Design Of An Automobile Exhaust Heat Energy Recovery Device Based On Linear Generator

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Abstract: The device collects the heat energy in the exhaust gas of the car, and realizes the recovery and utilization of the heat energy according to the unique heat energy collection device and the highly efficient linear opposed generator. Through the experiment, it is obtained that the exhaust temperature of the fuel car after doing work can reach about 600-800°C, and if it is a turbocharged engine, the exhaust temperature can reach more than 900°C. Investigations and studies have shown that only 20% to 45% of the energy released by automobile fuel combustion is effectively used, and the rest is dissipated as heat. Among them, the energy carried by engine exhaust accounts for 50%-60% of the total dissipated energy. Therefore, we recover the exhaust gas of the car and convert the low-quality thermal energy into high-quality directly usable electrical energy and use it reasonably. In this work, a set of automobile exhaust heat energy recovery device is designed to modify the automobile exhaust pipe part. In the scheme, the exhaust pipe manifold is converted into a spiral structure, and the opposite linear generator is designed. We use the spiral structure to heat the high-temperature thermal energy in the exhaust gas, heat the internal water to high-temperature, high-pressure saturated steam, and then send it to the opposite linear generator cylinder. Our design makes use of the exhaust sequence of the engine, opposites each other, and works back and forth to achieve the purpose of energy recovery [1]. In this scheme, only the exhaust manifold needs to be modified, and no other consumables other than water are needed during operation. The recovered energy can be used for automobile driving and storage. At the same time, the absorption of high-temperature exhaust gas will also reduce the emission of nitrogen oxides. Through this scheme, energy recovery and the elimination of harmful gases can be achieved at the same time, and the purpose of energy saving and emission reduction can be achieved [2].

1. Introduction
With the rapid economic development, the number of cars in China has increased rapidly at an average rate of more than 11 million vehicles per year. However, only about 25% of the heat released by current automobile fuel combustion can be effectively used, and more than 30% of the heat is directly discharged into the environment with vehicle exhaust in the form of waste heat. At present, my country is in the critical period of urbanization and industrialization, and the use of oil is increasing at a rate of about 4% per year. Fossil energy will run out one day. Scientists in China and the world have begun to focus on research projects that can reduce the dependence on traditional fossil energy and improve energy utilization, and strive to study new energy-saving technologies and explore new energy. This part of energy will be of great significance for improving the efficiency of automobile engines and reducing environmental pollution [3].
In addition, under high-temperature combustion conditions, NOx mainly exists in the form of NO, and NOx accounts for about 95% of the initially emitted NOx. However, NO easily reacts with oxygen in the air to generate NO2 in the atmosphere, so NOx in the atmosphere generally exists in the form of NO2. NO and NO2 in the air are converted to each other through photochemical reaction to reach equilibrium. At higher temperatures or in the presence of cloudiness, NO2 further interacts with water molecules to form the second most important acid in acid rain-nitric acid (HNO3). The photochemical pollution produced by NOx and HC can directly damage plants. If human inhaled gas has eye and upper respiratory tract irritation symptoms, such as throat discomfort, dry cough, NOx is also one of the main detection indicators of automobile exhaust. If we reduce the high temperature of exhaust gas, it can also effectively reduce NOx emissions.

The traditional steam power generation system is complicated and bulky, and is not suitable for automobiles. By modifying the exhaust exhaust manifold of the automobile without affecting the inner diameter of the original manifold, it will not affect the engine performance. According to the characteristics of the engine cylinder exhaust, the high temperature exhaust gas is circulated and discharged in sequence from 1, 3, 4, and 2, and absorbs high-temperature heat energy in the improved manifold to make saturated steam circulate in the closed process for heating, work, and cooling. Since the heating medium is saturated steam, the work process No need to add lubricating grease. Because there are many equipments and components in the engine compartment of the car, the space is relatively small, so the design of the counter linear motor is used to work in combination, and the work and cooling are performed simultaneously. So that our design can maximize the efficiency of converting heat into electricity.

2. Design
Through the investigation of the automobile engine and the analysis of the step change of the exhaust gas temperature, the temperature of the exhaust gas that has just been worked out from the engine cylinder in the exhaust manifold is relatively high at about 800 ℃, if it is a turbocharged engine exhaust The temperature can reach above 900℃. This work is to extract electrical energy from the exhausted high-temperature exhaust gas.

**Exhaust manifold design.** The exhaust manifold is connected to the cylinder block of the engine, and the exhaust gas of each cylinder is collected and introduced into the exhaust manifold. Currently, the commonly used exhaust manifolds are divided into cast iron manifolds and stainless steel manifolds in terms of materials and processing techniques. Types of. In this work, a third new concept of exhaust manifold is introduced. The inner diameter of this exhaust manifold is the same as that of the traditional exhaust manifold, so that it will not affect the exhaust performance of the engine. A high temperature resistant hollow spiral is designed on the inner wall The outer wall of the tube and spiral tube is tightly wrapped by a stainless steel tube. The exhaust pipe of the exhaust manifold is connected to the cylinder of the linear motor. Because the spiral pipe in the manifold needs to maximize the absorption of heat energy while working under high pressure, this work uses a circular spiral structure. Pure water is injected into the solenoid of the inner ring, and the pure water in the spiral tube is heated by the heat energy of the engine exhaust gas to absorb the originally lost heat energy and become saturated water vapor. During this process, the pressure in the spiral tube increases and is sent to the straight line through the connecting tube In the cylinder of the generator, the piston is driven to perform power generation [4]. After the work is completed, the gas temperature and pressure are reduced. The opposing cylinder pushes the piston back to realize the two opposing cylinders to perform power generation. In the process of the linear generator, the exhaust characteristics of the engine are used. The exhaust sequence of the engine is 1-3-4-2. The two cylinders of No. 1 cylinder and No. 4 cylinder, No. 3 cylinder and No. 2 cylinder are combined to form two opposite round trips. Linear engine, so that each manifold has a relatively large amount of time for heat exchange, thereby improving power generation efficiency while minimizing the occupation of the engine compartment by the equipment [5].

**Design of spiral exhaust manifold.** The main function of this structure is the heat exchange device of the exhaust manifold. The system uses the device in to collect the heat of the exhaust gas in the
exhaust manifold. Its structure is a unique design idea that can exhaust the exhaust gas from the engine at 800 °C. Perform heat exchange, work under the pressure of 2MPa caused by steam while increasing the heated area. At the same time, the exhaust gas of the engine can be reduced to about 300°C after exchange, which effectively avoids the generation of harmful NOx. The outlet end is close to the engine, and uses counter-current heat exchange with the engine exhaust gas. The temperature at the engine exhaust port is higher, which can make the steam there. Under greater pressure.

**Opposite linear generator.** Because there are many components in the engine compartment of the car and the space of the equipment is tight, designing an efficient and small-sized generator is also one of the core of this work. During the design process, fully analyze the engine's power and exhaust flow 1-3-4-2. Combine No. 1 cylinder with No. 4 cylinder, No. 3 cylinder and No. 2 cylinder to form two opposed round-trip linear engines, so that Each manifold has relatively more time for heat exchange. The linear generator uses a flat linear generator to improve the efficiency of power generation while minimizing the occupation of the engine compartment by the equipment. Both the magnet and the coil are made of silicon steel sheet with good magnetic permeability, and the magnetic force lines are emitted from the N pole of the permanent magnet [6]. The middle of the two permanent magnets makes the mover tooth pole have the role of magnetic permeability and enters the mover through the air gap. The magnetic pole enters the mover magnetic pole through the air gap in the stator through the U-shaped circuit, and finally reaches the S pole of the permanent magnet, forming a closed loop. The direction of the magnetic flux flow is known. The magnetic flux flow forming plane is perpendicular to the moving direction of the mover of the engine, which satisfies the characteristics of a linear magnetic field generator.

If the temperature of the exhaust gas entering the exhaust gas heat exchange device is 800°C and the temperature of the outlet of the manifold is 400°C, the heat quantity transferred to the liquid in the exhaust gas heat exchange device can be calculated. Assuming that the opening pressure of the pressure valve at the steam outlet of the exhaust gas heat exchange device is 1 MPa, the conversion efficiency of the system can be calculated by calculating the relevant performance parameters of the system as shown in Table 1.

| Calculation Item                  | Numerical Value |
|----------------------------------|-----------------|
| Engine Parameters                |                 |
| Fuel Consumption ( g/s)          | 1.97            |
| Exhaust Flow ( g/s )             | 31.02           |
| Exhaust Heat Taken Away By       | 30.07           |
| Heat Transferred To The Medium   | 9.01            |
| Effectiveness ( % )              | 30.0            |
| Opposed Engine                   |                 |
| Power ( kw )                     | 2.71            |
| Stroke ( mm )                    | 16              |
| Frequency ( Hz )                 | 5               |
| Effectiveness ( % )              | 60              |

### 3. Discussion

Based on the thermal efficiency of the engine, the heat exchange efficiency of the heat exchanger, and the conversion efficiency of the opposed generator that can be achieved by the existing technology, the heat conversion efficiency of the system can be calculated. At present, the indicated thermal efficiency of the engine is generally 30%-40%, and the effective thermal efficiency is 20%-30%. The heat taken away by the engine exhaust accounts for about 30% of the total heat of combustion; the heat exchange
efficiency of the heat exchanger generally refers to the absorption by the heating medium. Compared with the heat consumed by the heating medium, the maximum value can reach 90%. The conversion efficiency of the permanent magnet opposed linear generator refers to the ratio of the energy of the steam converted into the mechanical work of the piston and the heat of the heated steam, because it is the most direct work, the highest value can reach 60%.

Considering that the exhaust heat of the engine cannot be fully utilized, and the loss of heat energy from the pipeline, the heat exchange efficiency is 30% here. The ability after heat exchange can directly drive the permanent magnet opposed linear generator. Considering the steam transmission and mechanical losses, and the loss in the conversion of mechanical energy and electrical energy, set the efficiency to 60%, then the theoretical thermal efficiency $\eta$ of the system can reach: $\eta=30\%\times60\%=18\%$, that is, 18% of the engine exhaust heat can be converted into electrical energy recycle and re-use. If the effective work done by the engine to generate heat is equivalent to the heat taken away by the exhaust gas, it is equivalent to an increase of 18% in the effective power output by the engine.

4. Conclusion
This work is to modify the automobile exhaust manifold, without affecting the inner diameter of the original manifold, it will not affect the engine performance. According to the characteristics of the engine cylinder exhaust, the high-temperature exhaust is followed by 1, 3, 4, and 2. Circulating emissions, absorb high-temperature thermal energy in the improved exhaust manifold, so that saturated steam circulates in the closed process for heating, work, and cooling, which maximizes the efficiency of converting thermal energy into electrical energy. The device aims to design a new type of exhaust manifold with high thermal efficiency conversion, high temperature and high pressure resistance without changing the original diameter of the original exhaust manifold. At the same time, we designed a set of opposed linear generators. This work changed the huge and bulky image of traditional steam engines. The device makes full use of the characteristics of engine exhaust and combines the advantages of Stirling engines and linear generators. They are combined in pairs to form opposed generators, which are converted in the processes of heating, working and cooling. The advantages of this device are low manufacturing cost and high conversion efficiency, and its thermoelectric conversion efficiency can reach 18.03%.

References
[1] Sun Aizhou, Wang Peng, Li Zifei, Yuan Baoliang, Liu Jiangwei, Xu Xiuhua, Research on Performance Calculation of Organic Rankine Cycle Waste Heat Recovery System for Vehicle Diesel Engine[J]. Modern Vehicle Power. 2019(03)
[2] Zhang Xinlin, He Maogang, Zeng Ke, Zhang Ying. Screening of working fluid using steam power cycle of engine waste heat[J].Journal of Engineering Thermophysics. 2010(01)
[3] Yi Haixia, Yang Zhenglin, Jiang Yuanguang, Wu Haixiao. Research on matching and control of parallel hybrid electric vehicle power system [J]. Mechanical Design and Manufacturing, 2010, (6): 103-105.
[4] Li Shide. Research and application of tail gas waste heat recovery in diammonium phosphate plant [J]. Phosphate and compound fertilizer, 2017, (12): 31-33.
[5] Zhang Chuanming, Wei Mingshan, Shi Lei. Energy analysis and (exergy) analysis of the exhaust heat recovery system of diesel exhaust [J]. Journal of North China Electric Power University, 2012, (1): 49-53.
[6] Liu Duxian, Han Zhensheng. Analysis of the recovery and utilization of carbon dioxide in the exhaust gas of low temperature methanol washing[J]. Shandong Industrial Technology, 2016, (11): 43