THE USE OF A STIRLING ENGINE AND HIS CONTROL FOR THE PRODUCTION OF ELECTRICITY FROM WASTE HEAT OF METALLURGICAL PLANTS

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https://doi.org/10.37904/metal.2022.4442

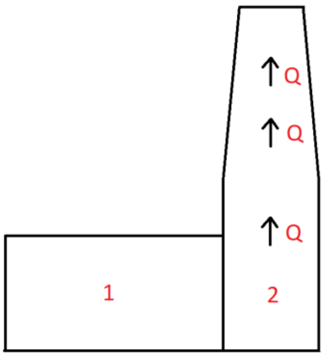
Abstract

This work deals with the utilization of waste heat of steel plants to generate electricity, using Stirling engine. It also deals with the design and connection of Stirling engine in the stack of metallurgical plant to utilize the waste heat energy to generate electricity. The focus of the paper is on optimization of power generation to achieve the highest efficiency of the engine. The efficiency improvement is achieved by measuring the temperatures at the cooler and heater and then controlling the flow of fluids that transfer energy to the motor. The Stirling engine is connected via a clutch and gearbox to an alternator which converts rotational energy into electrical energy. The control is implemented by a microcontroller and control elements such as taps and brake. The electricity generated in this way could be used to power the plant's measuring elements or to light the plant. The aim of this work is to design a power generator that uses the waste heat of metallurgical plants to save electricity.

Keywords: Stirling engine, generator, waste heat, regulation

INTRODUCTION

Metallurgical plants are technical workplaces equipped with heating furnaces to heat the material to working temperature. Heating furnaces in metallurgical plants are divided into solid fuel and electric furnaces. Solid fuel furnaces burn either natural gas or coke oven gas. Electric furnaces are divided into resistance, arc and induction furnaces. In resistance heating furnaces, heat is generated by means of a resistance wire (heating element) which is heated to a high temperature by the passage of an electric current. Arc heating furnaces generate heat by means of an electric arc that is generated between the electrode and the material to be heated. Induction furnaces heat the material by means of the electrical induction that occurs between the coil (electrode) and the material. In this process, not all of the thermal energy is used and some of it is lost in the form of waste heat **Figure 1**, which can be used to preheat technologically important variables or is taken as waste. In the case of waste heat, the energy is removed from the furnace working space through the chimney and discharged into the air as flue gas **Figure 1** number 2. [5,6].

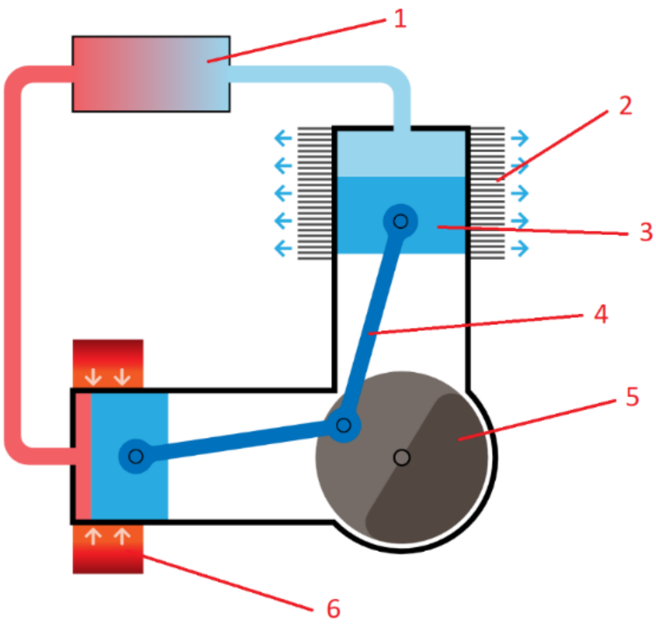


1) Materiál heating zone
2) Waste heat removal zone

Figure 1 Diagram of the metallurgical plant

For economic reasons, a Stirling engine could be used to convert this waste heat back into electrical energy that could be used to run the metering elements of the smelter. The electrical energy generated in this way could be used to power low voltage elements such as, for example, flue gas or air quality sensors in the plant [1,4,7].

The Stirling engine is a thermal machine working on the principle of cyclic compression and expansion of gas. The working gas is compressed in the cold cylinder **Figure 2** of the engine and expands in the warm cylinder where it increases its volume due to thermal expansion. In this way, thermal energy is converted into mechanical work. The working gas is in a closed circuit, which means that there is no exchange of working gas, but only a transfer of energy. The Stirling engine is characterised by its regenerator, which is a heat exchanger that stores heat energy between compression and expansion of the gas. A heater and cooler are required to supply the energy. The heater is designed to supply energy to the hot cylinder of the engine and the radiator is designed to cool the cold cylinder of the engine. The Stirling engine was invented as a competitor to the steam engine in 1816 but its use was only for situations where high power was not needed. The efficiency of the Stirling engine is up to 40% which is more than the steam engine. This type of engine is known for its quiet operation and the ability to use any heat source. For this reason, it is nowadays suitable as an alternative renewable energy source, for example in microgeneration [1,7].



1) Regenerator
2) Cold roller
3) Piston
4) Piston rod
5) Crankshaft
6) Warm roller

Figure 2 Stirling engine diagram

The heating is realized in a closed hydraulic circuit by means of a heater and a circulating pump **Figure 3**, which allows heat transfer by convection. The circuit consists of a heat exchanger into which the fluid is fed by a circulating pump. This fluid then flows to the hot cylinder of the Stirling engine where it feeds energy to the engine's hot cylinder. The cold cylinder of the engine must be cooled in order for work to be carried out. The cooling process is guaranteed by the cooling circuit, which consists of a radiator, a fan and a circulation pump. The circulator brings fluid to the cooling part of the cylinder where it extracts energy from the cold cylinder and delivers it to the radiator which transfers this energy to the radiator surroundings. The cooler may also include a fan which increases the efficiency of the cooler [4**,**7].

The aim of this work is to design a power generator that uses the waste heat of metallurgical plants in order to save electrical energy. Furthermore, the design of the control of the system and the design of the power transfer to the Stirling engine.

1. TECHNICAL SOLUTION

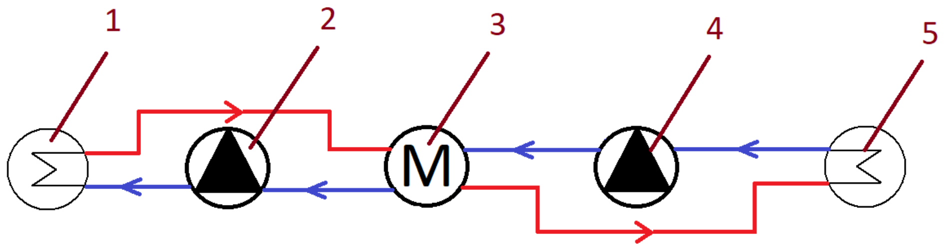


Figure 3 Stirling engine cooling and heating scheme

1) Heater
2) Circulation pump
3) Stirling engine
4) Circulation pump
5) Cooler

The engine crankshaft will be connected to an alternator via a controlled clutch and variator which is one type of power generator. A generator is an electrical device that converts the rotational energy of the drive shaft into electrical voltage **Figure 4**. A generator that generates DC voltage is called a dynamo, which is not much used nowadays because of its maintenance requirements. A generator that generates alternating voltage is called an alternator. AC voltage is generated by electromagnetic induction. Electromagnetic induction is the process by which an electrical voltage is induced when a conductor moves in a magnetic field. Alternators can be single phase, two phase or three phase. The induced voltage can then be rectified by a rectifier [3].

The generator is controlled by a microprocessor, which evaluates from the measured values the appropriate response for the regulatory authorities. Hence, for this reason of control solution we talk about In-Line control or the whole process is controlled by the control computer instead of the controller [2,3].

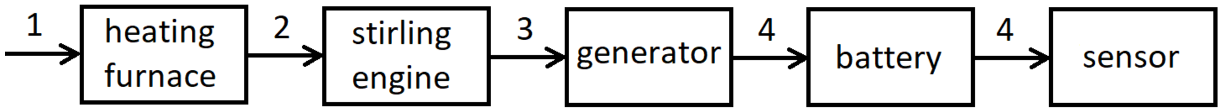


Figure 4 power generation block diagram

1) Fuel
2) Heat
3) Rotational energy
4) Voltage

Ortant variables in the system will be the temperatures of the working cylinders, the cooler and heater temperatures, the fluid flow in the cooler and heater circuits and the speed of the Stirling engine output shaft. Pt100 resistance thermometers, or a thermometer operating on the principle of resistance change with temperature, will be used to measure the temperatures in the heating and cooling circuits. Pt100 means that the thermometer has a resistance of 100 Ohms at a temperature of 21 °C. The temperature information is important because if there were a significant difference in temperature between the heater and the hot engine cylinder, the fluid flow in the hydraulic circuit would have to be increased. A similar problem would arise with the cold circuit if the cold cylinder was significantly warmer than the radiator temperature, this would mean that the cold cylinder is not being cooled optimally and the flow rate in the cooling hydraulic circuit would need to be increased, or a fan attached to the radiator would need to be switched on to facilitate heat dissipation to the surroundings. The flow rate will be measured using a vane flowmeter, which works by generating electrical power through the rotational motion of the vanes which are rotated by the flowing fluid. The flow rate information is important in order to give the microprocessor feedback as to whether liquid is flowing at all in the heating and cooling circuit. The speed measurement will be provided by an optical tachometer which works by counting the dot on the rotating shaft. It divides the count by 60 and then provides information on how many times it has seen that dot per minute. The measured value of the speed is significant because of the speed control by means of a variator. If there were no speed control by the variator, a situation could occur where the alternator would load the engine so much that it would stall.

2. MACHINE OPERATION

When the desired temperature difference is reached at the heater and cooler, a signal will be sent to the circulators which will transfer the energy to the engine's working cylinders. A signal will then be sent to the starter which will move the crankshaft, resulting in the Stirling engine being put into operation. Once the Stirling engine is in operation, a controlled clutch will be engaged to connect the engine shaft to the variator which will continuously increase or decrease the gear ratio to the alternator. The electrical voltage is then rectified and fed to the batteries to compensate for variations in the alternator output voltage.

3. CONCLUSION

In this paper, a design solution for the energy supply of a Striling engine, which uses the energy of waste heat of the flue gas in metallurgical plants, was proposed. Furthermore, the control of the whole system and the design of the system that feeds the energy to the Stirling engine was proposed. This solution could be used for metallurgical plants to reduce the cost of operation. This generated electricity could be used as a source for sensors in the metallurgical plant such as the flue gas sensor, or it could be used to power the lighting of the plant.

ACKNOWLEDGEMENTS

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic No. SP2022/74 and SP2022/80 and SP2022/86.

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