https://doi.org/10.26552/ pas.Z.2022.2.19

DESIGN AND IMPLEMENTATION OF EQUIPMENT FOR PARTIAL USE OF COMBUSTION ENGINE EXHAUST ENERGY

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Abstract

The content of the diploma thesis was the design and implementation of equipment for the partial use of exhaust gas energy of the internal combustion engine and the possibilities of using this equipment in internal combustion engines. The aim of this work is to design a scheme and 3D model of the converter for energy recovery from exhaust gases based on magnetohydrodynamics, and also to provide scientific information and inform the reader as much as possible about the theory of magnetohydrodynamics and the use of these theories in energy recovery. The work provides scientific information in the field of hydrodynamics, magnetohydrodynamics of engines and emissions and in the practical part is designed and built magnetohydrodynamic converter which was one of the main objectives of this work together with key information from the researched area and their application to the converter.

Keywords

Magnetohydrodynamics, Hydrodynamics, Exhaust gases, Magnetohydrodynamic accelerator, Combustion engine, MHD

1. INTRODUCTION

Today, great emphasis is placed on themaximum use of energy resources due to the constant growth of the population and increasing demands on electricity, which is in contrast to the ever-decreasing supply of fossil fuels and non-renewable energy sources. For these reasons, the aim is to obtain new energy sources, increase the efficiency of existing sources or use the recovery of existing energy. This effort is reflected in all industries, including transport. Transport is also under great pressure from the environment and increasing environmental pollution due to the constant increase in air, car and shipping traffic. For small aircraft and cars, the internal combustion engine is the most widely used power unit. It is used in a wide range of vehicles. However, fuel combustion in these engines is quite imperfect. Only part of the energy supplied by the fuel during combustion is used for useful power and the rest of the energy goes unused. Much of the energy is released into the ambient air by cooling and exhaust. Additional losses are caused by the friction of the moving parts of the engine and only a small part of the energy is used, for example, to heat the cabin or drive the turbocharger. The generated waste heat can be used in many ways, for example for conversion into electricity or for other purposes. It all depends on the technology used. One such new technology is magnetohydrodynamics.

Magnetohydrodynamic (MHD) generators or converters are devices used to produce electricity in a relatively unconventional way. They use the passage of an electrically conductive substance through a magnetic field. Michael Faraday was already studying this phenomenon and in 1832 he tried to observe it. He performed an experiment in which he tried to measure the electric current generated by the saltwater flow of the River Thames in London in the Earth's magnetic field. [1] His experiment was not successful and many years after that it was not possible to build a functioning experimental facility. The turning point came in the 50s of the 20th century, thanks to the development of plasma physics and the development of materials for extreme temperatures. In many countries, intensive research has subsequently begun with great optimism. However, due to challenging technological problems, it was significantly subdued for several years, and only the United States and the Soviet Union continued to develop. In the 70's, there was a renewed interest in the operation of public transport generators in several countries, but nevertheless it was not possible to overcome all the problems and there was never a large commercial use.

To a lesser extent, research continues to this day, using new materials and technologies. The idea of the future is the use of public transport generators and converters as a source of electricity at the outlet of the fusion reactor. Another possible option is the construction of generators using the movement of seawater.

The subject of this work is the construction of a small functional model of public transport converter, which will work with the energy of hot gases in a magnetic field created by magnets. This is a very unconventional device.

The theoretical part of the work is devoted to a historical overview of existing technical solutions using the energy of hot gases or energy of exhaust gases and theoretical knowledge of magnetohydrodynamics. The experimental part of the work then describes the design of a 3D model of public transport converter and the design and construction of the model itself. The experimental part also describes the measurement and test of the functionality of the magnetohydrodynamic transducer model and the evaluation of the measured results.

2. INTERNAL COMBUSTION ENGINE AS A SOURCE OF PROPULSION

Most internal combustion engines used today are reciprocating internal combustion engines for liquid fuels. During the conversion of thermal energy into mechanical energy, thermodynamic processes take place, during which the state of the working substance changes, which in the case of internal combustion engines are exhaust gases generated by the combustion of fuel. The fuel is not fed to these engines continuously, as in combustion turbines, but periodically. This raises certain problems, such as the generation of nitrogen emissions from incomplete combustion. All reciprocating internal combustion engines operate with open duty cycles, ie at the beginning of each cycle we supply a new working fluid with the same initial thermodynamic parameters, which performs work in the engine and leaves with lower temperature and pressure.

The principle of operation of reciprocating internal combustion engines is the combustion of fuels directly in the cylinder of the internal combustion engine. A mixture of fuels with air, or only air, is sucked into the cylinder, depending on the type of engine. This is followed by a compression stroke, at the end of which the fuel mixture is ignited by a spark in the case of a petrol engine, or the fuel is ignited by the heat of compression in the case of diesel engines. The thermodynamic processes taking place inside the engine describe the theoretical cycles. These cycles are divided into explosive with constant heat combustion, equal pressure with constant pressure combustion and a mixed cycle in which combustion occurs partly at constant volume and partly at constant pressure

2.1. Petrol engines

Four-stroke petrol engines are engines for light liquid fuels, especially gasoline. They work on the principle of the Otto cycle, but the actual work cycle is different. In the first time of the operating cycle, the piston moves from the top dead center to the bottom and sucks a mixture of liquid fuel and air into the combustion chamber. This mixture does not form as easily as, for example, gaseous fuels. The efficiency of the heat conversion depends on the quality of the ignition mixture, because imperfect combustion occurs when the fuel is mixed poorly with air. This reduces the amount of energy gained that is contained in the fuel. In the second time of the cycle, the mixture is compressed (the temperature of the mixture reaches 350 ° C to 450 ° C), in the next third time the mixture is ignited by an electric shock and expands (temperature 2000 ° C to 2500 ° C). This time is also the only working time of the four-stroke engine. The fourth and final time of the cycle is the exhaust, in which the exhaust gases (temperature 800 ° C to 900 ° C), generated during combustion, leave the combustion chamber through the exhaust pipe without further use into the ambient air. One working cycle takes place during four piston strokes. This working cycle shows us the working diagram of the actual working cycle of the petrol engine.

2.2. Diesel engines

The diesel engine differs from the petrol engine mainly in the way of creating ignition mixtures. Only air is sucked into the diesel engine (first time - suction), which is then compressed (second time - compression), which causes heating (temperature 600 ° C to 900 ° C). The compressed mixture is injected with fuel, which ignites due to the temperature and expands (third time - expansion). Therefore, the compression ratio must be large enough for the compressed air to reach a compression temperature higher than the ignition temperature of the fuel. Subsequently, the exhaust valves are opened and the exhaust gases at a temperature of 600 ° to 700 ° are released into the air (fourth time - exhaust). The theoretical operating cycle of a diesel engine is shown in a mixed Sabbath cycle, but it also differs from the actual operating cycle.

The thermal balance of a diesel engine differs slightly from a petrol engine. The use of a mixed duty cycle increases the amount of energy converted to efficient engine operation. This can be seen in the diagram (Fig.4). With a diesel engine, the heat is used efficiently to drive the Qe axle (30% to 45%). Losses of combustion imperfections Qns (0% to 5%), radiation Qs (0% to 5%) and mechanical losses Qm (5% to 10%) are the same as for ignition. The values of losses in exhaust Qv (25% to 45%) and cooling (15% to 35%) differ [6]

3. THERMAL BALANCES OF ENGINES

Table 1 Thermal balances of engines

Thermal balances		**Petrol engine**	**Diesel engine**
Supplied heat		100%	
Energy efficiently used		25-35%	30-45%
Losses	Cooling	12-30%	15-35%
	Exhaust	30-50%	25-45%

The values given in the table show that the diesel engine uses the energy supplied by the fuel more efficiently than the petrol engine. Comparing the individual losses of both types of internal combustion engines, we can then determine the place that could be most effective for the application of some technology to use energy from exhaust gases. With a petrol engine, the biggest losses are exhaust gases, so it would be a good idea to place a heat recovery unit or other suitable device in the exhaust line. To place the unit in the exhaust pipe, it is important to know its effect on the behavior of the exhaust gases passing through it. Back pressure may build up in the unit or the temperature may drop so sharply that it would adversely affect the discharge of gases from the combustion chamber [12]. The installation location of the unit is selected according to the temperatures at which it operates. However, it is important to take into account that there is also a catalytic converter in the exhaust pipe, which requires higher operating temperatures for its function. Therefore, it is important to decide whether the unit will be located in front of or behind the catalytic converter. On the other hand, in the case of diesel engines, they make up a significant part of the cooling loss due to the higher operating temperatures of the engine, so it would be appropriate to use this waste heat as well.

3.1. Exhaust gas formation

Combustion of gasoline or diesel is an oxidation process in which the combustible components of the fuel (C, H or S) combine with oxygen. The energy contained in the fuel is converted into heat and the ambient air, which contains 21 volume percent oxygen, acts as an oxidant. [13]

An internal combustion engine needs a certain ratio of air and fuel to operate. Ideally, 14 kg of petrol and 1 kg of diesel require 14.5 kg of air to burn 1 kg of petrol. If we convert the weight ratio to volume, we will need about 10,000 liters of air to burn 1 liter of fuel. This ideal mixing ratio is sometimes referred to as a stoichiometric mixture. To facilitate the description of the individual regimes, a coefficient of excess air - lambda - has been introduced. A value of 1 indicates an ideal ratio, values greater than 1 belong to a lean mixture, values less than 1 represent a rich mixture. Although different engine operating modes use different mixes, from poor (lambda 1.05 - 1.3) offering low part load consumption to rich (lambda 0.85 - 0.95) for high full power deployment, the stationary (steady) mode of operation of the engine in today's engines is in a narrow interval around lambda 1 (mixture required for proper operation of the catalyst). This applies to naturally aspirated engines as well as supercharged engines. [13]

4. OVERVIEW OF TECHNICAL SOLUTIONS FOR THE USE OF EXHAUST GAS ENERGY

Many technologies are known in the industry which are suitable for use in the recovery of waste heat from a production process in the production of heat and electricity. Heat engines (Stirling engine, Rankin-Claus cycle, etc.) are often used for this purpose. Thanks to new modern materials, thermoelectric generators using the Seebeck effect are also beginning to appear for the use of waste heat in smaller applications [23];

Internal combustion engines already use devices that use the kinetic energy of the exhaust gases (turbochargers) to improve the efficiency of the engine. However, a relatively large amount of energy remains in these gases, which could be converted into another type of energy. As stated [25] according to the method of thermal energy conversion, the device is divided into

1) Thermo - dynamic:

- Stirling engine
- Rankine-Clausian cycle (steam or organic)

2) Thermo - electric:

- Seebeck phenomenon
- Thermophotovoltaics
- Thermal emission converters
- Thermal tunneling

3) Thermo - chemical

- Fuel cells
- Autothermal reforming (hydrogen production)
- Pyrolysis
- Gasification

4) Thermo – acoustic

Chapter 1 lists the common thermal efficiencies of internal combustion engines; the range of the petrol engine was 25-30%, the diesel engine 35-40%. As stated in the introduction, efficiency can increase efficiency with modern technologies, but not to a value higher than 45% [26]. This means that even in the most efficient modern engines, more than half of the energy supplied is not used and is dissipated in the form of waste heat.

Many exhaust energy technologies have been developed and are dominated by the following: mechanical turbo-compounding, electrical turbo-compounding, turbocharger, thermoelectric generator, six-stroke internal combustion engine and Rankine-Clausian cycle. [27], [28] To compare efficiency engines and technologies for the use of waste heat, a quantity called specific fuel consumption (msp) is often used. Msp indicates the ratio of the amount of fuel and the work obtained from this amount. The unit of msp is g.kW-1.h-1. The smaller the msp, the better the fuel utilized [29], [30].

5. THEORETICAL KNOWLEDGE OF THE PROBLEM OF PUBLIC TRANSPORT

At present, projects that operate on the principle of magnetohydrodynamics (MHD) are mostly only on a theoretical level because not all questions have yet been answered, such as efficiency or feasibility itself. Magnetohydrodynamic power generation provides a way to generate electricity directly from a fast-moving stream of ionized gases without the need for any moving mechanical parts - no turbines and no rotary generators. Several public transport projects started in the 1960s, but overcoming the technical challenges associated with creating a practical system proved to be very costly. Interest subsequently waned in favor of nuclear energy, which has since become more attractive.

Public transport power generation has also been studied as a method of obtaining electricity from nuclear reactors as well as from more conventional fuel combustion systems. [42]

5.1. Fundamentals of magnetohydraulics

Magnetohydrodynymics is the study of the behavior of a conductive fluid (liquid, gas or plasma) in a magnetic field. The relative motion of the conductive fluid and the magnetic field induces an electric field and currents. Electric currents build up a magnetic field in their surroundings and this mechanical effects affect the return movement of the conductive fluid. It is a complicated interaction of a conductive fluid with an electromagnetic field, strongly nonlinear phenomena and mutual transformations of magnetic, mechanical and thermal energy. The initial mechanism of transformation can be both a strong electric field (electric discharges) and strong currents and a strong magnetic field or a relatively intense mechanical movement of the plasma relative to the magnetic field. The first beginnings of magnetohydrodynamics were associated with experiments performed with mercury. In the 20s and 50s, it has inspired the further development of solutions to cosmic problems from the Earth's core, the Sun, stars and plasma in interstellar space. In the later period, laboratory research was developed, especially in the maintenance of plasma by magnetic field for controlled nuclear fusion. Galactic plasma, the interior of stars, laser and pincer plasma with high energy density in terrestrial laboratories combine a number of analogies through huge differences of tens of orders in spatial and temporal dimensions. In the cosmos, magnetic fields are the source of energy transformations, and in the laboratory environment, strong electric fields or intense electromagnetic radiation from powerful lasers.

Magnetohydrodynamics provides a deeper understanding of the context in space and the phenomena associated with high energy concentrations in laboratories for the study of X-ray sources and nuclear fusion. The magnetic field is a source of a form of noble energy with a strong self-organizational ability, manifested e.g. in magnetohydrodynamic turbulences, magnetic dynamics and stable annular and helical structures. [42]

6. DESIGN OF A SCHEME AND 3D MODEL OF A PUBLIC TRANSPORT CONVERTER FOR OBTAINING ENERGY FROM EXHAUST GASES

In order for the design of the magnetohydrodynamic transducer to work, it had to meet certain important conditions. The first and most important condition for operation was the fulfillment of the structure from the point of view of physical laws. We have verified this functionality by applying the physical laws that are responsible for the operation of our drive. Another important point that supported us in the fact that the device will work was the existence of some already functioning devices that use magnetohydrodynamic drive, and therefore for our public transport converter to work, it was necessary to follow the principles of operation such as the material used.

6.1. Principle of operation

The magnetohydrodynamic (MHD) converter we designed is used to directly convert thermal energy or heat into electrical energy. The basis is a fast flow of hot gases in the exhaust pipe containing free charged particles. If such a gas flows through a transverse magnetic field, the Lorentz force acts on the moving charged particles. [45]

This means that the positively and negatively charged particles divide inside the converter in the direction of the magnetic field in two directions to the stripped copper plates from which the copper conductor is led through which we dissipate the acquired electrical energy and thus obtain a closed electrical DC circuit.

We designed the device in the Creo 5.0 program, which enabled us to thoroughly develop a 3D model of the converter, which helped us in the later implementation.

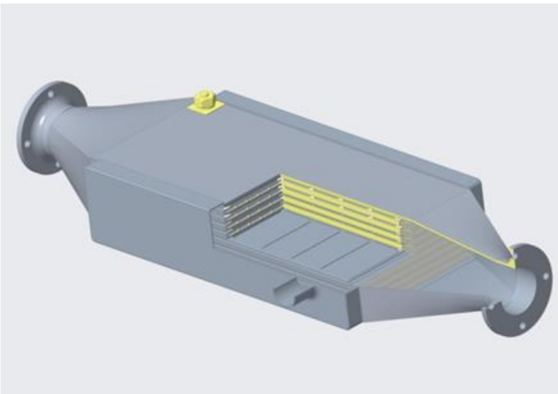

Figure 1 MHD generator

6.2. 3D model simulations

Another part of our work was simulations and analyzes of gas flow in the public transport inverter, so that we can imagine how hot gases will behave when passing through the inverter, whether vortices and the like will form. To create simulations and analyzes, we used the Ansys Discovery 2020 program, which allowed us to examine the gas flow in detail and also set the flow rate or gas temperature. We performed the first simulations on the first prototype model, which we improved even later according to the simulation results. The initial simulation was performed with hot gas which had an inlet temperature of 800 °C and a speed of 5 m / s.

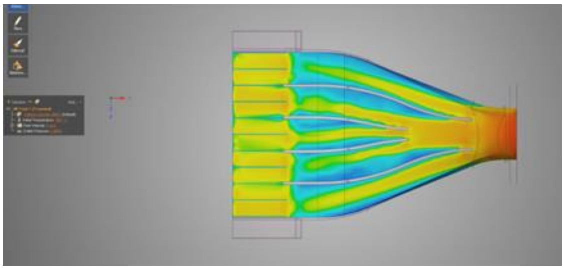

Figure 2 Model simulations

7. PRACTICAL IMPLEMENTATION OF A SIMPLIFIED PUBLIC TRANSPORT CONVERTER FOR OBTAINING ENERGY FROM EXHAUST GASES

After developing the design of the public transport converter, we embarked on the practical implementation of a domestic simplified converter. We used the proposal we described in the previous chapter and the theoretical knowledge we gained. During the implementation of the converter, we often encountered complications, but we managed to solve them all. We described the course of construction of the converter as we actually proceeded together with the complications that arose.

We decided to make the body of the public transport converter from tiles, which had to be prepared first and cut to suitable dimensions. in the initial stage of implementation of this device, it was necessary to obtain all the components to build a functional model of public transport converter. As mentioned above, from a logical point of view, ceramic tiles came to the skeleton of the device, which we cut to the desired shape and then glued with contact glue. After gluing the parts, we tried to heat the frame of the converter to a higher temperature and we found that the contact glue does not resist thermal radiation and the frame began to disintegrate, for this it was necessary to provide other more suitable fire resistant glue that we managed to buy, it is a high strength fast drying glue. a mammoth that passed the subsequent test and the converter skeleton remained solid even at high temperatures.

To successfully complete the test, it was necessary to provide state-of-the-art measuring equipment. For this test we used a professional digital multimeter brand FLUKE (see picture) which we connected to the plus and minus electrode of the public transport converter. To generate hot gases, we used a Berner gas burner that can generate a temperature of up to 800 °C. In the subsequent test, we injected hot gases through the skeleton diffuser through a magnetic field that distributed the positively and negatively charged particles of this gas to the measuring electrodes, which then transmitted the data to the measuring device. we repeated the test several times with a positive result. each time we managed to measure approximately the same values at the level of 50 mV. During the test, we managed to generate a direct current voltage and thus produce electricity from hot gases.

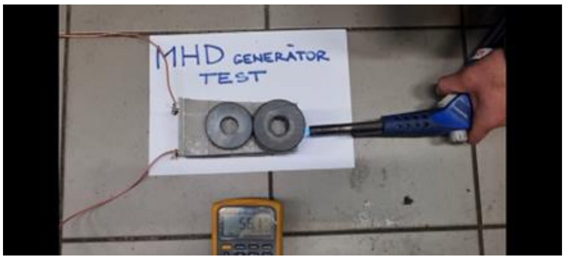

Figure 3 MHD generator test

8. CONCLUSION

This diploma thesis dealt with the design and construction of a magnetohydrodynamic transducer using permanent magnets and a conductive substance formed by hot gases. The theoretical part of the work lists the existing technical solutions that use the energy of exhaust gases and also explains the basic theoretical principles causing the operation of public transport converter.The experimental part describes the design of the public transport converter as well as the implementation of a simplified converter, which was constructed and which, together with its measured parameters, is the main output of this work. There is a problem of design and construction of individual elements of models. The measurement of parameters on the public transport converter model follows. The practical part also describes the measurement procedure. It goes without saying that all measured values and knowledge are presented and described, which are evaluated in the following paragraphs. When evaluating the measured parameters, it is first necessary to note that the primary goal of this work was to verify the theoretical function of the public transport converter. For this purpose, the model was designed and built from the ground up. The basic parameter that can be measured on the generator is the voltage on the unloaded electrodes. However, we also managed to measure direct current. When comparing the measured voltage with the theoretically assumed, we see that the values are very similar. The assumed theoretical value was 50 mV. The measured values on the individual electrodes of our inverter are 56.1 and 48.8 mV. The deviations are mostly due to the impossibility of precisely eliminating the effect of electrode polarization. In all measurements, the maximum generated voltage is close to the expected value, thanks to which we can confirm the function of the magnetohydrodynamic converter.Overall, the results achieved can be considered very convincing and it can be stated that the expectations and the assignment were met. A space is now opening up for further research, in which a number of optimizations could be made concerning the design itself as well as the measurement of parameters. Then it would be possible to achieve greater efficiency of the converter with the possibility of more accurate measurement of its parameters.

ACKNOWLEDGMENT

This paper is an output of the project of the Ministry of Education, Science, Research and Sport of the Slovak Republic KEGA No. 048ŽU-4/2020 "Increasing key competences in aircraft maintenance technology by transferring progressive methods to the learning process".

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