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Miniature Thermoelectric Power Plant

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Abstract. *This paper describes a miniature thermoelectric power plant made with the boiler and the water pump from an old starch iron. It also uses a computer cooling fan, which serves as electric power generator. The boiler vaporizes the water it receives from the water pump. Then, the steam is injected on the turbine of the fan, making it twirl. The voltage generated by the fan is enough to lighten a couple of LEDs. A wooden case with a chimney encloses all the referred devices.*

Keywords. Electrical Power Systems, Thermoelectric Power Plant.

1. Introduction

Electric energy availability has become of primordial importance in modern societies. In fact, it is so important that its fail can stop a whole city: modern trains, hospitals and industries, for example, would stop without electric energy.

There are several ways of producing electric energy (for example, through hydroelectric, thermoelectric or wind power plants [1,2]). Thermoelectric power plants have several environmental issues [3], but they are heavily used around the world.

This paper describes the working principle of thermal power plants and presents a miniature steam thermoelectric power plant (Fig. 1 and Fig. 2) made with old starch iron parts.

The miniature made its first appearance at *Oficinas de Electricidade* (Electricity Workshops), integrating part of *Robótica 2006 – Festival Nacional de Robótica* (National Robotics Festival), which happened in Guimarães, Portugal, between April 28 and May 1, 2006.

2. Thermal power plants

Thermal power plants generate electricity by means of combustion: coal, oil or natural gas is burned, heating a boiler to produce steam. The steam is fed into a steam turbine, causing rotational movement. An electrical generator, connected to the turbine shaft, converts the rotational movement into electrical energy. The steam coming from the turbine is then condensed and the resulting water is fed into the boiler, again. Fig. 3 shows a diagram of a real-world thermal power plant [4].

Figure 1. Miniature thermoelectric power plant at *Oficinas de Electricidade* (Electricity Workshops), in 2006.

Figure 2. Top view of the miniature.

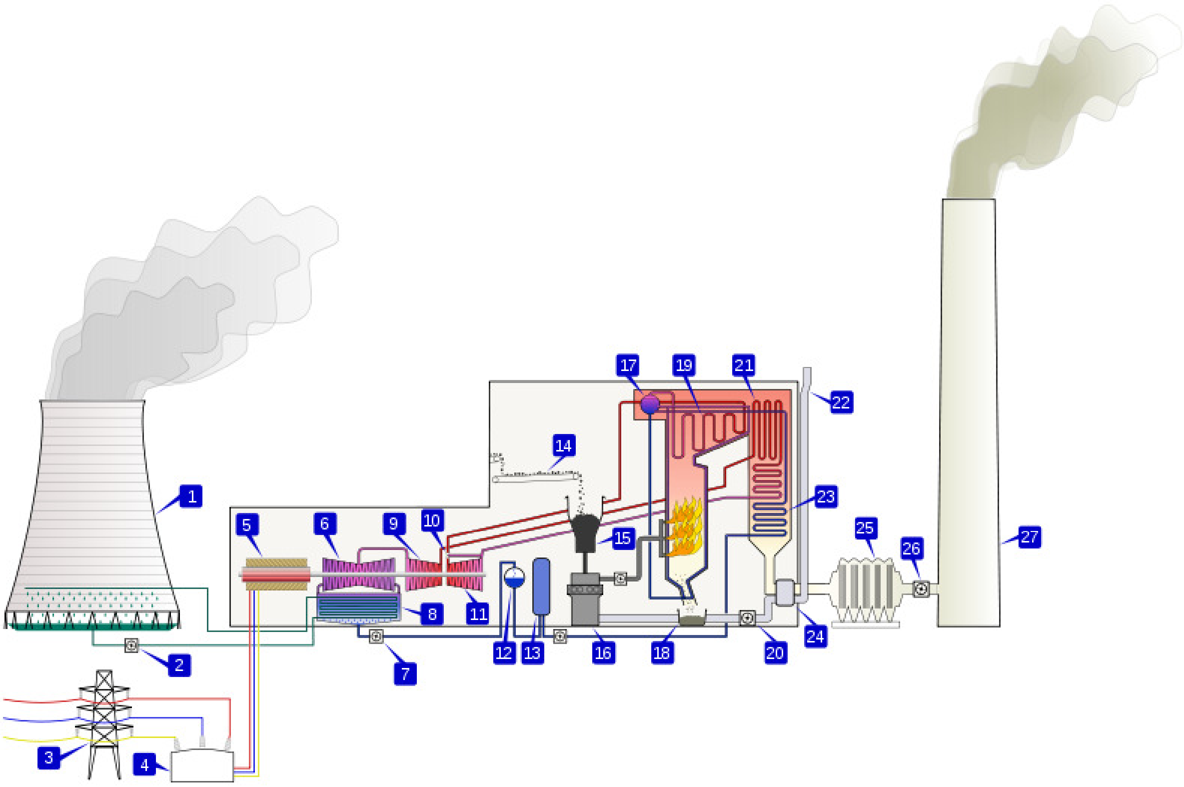


Figure 3. Thermal power plant [4]

The main components of a thermal power plant and their functions are the following [3, 4]:

1. ***Cooling tower*** *– if there is no water stream near the power plant, cooling towers are used to cool the condenser, transferring heat to the atmosphere.*
2. ***Cooling water pump*** *– circulates water from the cooling tower to the condenser.*
3. ***Outgoing transmission line*** *– transports electrical energy generated in the power plant.*
4. ***Step-up voltage transformer*** *– raises voltage and lowers current levels coming from the generator, making them more suitable for transport lines.*
5. ***Electric generator*** *– converts mechanical energy to electricity.*
6. ***Low-pressure turbine*** *– usually, there are three steam turbines connected in series; this is the last one and has the larger blade diameter.*
7. ***Condensate pump*** *– pumps water from the condenser to the boiler.*
8. ***Condenser*** *– this is where the low-pressure steam coming from the turbines is condensed into water, again.*
9. ***Intermediate pressure turbine*** *– this turbine is the second stage and has intermediate blade diameter.*
10. ***Steam governor valve*** *– is responsible for controlling steam in order to keep turbines and generator rotating at constant speed.*
11. ***High-pressure turbine*** *– the first stage turbine, with smaller blade diameter.*
12. ***Deaerator*** *– removes air dissolved in the water to be fed to the boiler.*
13. ***Feedwater heater*** *– preheats water to be fed to the boiler in order to increase efficiency.*
14. ***Coal conveyor*** *– transports coal from the outside of the feeding system.*
15. ***Coal hopper*** *– combustible feeding system.*
16. ***Coal Pulverizer*** *– mechanical fuel grinding mill that coverts pieces of coal into a fine dust, adequate to be blown into the furnace and burn rapidly.*
17. ***Boiler drum*** *– this is a reservoir containing water and steam and separates one from the other.*

18. ***Ash hopper*** *– this is where non-combustible ashes from the furnace are collected.*
19. ***Superheater*** *– it is a device used to further heat the saturated moist steam, converting it into higher pressure and higher temperature dry steam, while lowering boiler water consumption.*
20. ***Forced draft fan*** *– feeds the furnace with large quantities of air needed for the combustion.*
21. ***Reheater*** *– heats the steam exhausted by the high-pressure turbine before it enters the medium pressure turbine, to increase system efficiency.*
22. ***Air intake*** *– pipe that conducts the air from the environment to the furnace.*
23. ***Economizer*** *– heats the water going into the boiler, increasing efficiency.*
24. ***Air preheater*** *– heats the air before it enters the furnace, in order to increase efficiency.*
25. ***Precipitator*** *– this device causes precipitation of several particles contained in the combustion gases, acting as a filter and preventing these particles to go to the environment.*
26. ***Induced draft fan*** *– carries gases and other particles resulting from the combustion through filtering systems and then to the chimney.*
27. ***Chimney Stack*** *– exhausts combustion gases to the atmosphere.*

The maximum theoretical thermal power plant efficiency is given by equation 1, where η is the efficiency, T_2 is the turbine input steam temperature in Kelvin and T_1 is the turbine output steam temperature, also in Kelvin. Since T_2 is limited to a value the turbine safely withstands and T_1 can't be lower than ambient temperature (about 293K), η is inherently low [3].

$$\eta = 1 - \frac{T_2}{T_1} \qquad \text{[eq. 1]}$$

3. Power plant operation

This section describes the functioning of the main components of the power plant, which was built with:

- 1 water pump
- 1 boiler of a starch iron
- 1 electrical valve
- 1 computer cooling fan
- 1 water tank
- 1 ejector
- 2 LEDs
- 2 resistors of 500 Ω
- 2 position switches
- 1 Pressure switch
- 1 Teflon pipe

Additional materials were, among others, a cork sheet, a wooden base and spray paint.

3.1. Water pump

The water pump (Fig. 4) is needed to pump water from the water tank to the boiler, so that can be transformed into steam.

The pump works with 230V.

3.2. Boiler

The boiler (Fig. 5) works with 230V and its power is 1350W. The current absorbed by the boiler is 6A. The pressure inside of the boiler is approximately 3 bars.

When the temperature inside of the boiler is higher than 105ºC, a LED placed near the switches is on (see figure 6) to indicate that the boiler is heating up.

When the temperature arrives to 120ºC, the LED is switched off and the boiler starts to cool down. Now, the switch of the ejector is ready to be switched on, freeing the water steam through the fan.

The boiler has an electrical valve that cuts current when the temperature inside of the boiler reaches 200ºC.

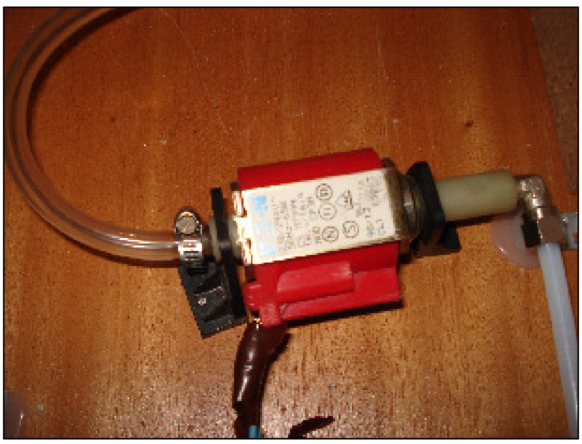


Figure 4. Water pump

3.3. Computer cooling fan and output LEDs

The fan used in the miniature is a 12V computer cooling fan, installed inside the power plant chimney (Fig. 6).

When the water steam leaves the ejector, the fan starts turning, generating voltage at its terminals.

When the voltage is enough, two LEDs connected to the fan terminals lighten up (Fig. 7). The ejector is pointed in a way such that the voltage at the terminals of the fan is as high as possible.

3.4. Switches

The miniature has two position switches and one pressure switch (Fig. 8).

The pressure switch (Switch 2) corresponds to the water pump. When it is pressed, it switches the pump on, filling the boiler with water. Switch 3 is needed to turn on or off the boiler. Switch 1 opens the ejector so that the water steam may go to the fan.

3.5. Electrical outline

Fig. 9 depicts the outline of the electrical circuit used in the miniature.

4. Tests and construction details

Before the construction of the miniature thermoelectric power plant, several tests were performed in order to verify the reliability of the materials used.

First, the boiler was filled using the water pump. Then, through a pipe of Teflon, the boiler was linked to the ejector. The pipe of Teflon was used because the temperature of water steam in the output of the boiler is higher than 100ºC and pressure is, approximately, 4 bars (value not measured). The pipe tolerates temperatures up to 200ºC and 10 bars pressures.

The next step was testing the voltage generated at the terminals of the fan by the passing steam. The maximum peak voltage obtained was 2.5V. The series made with a 500Ω resistor and two LEDs in parallel were connected to the terminals of the fan. The resistor was required to limit the current in LEDs.

The power plant has a very poor efficiency. In fact, the current required to heat the water is 6A, resulting in a 1320W input power.

When the tests phase concluded, the construction of the structure was initiated. First, the walls of the miniature were constructed and painted with spray. Then, the boiler was fixed in the wooden base.

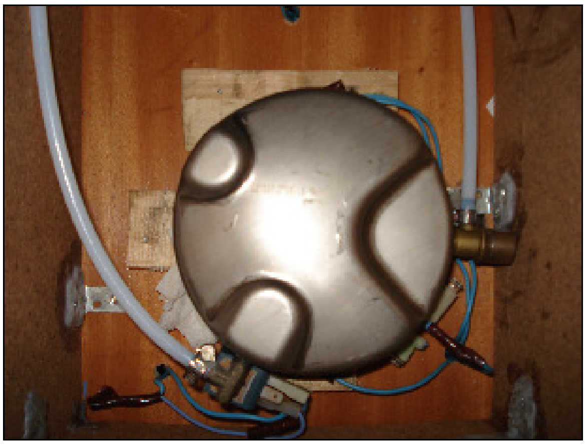
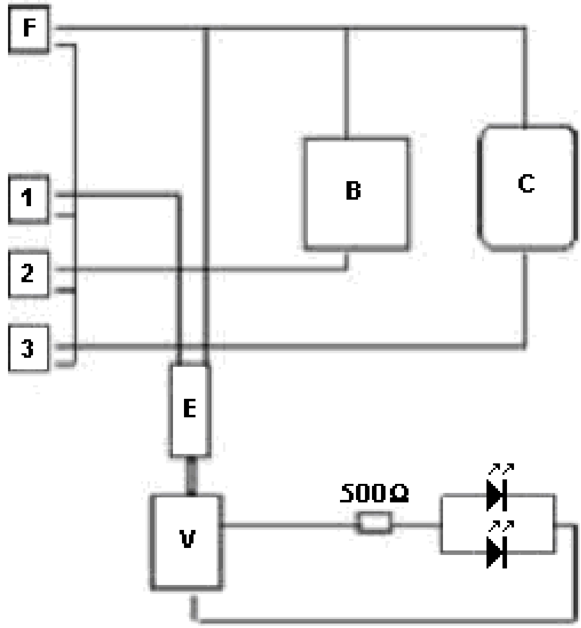


Figure 5. Boiler

Figure 6. Fan inside the chimney

Figure 7. Output LEDs.

Figure 8. Switches



F – Power source
1 – Ejector switch
2 – Water pump switch
3 – Boiler switch
E – Ejector
V – Computer cooling fan
C – Boiler
B – Water Pump

Figure 9. Electrical outline

The next step was the construction and painting of the roofs and the chimney (this latter that was painted in white and red). Finally, the ejector and the fan were fixed inside the chimney.

Part of the water steam used in the energy generation turns back into water inside the chimney and returns to the water tank.

5. Conclusions

A miniature steam thermoelectric power plant was presented. It was built using old starch iron parts and a computer cooling fan.

Construction and operation details were explained. The voltage generated by the power plant is enough to lighten two LEDs.

Energy efficiency is very low. This is because the built thermoelectric power plant is far from being optimized, like a real world one is. From the descriptions presented is the text, although the working principle is the same, there are profound differences between a real thermal power plant and the model described in this paper, that directly affect efficiency.

The major difference is the steam temperature difference between steam going to and exiting the turbine. In a real world plant, steam enters the turbine at 550ºC (823K) [3], and exits at a relatively low temperature, although higher them ambient temperature. In this model, the steam enters the turbine at about 120ºC (393K), and leaves the turbine still very hot: steam temperature was not measured, but it is hot enough to burn the skin. According to equation 1, the lower the temperature difference, the lower the efficiency.

Despite of its very poor efficiency, the device is very eye-catching and especially suitable for science fair events.

6. Acknowledgements

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7. References

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