear as if it were in emergency mode, or as if the engine required us to shift to a higher gear. If we choose an angle, for example 15° , we will achieve a slightly lower maximum power, but after exceeding the given speed, the engine power will not drop so extremely and will maintain a certain power [1].

The constriction is in most cases twice the diffuser used in the expansion chamber. There we chose the angle $A_1 8^\circ$, so in the part of the guide cone we will use the narrowing $A_2 16^\circ$ [1].

Based on the selected angle, we can calculate the length of the tapering cone:

$$L_2 = \left(\frac{D^2}{2} \right) \cdot \cot(A_2/2) \quad (4)$$

Where:

L_2 – cone length (mm)

D_2 – mean exhaust diameter (mm)

A_2 – taper angle ($^\circ$)

$$L_2 = \left(\frac{100}{2} \right) \cdot \cot g(8)$$

$$L_2 = 355,76 \text{ mm}$$

The length of the tapered cone is 355.76 mm.

3.2.4. Theoretical cone length

We calculate the theoretical cone length as:

$$L_6 = \left(\frac{D_2 - D_3}{2} \right) \cdot \cot(A_2/2) \quad (5)$$

Where:

L_6 – theoretical cone length (mm)

D_2 – mean exhaust diameter (mm)

D_3 - outlet pipe diameter (mm)

A_2 – taper angle ($^\circ$)

$$L_6 = \left(\frac{100 - 24,8}{2} \right) \cdot \cot(8)$$

$$L_6 = 267,53 \text{ mm}$$

The length of the outlet pipe is 267.53 mm.

3.2.5. Exhaust elbow

The longer the exhaust elbow, the smoother the onset of power. It is recommended to choose a coefficient for calculating the length from 6 to 11. [1] Since we want to achieve a refined running of the engine in travel mode, but at the same time we do not want to lose a lot of power, we choose the value 8.

We calculate the knee length as follows:

$$L_3 = D_1 \cdot k_k \quad (6)$$

Where:

L_3 – exhaust elbow length (mm)

D_1 - exhaust knee diameter (mm)

k_k – coefficient for calculating the knee length (-)

$$L_3 = 40 \cdot 8$$

$$L_3 = 320 \text{ mm}$$

The length of the knee after fitting into the formula is 320 mm.

3.2.6. Exhaust length from the exhaust duct to the cone

Another dimension for the design of the engine is the length from the beginning of the exhaust duct, ie from the edge of the piston, to the beginning of the cone. We calculate it as follows:

$$L_1 = L_t - \left(\frac{L_2}{2}\right) \quad (7)$$

Where:

L_1 – exhaust length from piston edge to cone (mm)

L_t – tuned exhaust length (mm)

L_2 – cone length (mm)

$$L_1 = 1187,4 - \left(\frac{355,76}{2}\right)$$

$$L_1 = 1009,52 \text{ mm}$$

The length of the exhaust from the edge of the piston to the cone is 1009.52 mm.

3.2.7. Length of the middle part of the exhaust

We calculate the length of the middle part of the exhaust:

$$L_5 = L_1 - (L_3 + L_4) \quad (8)$$

Where:

L_5 – length of the middle part of the exhaust (mm)

L_1 - exhaust length from piston edge to cone (mm)

L_3 - exhaust elbow length (mm)

L_4 - diffuser length (mm)

$$L_5 = 1009,52 - (320 + 429)$$

$$L_5 = 260,52 \text{ mm}$$

The length of the average exhaust length after installation is 260.52 mm.

3.2.8. Outlet piping

According to the author, the outlet pipe has a diameter between 0.58 and 0.62 times the diameter of the supply pipe and its length is equal to 12 times its own diameter. [1] This part of the exhaust is more sensitive to changes in diameter than to changes in length. This calculation only brings us closer to the optimal solution, it is necessary to adjust it in our own measurements so that we achieve the best possible result.

We calculate the diameter of the outlet pipe as:

$$D_3 = D_1 \cdot k_v \quad (9)$$

Where:

k_v – coefficient for calculating the outlet pipe diameter (0,58÷ 0,62)

D_3 – outlet pipe diameter (mm)

D_1 – exhaust knee diameter (mm)

$$D_3 = D_1 \cdot 0,62$$

$$D_3 = 24,8 \text{ mm}$$

The straight pipe outlet after installation is 24.8 mm.

We calculate the length of the outlet pipe as:

$$L_7 = D_3 \cdot 12 \quad (10)$$

Where:

L_7 – outlet pipe length (mm)

D_3 – outlet pipe diameter (mm)

$$L_7 = 24,8 \cdot 12$$

$$L_7 = 297,6 \text{ mm}$$

The length of the outlet pipe is 297.6 mm.

When designing, it must be borne in mind that if the diameter is too long or the pipe is too long, both cases excessively limit the output of the resonant exhaust system. The temperature rise can be so sudden that the engine can overheat [1].

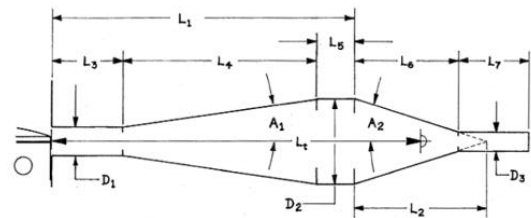


Figure 6:: Dimensions of the resonant exhaust system. [1]

3.3. Exhaust production and testing

The production took place in the following steps. Based on the calculation, we cut out individual parts of the exhaust from steel sheets, where we could not forget to subtract the length of the exhaust duct from the calculated tuned length of the exhaust. We continued by turning the individual parts. The exhaust elbow and outlet pipe had dimensions that could be purchased. We

subsequently welded the individual parts (welding - joining metal parts by heat).

We continued with the surface treatment, especially by grinding it, so that we had a perfect base for the surface heat-resistant paint, which is intended for the exhaust system. Usually, resonant exhaust systems are not surface-treated, but due to the fact that the experimental engine is not used as often and can also serve as a teaching aid and students will be able to touch it, we decided to surface-treat it.



Figure 7: Exhaust system production. [Source: Authors]

We also had to solve the exhaust mount, which cannot be fixed. The exhausts are attached to the engine with flanges and springs. In the next part, the exhausts are attached using silent blocks and other springs. Flexible mounting prevents fatigue of individual materials, whether the expansion chamber itself, the motor, but in our case also the stand.



Figure 8: Exhaust system installation. [Source: Authors]

4. COOLING SYSTEM

An internal combustion engine is a heat engine in which physico-chemical processes take place, during which energy is released from the fuel and high pressures and temperatures are created. Reciprocating engines use potential energy and thus hot flue gas pressure energy. Approximately 30% of the heat supplied is converted into useful work and up to 25% of the heat is removed in the cooling itself. The heat dissipated by cooling is loss-making, we do not get any work from it. However, it has an important role to play in ensuring sufficient heat dissipation from the thermally stressed parts of the combustion chamber to maintain proper operating temperatures. Much of the heat is removed from the walls of the cylinders and heads, and only a small part passes into the oil. In aviation, air-cooled engines are used to a greater extent. Their advantage is lower weight, very good reliability and less vulnerability. An air-cooled engine has statistically 20% fewer failures than a liquid-cooled engine [11].

4.1. Cooling design

With in-line reciprocating engines, we often encounter the problem of insufficient cooling of the rear rows of cylinders and heads. Our goal was to direct a sufficient amount of air flow to this area. We physically measured part of the engine and it was modeled in SolidWorks. In Inventor, we continued to design and shape the deflectors. We created several designs on an ongoing basis, which we simulated in the Autodesk CFD program, and gradually we got to the final version of the deflectors, which will solve the mentioned problem of rear cylinder overheating.

4.1.1. Object measurement and modeling

The first step in our work was to thoroughly measure the parts in which the cooling itself takes place. We decided to use only two engine cylinders for the simulation. Since the original deflectors were also designed, each pair of cylinders had its own deflector. Deflectors are a reflection of the mirror.

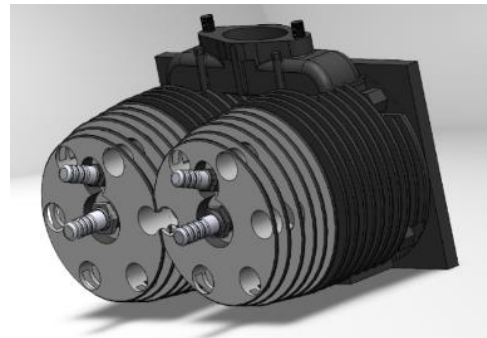


Figure 9: M60 engine heads. [Source: Authors]

4.1.2. The simulation

The simulation took place in three parts. And in the simulation of the engine itself, followed by the simulation of the deflector, kt. created by the previous engine owner and finally a simulation of the proposed deflector. The input data to the simulation were air velocity 50 m / s and temperature 21 ° C. In the shape of a deflector, we were limited by the space before entering the deflector, where the propeller is actually located.

a) Simulation of the original deflector

In this simulation, we created a deflector model created by the previous engine owner. The motor is currently used only on stands, to which the shape of the deflector itself tried to adapt. We see that although the author tried to keep the air supply to the engine as large as possible, the air did not have enough space around the engine and especially the deflector shapes were not smooth enough to ensure the necessary flow. In the critical part, behind the second cylinder, the flowing medium moved too slowly. As a result, very little heat was removed from this area, which caused the rear cylinder of the engine to overheat.

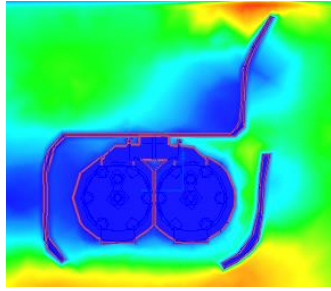


Figure 10: Simulation of the original deflector. [Source: Authors]

b) Simulation of the proposed deflector

Countless simulations preceded the final deflector. When designing it, we worked with various shapes, which we gradually adapted with small modifications. In the first stage, we had proposals, kt. they also consisted of several deflectors, which were to use the principle of the Bernoulli equation. However, this did not prove to be the right way to optimize the shape, so we returned to the two-part deflector. In order to ensure a sufficient amount of air and its sufficient speed in the headspace, we had to expand the input device. This proved to be the case with the first designs, and we continued to work only on optimizing the shape in order to direct the air to the problems of the part behind the second cylinder as much as possible. Continuous shape optimization eliminates the emerging air vortices shown in the figure. The proposed deflector is widened at the inlet, which should ensure a sufficient supply of flowing air. The shape tapers smoothly and directs more air into the space behind the second cylinder. By achieving smoother deflector shapes, the emerging air vortices were also alleviated.

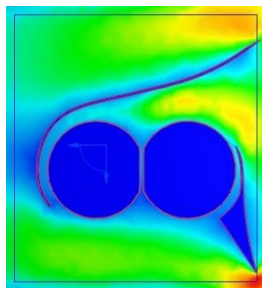


Figure 11: Proposed deflector. [Source: Authors]

In the resulting deflector, the shapes were optimized to such an extent that the velocity of the medium behind the second cylinder increased almost threefold compared to the original deflector. With the original deflector, we reached an average speed of about 10 m / s behind the second cylinder (area 3). With the new deflector, we reached a speed of 30 m / s.

Area	Flow rate (m / s)
1	1
2	50
3	10
4	20

Area	Flow rate (m / s)
1	20
2	65
3	30
4	30

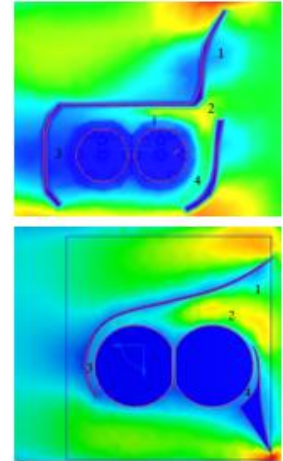


Figure 12: Original and new deflector. [Source: Authors]

Furthermore, it was possible to increase the speed at the entrance to the deflector (area 2), where the speed of the original deflector reached 50 m / s, the proposed deflector is 65 m / s.

4.2. Deflector design

After optimizing the deflector, we decided to test the correct dimensions by creating a paper template. The production of the designed deflector subsequently continued by firing the individual parts, creating technical holes for the spark plugs themselves and also for the carburetors.

We first placed the deflectors in place and then we spot welded them to verify their correctness, or to reveal some other shortcomings. After testing them, we went on to the welding itself. The deflectors are made of aluminum embossed alloy sheet, which we chose mainly due to its low density and low weight. The same steel sheet would be much heavier. And so we save fuel by reducing weight. With the right surface treatment, this aluminum sheet is corrosion-resistant and shows no signs of aging.

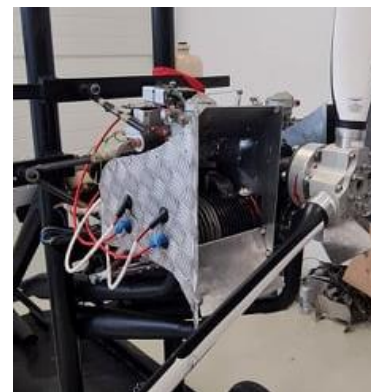


Figure 13: Installation of the proposed deflector. [Source: Author]

5. CONCLUSION

The article demonstrates the design and implementation of an exhaust and cooling system for the required power, consumption and torque of a two-stroke engine. We believe

that the harmonization of all systems, whether the exhaust, cooling, injection and oil systems, but also the ignition system, will return the favor of two-stroke engines to their users and will thus be used to a greater extent. The simplicity of these engines is also due to their design simplicity, which makes the engine lighter and smaller and its production but also maintenance easier.

The article explains the resonant waves and their influence on the motor parameters. The reader will learn how to design your own exhaust system, the individual parts and their dimensions affect the power and engine speed. It also documents the resonant exhaust calculation for the M60 experimental engine to be used in cruising mode. Another goal of the article was to optimize the shape of the deflectors, which in the original design caused overheating of the rear cylinders. The article compares the original deflector of the experimental engine M60 with the new designed deflector and acquaints the reader with the design optimization and simulations of the new deflector. The chapter ends with the production of deflectors and also shows the final deflector.

The result of the article are four resonant exhausts and two cooling system deflectors designed for the travel mode of the M60 engine, which contribute significantly to the proper functioning of the engine and keep its operating values and temperatures within the correct ranges.

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