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Microcontrollers diagnostic system for evaluation of Stirling engine

***Abstract**. In this paper we present the microcontroller system for diagnostic and evaluation of the Stirling engine performance. For this purpose the model for the prototype engine analysis has been developed, to present the engine's improved benchmarking results. The functioning of this engine has been analysed with the aim to find and optimize the main working parameters. To obtain this goal the Stirling engine has been equipped with different kinds of electronic sensors. A microcontroller testing circuit has been designed, which uses the acquisition of data from the data module.*

***Streszczenie.** Artykuł prezentuje system pomiarowy z mikrokontrolerem, diagnozujący i oceniający efektywność pracy zbudowanego silnika Stirlinga (zgłoszenie patentowe ipo.gov1310365.5). W tym celu zaimplementowany został model analizujący parametry silnika z różnymi ustawieniami zespołów zewnętrznych (takich jak zawory, nagrzewnice) oraz przy różnym medium roboczym, celem znalezienia i optymalizacji odpowiednich wartości roboczych parametrów modelu. Silnik Stirlinga został wyposażony w szereg elektronicznych czujników. Zaprojektowany układ testujący pracuje w systemie „embeded" z wykorzystaniem mikrokontrolerów w układzie hierarchicznym. (**Mikrokontrolerowy system diagnostyczny do badań silnika Stirlinga**).*

Keywords: Stirling Engine, heat transfer, regenerator, performance.
Słowa kluczowe: Silnik Stirlinga, obieg ciepła, regenerator, wydajność.

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Introduction

The Stirling engine is a multi energy-sourced engine, as it may use solar energy, combustion energy and heat from old coal refuse heaps. They make considerably less pollution than the traditional engines. The absence of explosive nature in converting heat energy into mechanical one, conveys to silent and cleaner operation. The Stirling engine works in a closed cycle, as shown in Fig. 1. As the working gas here is helium, trapped in the machine undergoes the following transformations: from point 1 → 2 isothermal compression, from point 2 → 3 isochoric heating, from point 3 → 4 isothermal expansion, from point 4 → 1isochoric cooling.

The expansion volume is maintained at high temperature, and the compression volume is maintained at low temperature. The theoretical efficiency is equivalent to the Carnot cycle.

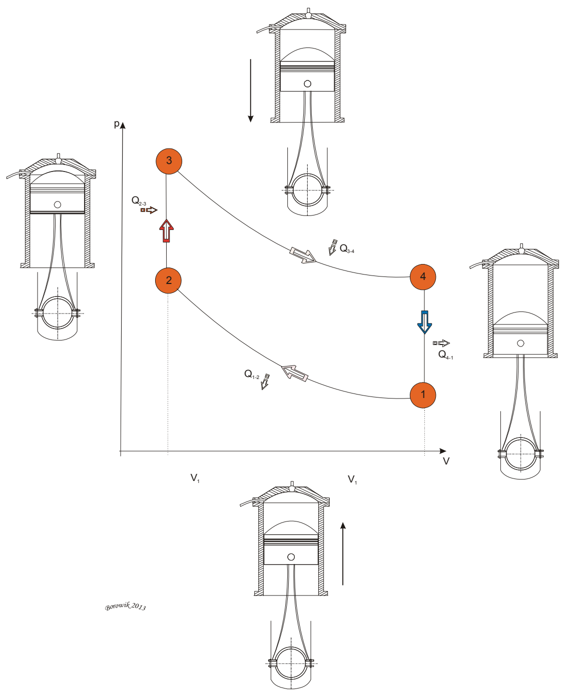

Fig.1. Thermodynamic cycle of the Stirling engine

Thermodynamic cycle of the Stirling engine

In this cycle a constant mass of helium is alternately: relaxed, cooled, compressed and warmed. The processes of heating and cooling are improved by using a regenerator. The regenerator is generally a metal cylinder constituted by an annular unit. Matrix for the regenerator is based on 0,14mm steel wire. It works as a thermal sponge, which alternatively absorbs and releases heat.

The objective of the research was to study the Alfa type Stirling Engine, which has been developed in order to perform modernization and to make a benchmark of it efficiency. The Alfa engine shown in Fig. 2 consists of two separate cylinders, and each one has its own piston.

The Stirling engine with Ross Yoke linkage

The power output is produced by the separate motions of the individual pistons. Drive mechanism poses some problems for the Alfa type Stirling engine, since discontinuous motion is required to achieve the volumetric changes that result in a net power output.

For this reason, in this engine for transferring dual piston motion into rotational motion - the Ross yoke mechanism has been implemented.

The Ross yoke mechanism does not produce sinusoidal volume variations and has the advantage over the traditional system by minimizing lateral forces acting on the pistons and leading to a more efficient and compact design.

The objectives of the test bench are mainly to characterize the performance of Stirling engines and to evaluate different control strategies for engines, which operate with variable heat sources.

With respect to the thermal metrology conditions, the engine is equipped with 8 thermocouples, 4 pressure transducers and volume transducers.

The microcontroller based system measures Torque and Rpm on the main shaft. Using this data volume a transducer will determine the total air volume trapped in the 2 rooms, as well as in the regenerator. It delivers the signal of continuous tension. Its maximum corresponds to V_{max} = 230 cm^3 and the minimum corresponds to V_{min} = 120 cm^3.

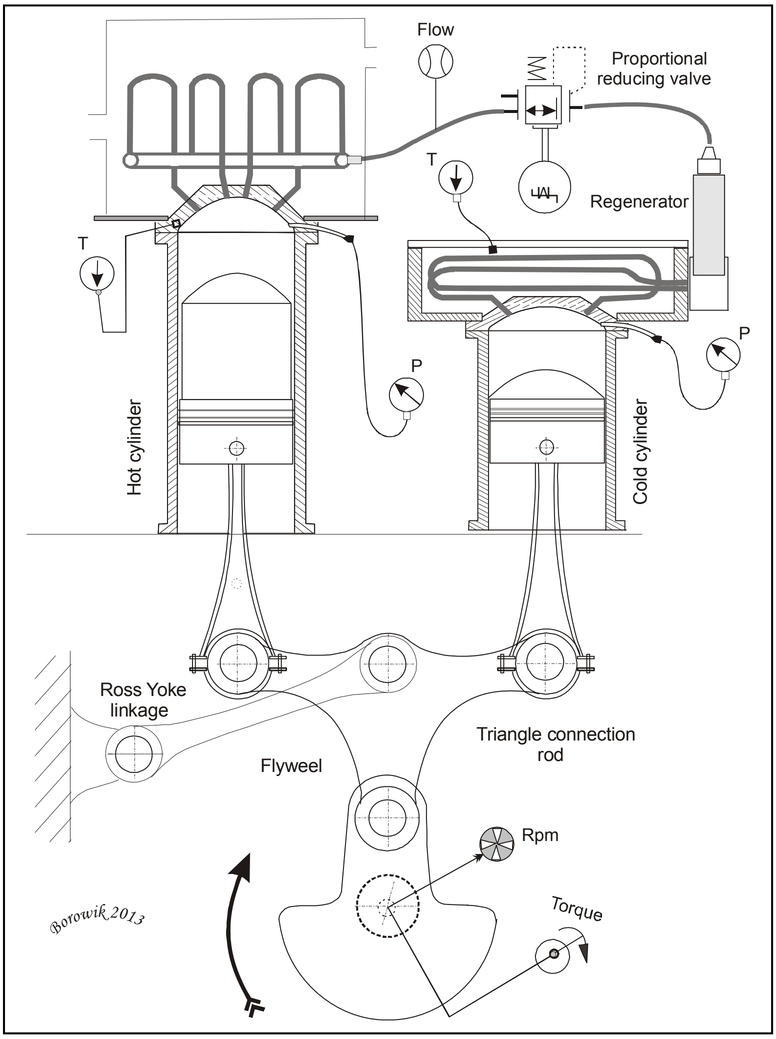

Fig. 2. The Stirling engine with Ross Yoke linkage

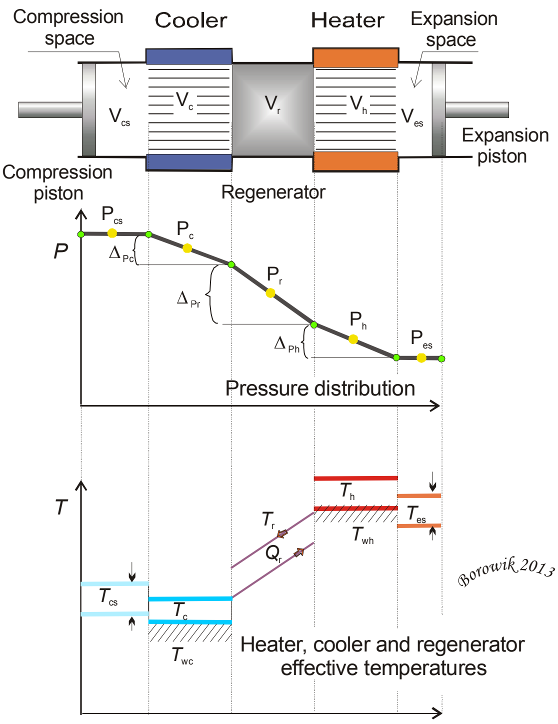

Fig. 3. Stirling engine testing facilities

Voltage delivered by this transducer is proportional to the volume of gas shunt in the Stirling engine, as shown in Fig. 3.

A letter V denotes Volume, a letter P denotes Pressure, a letter T – Temperature, a letter Q – Heat, a letter R - gas constant, m – mass of gas in different component and some of these letters have the following subscripts: *cs* – denoting a compression space, *c* – a cooler, *r* – a regenerator, *h* – a heater, *es* – an expansion space, and *w* – wall, so for example T_{wc} denotes a temperature of a cooler's wall.

The temperature of the gas in the various compartments can be calculated from the perfect gas law:

$$T_{cs} = P_{cs} \cdot V_{cs} / R \cdot m_{cs}$$

$$T_c = P_c \cdot V_c / R \cdot m_c$$

$$T_h = P_h \cdot V_h / R \cdot m_h$$

$$T_{es} = P_{es} \cdot V_{es} / R \cdot m_{es}.$$

The figure shows the pressure and the temperature distributions in the various engine compartments. The heater and the cooler walls are maintained isothermally at temperatures: T_{wh} and T_{wc} *respectively.*

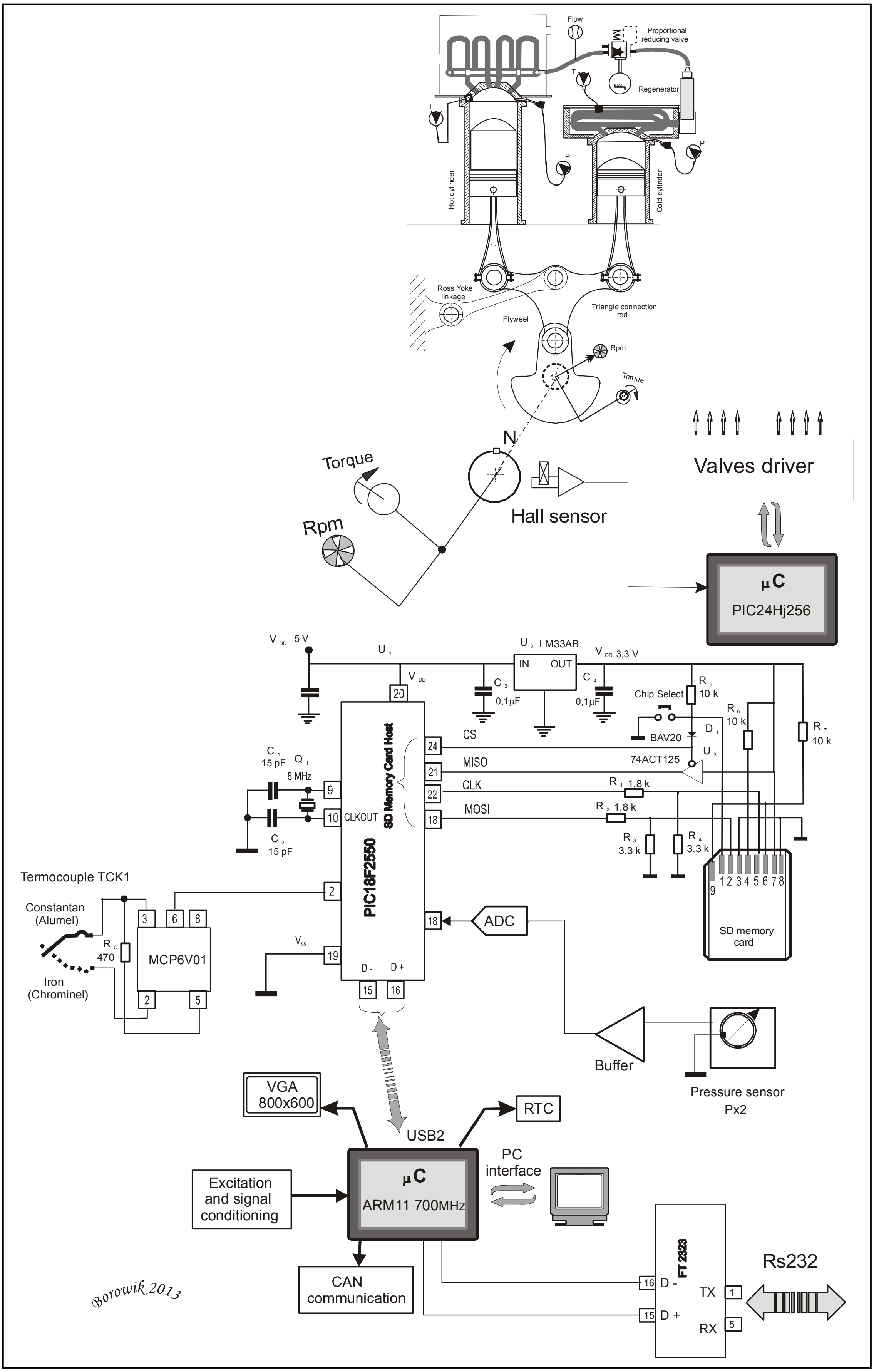

Fig. 5. The Stirling engine testing facilities

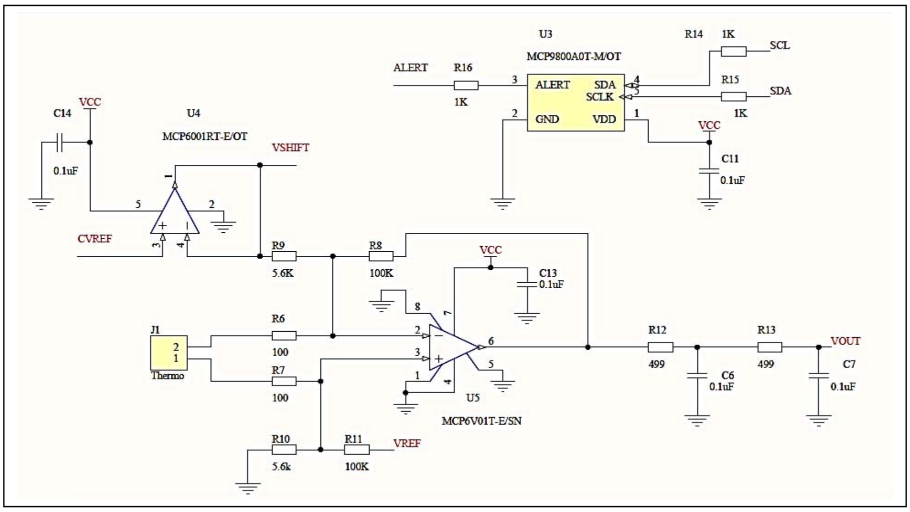

Fig. 4. The thermocouple circuit for temperature monitoring in the Stirling engine

The thermocouple circuit for temperature monitoring in the Stirling engine

To reach those objectives the system has been equipped with sensors, actuators and management software that allow a flexible operation.

The test platform is composed of different subsystems: heating and cooling subsystem, electric subsystem, management and control subsystem. The platform allows testing the Stirling engine under different filling pressures, shaft speeds and hot temperatures of the heat exchanger.

Related to the last one, a temperature control loop implemented in the hot air generator controller (independent of the engine operating conditions) allows the hot temperature of the heat exchanger, fixing whatever engine control system employed.

The management software permits running semi automatic tests at different operating conditions, and with its manual version, testing new strategies for start and stop procedures. The temperature of the engine is subject to thermal regime conditions. In the conducted testing as thermoelectric sensor Fe-CuNi/J/ class 1 we used transducers (thermocouple type TTJ/KE-361), what is shown in the schematic diagram in Fig. 4.

The thermocouple matches the characteristic of type J (Iron-Constantan) and is trimmed for type K (Chromel-Alumel) inputs. Thermocouple amplifiers shown in Fig. 2 represent calibration accuracies ± 1 °C, working with cold Junction Compensation and High Impedance Differential Input. It combines an ice point reference with a prefabricated amplifier to produce a high level (equal to 10 mV/°C) output directory from a thermocouple signal.

It can be used to amplify its compensation voltages directly, thereby converting it to a stand alone Celsius transducer, with a low impedance voltage output. It includes Reference temperature U_3 MCP9800A0T digital temperature sensor. The register setting allows for user selectable 12-bit temperature resolution measurements. The sensor works in industry standard I2C. To reduce the amount of circuitry the application monitors only four signal channels, but any number of channels supported by the PIC18F2550 microcontroller could be monitored (Fig. 5).

The Stirling engine testing facilities

In order to monitor the Stirling engine performance some temperature sensors have been mounted. Measuring the temperature in the Stirling engine is not a simple matter because of the small volumes involved in the exchangers and the fast changes of the temperature of the working gas during the thermodynamic cycle. So, only the average temperature can be measured during a single cycle. The engine has been equipped with 5 temperature sensors inside the regenerator, one inside a tube from the hot side of the heat exchanger, one inside the one from the cold side, and two inside the compression chamber. Other temperature sensors were mounted in the water circuit, in the carter and in the exhaust gas circuit. The compression chamber pressure has been also monitored, together with the rotational speed of the crankshaft and the output electric power generator.

Figure 5 shows a measuring system for the cold energy used in the Stirling engine. Working gas temperature and pressure are measured at the three points, which are: the compression space, the expansion space, and the buffer space. Wall temperature of the cold side heat exchanger is measured at the top and the bottom side.

Conclusions

Through this test bench we can carry out experimental analysis of the α Stirling engine, which allows us to investigate the importance of applying the correct buffer volume pressure in order to obtain advantages in term of the power on the shaft. Taking into account the resulting energy dissipation leads to severe limitations on the maximum attainable thermal efficiency, and non-dimensional power output *P*. These limitations are independent of the regenerator conductance.

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