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The laboratory test stand of the ORC micro power plant

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Abstract: *The article presents the design and implementation of the laboratory test stand of the micro power plant with an Organic Rankine Cycle (ORC). The test stand was created to research different constructions of micro-turbines operating on a low-boiling agent. The electric power of these micro-turbines is 2-3 [kW]. There are measuring sensors connected to the test stand, which are necessary to collect information about the work of the whole ORC system. This laboratory test stand was built in the Szewalski Institute of Fluid Flow Machinery in Gdansk. The research on the newly constructed test stand were performed and some of the results are shown in this article.*

Keywords: *test stand, micro power plant, Organic Rankine Cycle, micro-turbines, CHP (Combined Heat and Power).*

1. Introduction

The article presents the construction and start-up results of the laboratory test stand acting as a micro power plant (with a supersonic micro-turbine) based on the Organic Rankine Cycle (ORC) system. During the study, the entire system operating with a low-boiling agent HFE 7100 with various service conditions was tested. The characteristics of the installation for the operation variant of the ORC with regeneration were determined. During the tests the flow heater for thermal oil was used as a heat source. Several tests with different flow rates, temperatures of the working medium, glycol solution and thermal oil were performed. The article presents sample plots of rotational speed, electric power generated by a micro-turbine as well as pressure waveforms, temperature waveforms and HFE 7100 degrees of superheat.

2. Research object characteristics

The micro power plant test stand has been built as an integrated ORC system, in which all the components are placed on a supporting structure and are controlled and monitored by using a single automatic control system [1]. This system was used to develop a prototype micro CHP plant designed for the combined production of electricity and heat using biomass as fuel. Long distances and easy access to all system components allow for quick replacement and the introduction of various modernizations. The test stand used during the research is the universal solution that allows, among others, to conduct studies of different design solutions for microturbines, pumps, heat exchangers, valves, etc. The control system for use in the prototype of a micro CHP plant was also tested on the test rig. The schematic view of the test stand is shown on figure 1.

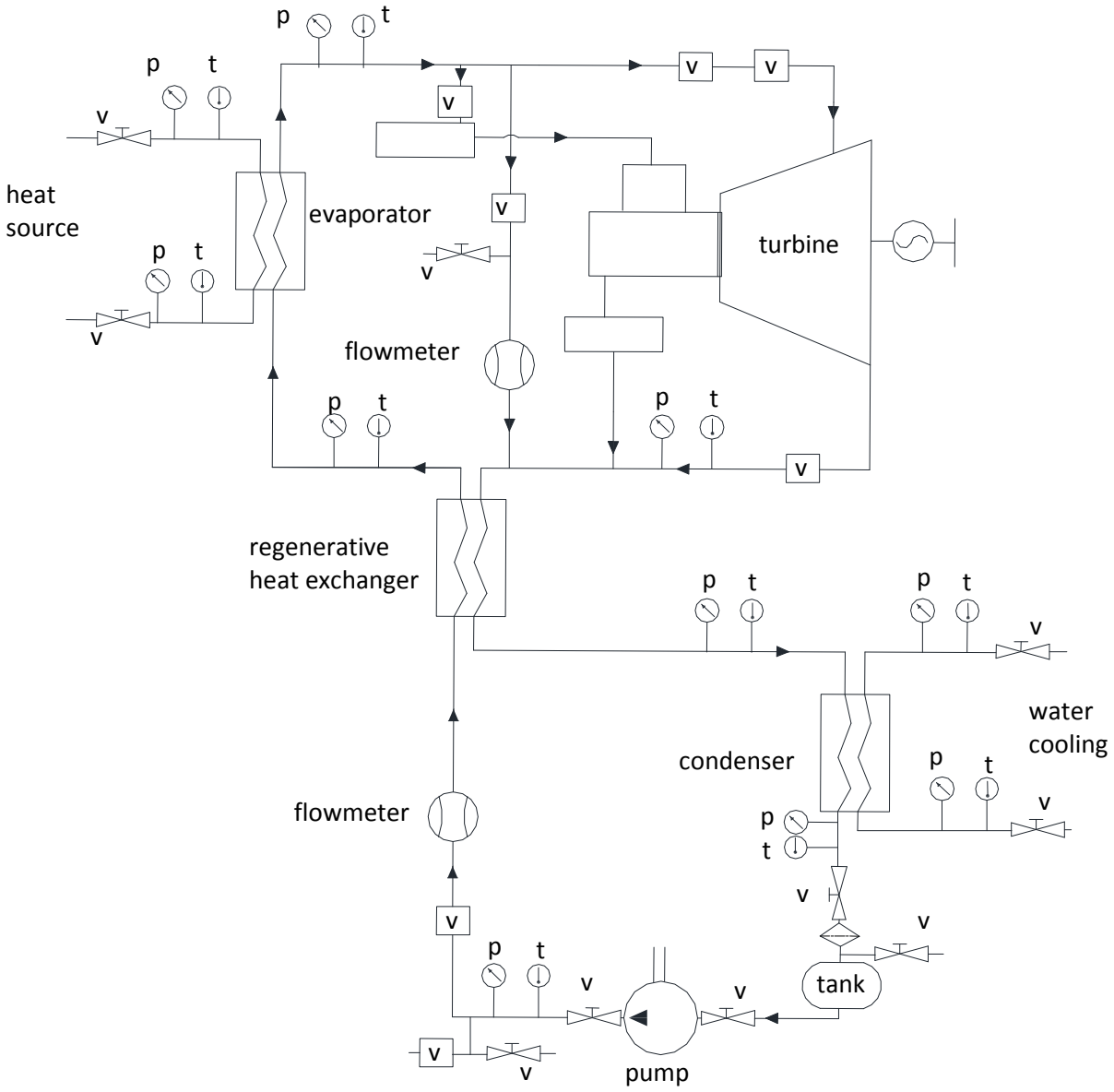


Figure 1: Schematic view of research test stand. v- valve, p – pressure measurement, t – temperature measurement

The working medium is pumped through the circulation pump through a regenerative heat exchanger to the evaporator, where heating and evaporation at specific and controlled parameters take place. Then it goes to a microturbine, where its energy is converted into rotational motion of the rotor coupled to electric generator. After expansion in the turbine flow system, the working medium is directed to a regenerative heat exchanger where it gives off some heat to preheat the liquid medium for feeding an evaporator. Then the medium goes to the condenser, where during the phase change it heats the water. In the target cogeneration system, water is a source of heat for the end user. The working medium from the condenser flows into the tank where it is collected by the circulation pump, thereby closing the cycle. The test system is equipped with sensors for pressure, temperature, flow rate and an appropriate set of security sensors for correct work of the high-speed turbine.

The model and the actual test stand is shown in figure 2. In the described configuration a single-stage supersonic microturbine was installed. The turbine is located at the highest accessible point of the test stand (figure. 1), which preserves it from flooding by the working medium in liquid form.

a) b)

Figure 2. View of the research test stand, a) Autodesk Inventor model, b) real construction.

Installation microturbines bench and is supersonic hermetic structure, since the entire system, both the power supply and the bearings of the flow system used is a pair of the same working medium [2, 3]. This entire installation is a hermetically sealed structure. To feed the flow system as well as the bearings, a steam originating from the same working medium is used [2, 3].

The basic elements of the supersonic microturbine are single-stage radial impeller, electric generator with so-called rare-earth magnets and a set of bearings. All components are sealed in the body with a water jacket that cools the generator. The working medium in the ORC is low-boiling medium labeled as HFE-7100 [4]. Tested microturbine has got the following design parameters [5-8]:

a) nominal speed - 35 000 rpm,
b) power output – 3.26 kW
c) initial pressure - 11 bar,
d) initial temperature - 156 °C

The views of the microturbine and method for mounting it, on the micro power plant test stand, are shown in figures 3.

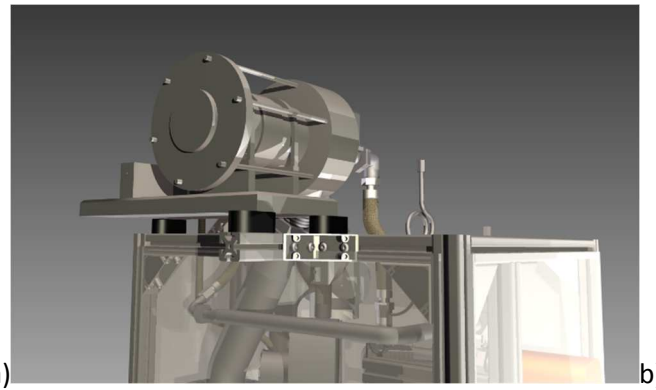
a)  b)

Figure 3. View of the turbine on the research test stand, a) Autodesk Inventor model, b) real construction.

3. Research results of the test stand based on the ORC system

Before starting on the supersonic turbine is set the appropriate thermodynamic parameters of the working medium HFE 7100 (ie delivery pressure and temperature, return pressure and temperature, flow rate). The next step before running the microturbine was preheating of the bearings and the turbine casing. After turbine preheating, rate of the working medium to the turbine was increased. Operation with bypass valve (EZP2) fully closed is shown in figure 4.

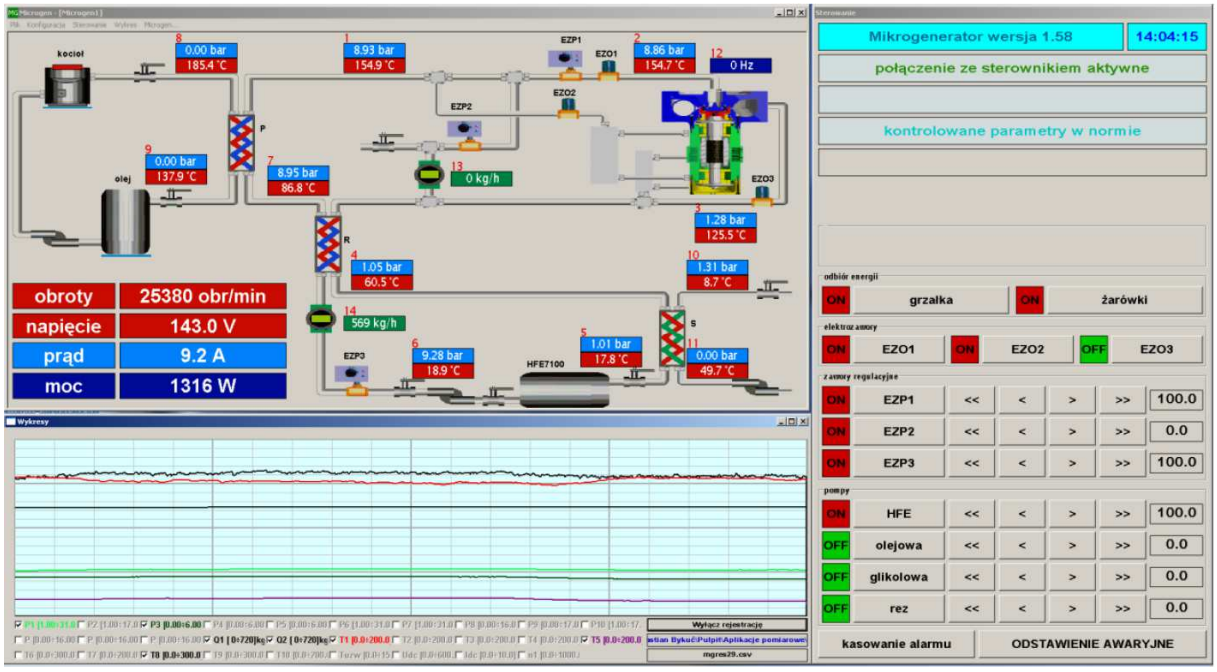


Figure 4. Control program window during microturbine testing on the test stand [9].

Figure 5 shows that at a differential pressure (between inlet and outlet of the microturbine) of 7.58 bar and at a flow rate of 569 kg / h (i.e. 158 g / s) electric power generated at the generator terminals amounted to 1316 W.

During the test stand start-up several series of measurements were carried out. The article contains a description of one of them.

The medium pressure waveforms in the time domain, recorded at the heat exchanger, for the first set of measurements, are presented in figure 5.

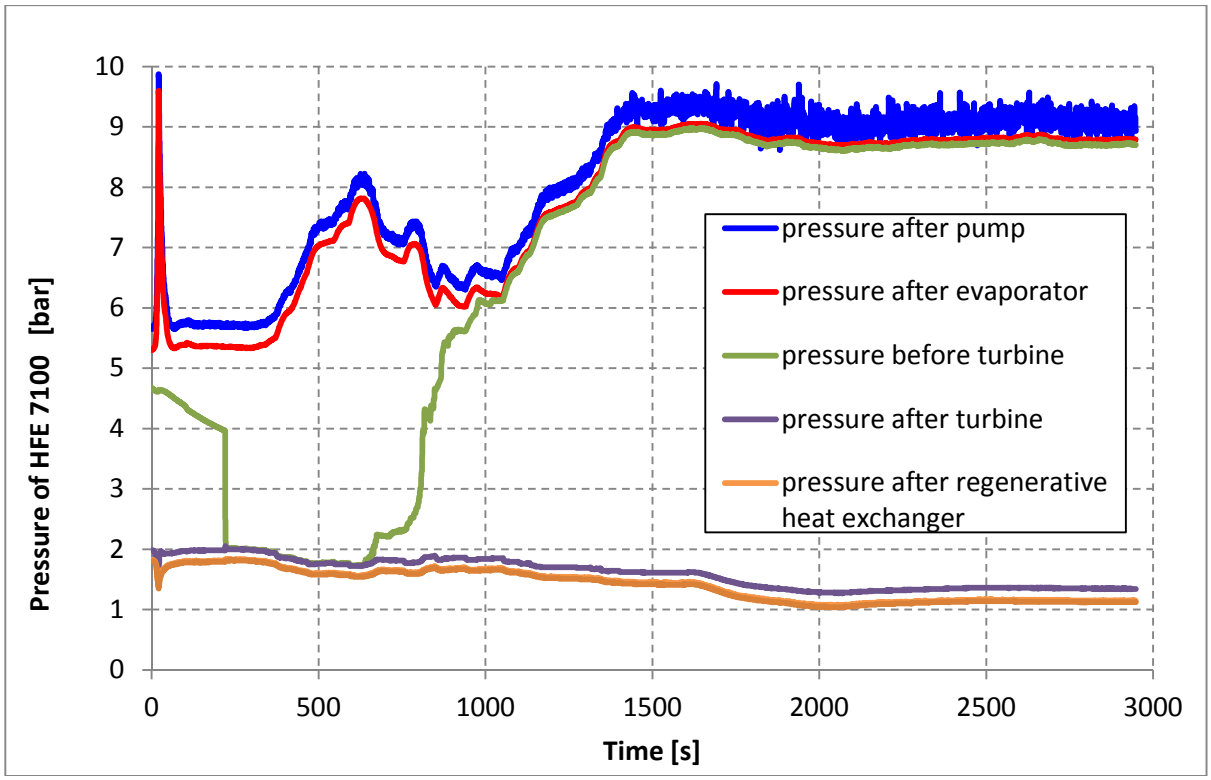


Figure 5. Pressure waveforms of HFE 7100 in the time domain, recorded at the test stand, during supersonic microturbine testing [9].

In the presented series of measurements in steady state (i.e., in the range from 2000 to 2950 s) the following pressure values were recorded in the ORC installation: after the pump approximately 9.3 bar, after the evaporator approximately 8.5 bar, at the inlet to the microturbine 8.4 bar, at the outlet of the microturbine approximately 1.3 bar and after the regenerator and condenser approximately 1.2 bar.

The HFE 7100 temperature waveforms in the time domain, recorded at the ORC test stand, with an electric heater of thermal oil are presented in Figure 6.

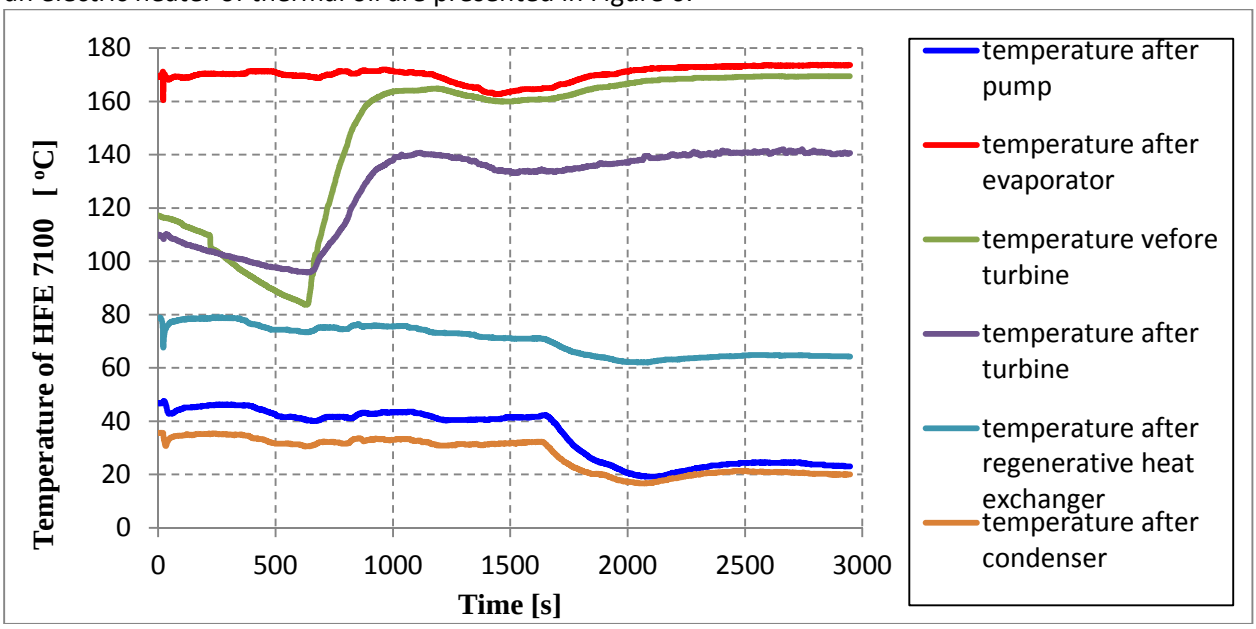


Figure 6. The HFE 7100 temperature waveforms in the time domain, recorded at the ORC test stand, during supersonic microturbine testing [9].

During the measurements (for the first measurement series - figure 10) the following temperatures of the working medium were registered: after the pump it was in the range from 19 °C to 48 °C, after the evaporator it was in the range of 165 °C to 174 °C, at the inlet to the microturbine it ranged from 85 °C to 170 °C, at the outlet of the microturbine it was in the range of 97 °C to 140 °C, after the regenerator it was in the range of 61 °C to 80 °C and after the condenser it was in the range of 18 °C to 35 °C.

The HFE 7100 overheating degree waveforms in the time domain, recorded at the ORC test stand, with an electric heater of thermal oil during supersonic microturbine testing are presented in figure 7.

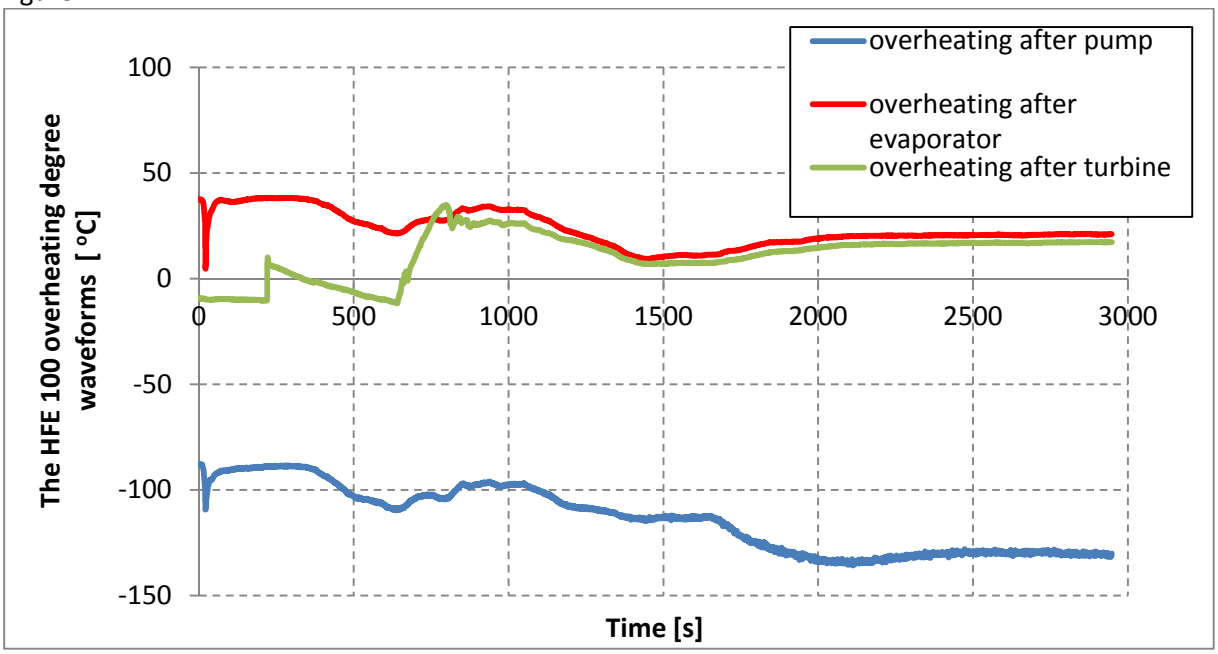


Figure 7. The HFE 7100 overheating degree waveforms in the time domain, recorded at the ORC test stand, during supersonic microturbine testing [9].

In Figure 7, we can observe the maximum overheating degree of the low boiling agent HFE 7100. In couple measurement series the higher results of temperature was: after the gear pump HFE 7100 amounted to approximately -130 °C, suggesting a substantial HFE 7100 supercooling. In addition, the following overheating degrees of the working medium have been reported: after the evaporator - about 32 °C, before the microturbine - 28 °C, after the microturbine - 50 °C. Overheating of the working medium before and after the microturbine proves correct operating parameters for the HFE 7100 agent. The high values of overheating degrees before and after microturbine protect against working medium outdropping and turbine set damage (eg due to erosion of the blades).

Figure 8 shows the rotational speed of the microturbine in the time domain, measured on the ORC test stand (with an electric heater of thermal oil) of micro power plant, for the first series of measurements.

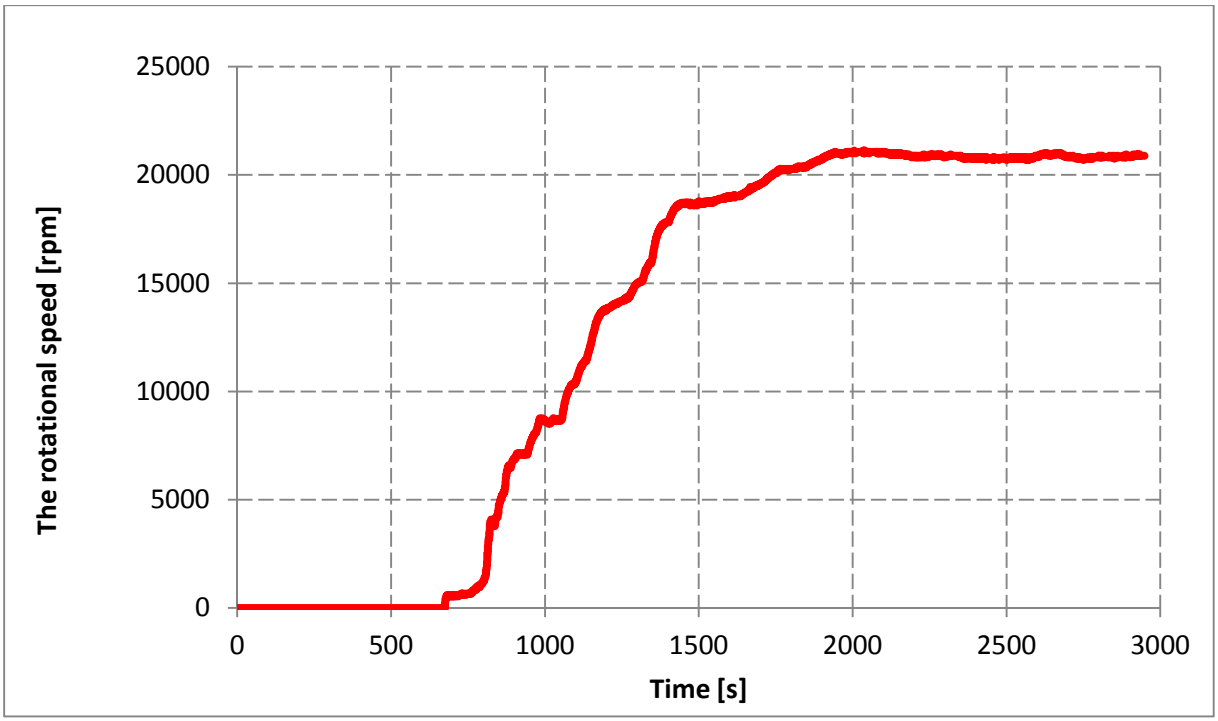


Figure 8. The rotational speed values of the supersonic microturbine in the time domain, recorded at the ORC test stand [9].

Figure 8 shows that the maximum rotational speed of the microturbine was approximately 21,000 rpm and remained at this level for about 1000 s (i.e., in the range of 1900 to 2900).

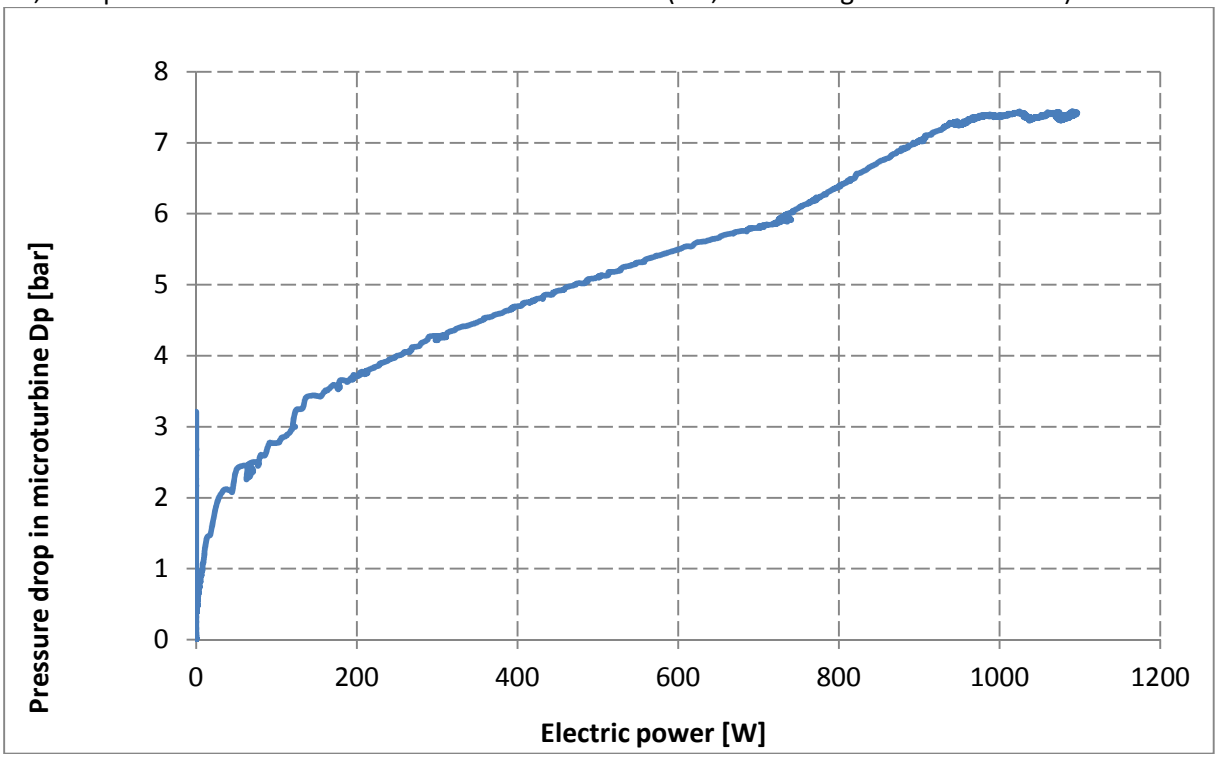


Figure 9. Pressure drop as a function of electric power generated by the supersonic microturbine, recorded at the ORC test stand [9].

The measurements (figure 9) show that the microturbine generates about 1100 W of the electric power at a differencial pressure of 7.5 bar.

4. Summary and conclusion

The studies of the ORC cycle with a supersonic microturbine were conducted. It can be concluded that all systems work together as a unit (ie heating, cooling and working medium) in the ORC cycle allow control and stable work of the test stand.

On the ORC test stand with the supersonic microturbine and gear pump maximum pressure in the installation was approximately 9.5 bar. The maximum values of the working medium temperature were: after the evaporator approximately 163 °C, at the inlet to the microturbine 158 °C, at the outlet of the microturbine approximately 131 °C, after the regenerator 61 °C and after the condenser approximately 20 °C.

During initial tests the largest electrical power equal to 1350 W was obtained at a speed of 25500 rpm. The differential pressure (between inlet and outlet of the microturbine) reached then approximately 7.6 bar and the temperature difference of the HFE 7100 (between inlet and outlet of the microturbine) was at 28-30 C. During the further research on the described test stand, the electrical power of more than 2100 [W] was obtained.

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