PROPOSAL OF A NEW CONSTRUCTION OF STIRLING ENGINE REGENERATOR

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ABSTRACT

This article describes the function and construction of the Stirling engine regenerator. Its model was constructed in UEEN laboratory and was analyzed and measured to obtain new knowledge of its features. Based on this, a proposal for the new construction of the Stirling engine regenerator was made.

1 MODEL OF STIRLING ENGINE

The model of the Stirling engine constructed by the Department of Electrical Power Engineering (Figures 1 and 2) is combination of Beta and Gamma type. The displacer, having also a function of regenerator, and the power piston of engine lie in one axe. This model has a low load (watt's unit) and serves for experimental research and educational objects.

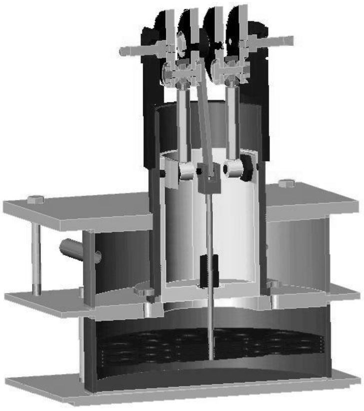

Figure 1: Cross-section of the model.

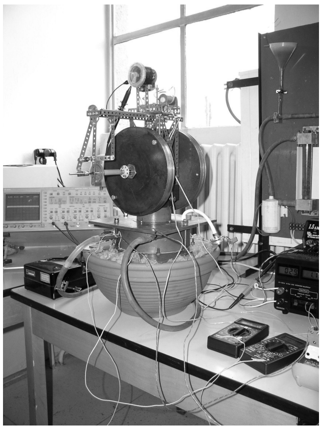

Figure 2: Picture of laboratory model.

2 CALCULATED AND MEASURED CHARACTERISTICS

We used real constructional parameters of device to calculate coefficients and values calculations described by Schmidt's theory. This is the only way how it is possible objectively compare features of real and simulated engine. It is true some characteristics of theoretic analyze are not applicable in practice. It is concerned as for mathematic description of motor piston move that is differ from theoretic projection of this move. Input data of model:

- diameter of cylinder and piston $= 0.072\ m$,
- diameter of displacer piston $= 0.168\ m$,
- diameter of move piston cylinder $= 0.17\ m$,
- stroke of piston $= 0.036\ m$,
- temperature of expansion $T_E = 155\ °C$,
- temperature of compression $T_C = 20\ °C$,
- phase angle $\varphi = \frac{\pi}{2}$,
- presure $p_{str} = 101325\ Pa$,
- stroke capacity of expansion space $V_{SE} = 0.0008171\ m^3$,
- stroke capacity of compression space $V_{SC} = 0.0001465\ m^3$,
- dead volume of expansion space $V_{DE} = 0.0004478\ m^3$,
- dead volume of expansion space from all compression space $V_{DC} = 0.00000384\ m^3$,
- motor speed $n = 70\ min^{-1}$.

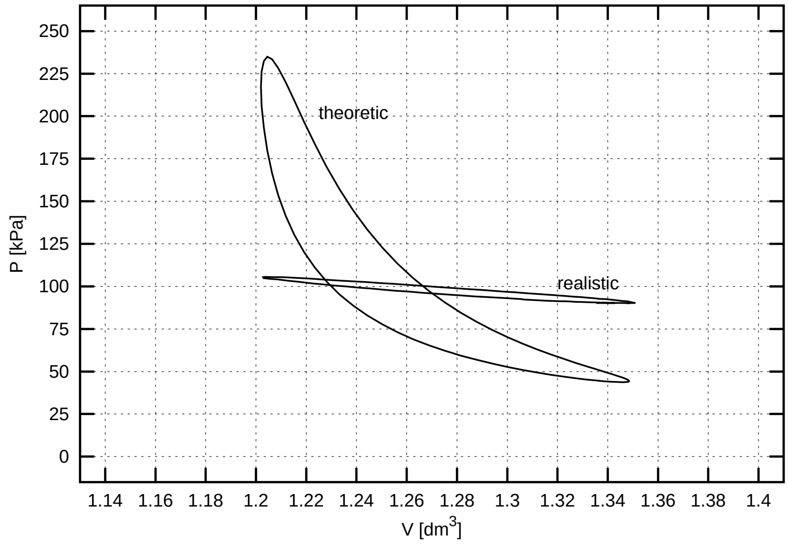

Figure 3: p - V diagrams of theoretic and realistic engine.

Expansion temperature, compression temperature and motor speed we gained by measure with temperature input $P = 130W$. The other parameters are related with motor construction and are constant. We used Schmidt beta-type theory for our analyze because it is most alike to model constructed in laboratory UEEN. Constitute to these theory formulas we gained theoretic $p-V$ diagram demonstrated on Figure 3. It is related to elected temperatures and motor speed. Theoretic $p-V$ diagram we compared with real diagram gained by measure. Diametrical difference between theoretic and real diagram is evident. So our conclusion is follows: expansion and compression processes do not run by these measure temperatures. The reason is we are not able to measure gas temperature by expansion and compression. Temperatures that we are measure are temperatures of hot and cold motor board. Real gas temperatures are so wholly different. That is way we did new calculation and the temperatures adapted in order to theoretic and real diagram are equivalent. We found out that the temperatures proportion for theoretic and real diagram equivalent is cca 0.843 and it could be $T_E = 35.0\ °C$, $T_C = 29.5\ °C$.

We found out that Stirling engine has many imperfections. Real expansion and compression temperature is very different from measured values which ones we considered close to compression and expansion temperatures. This difference is caused by missing of regenerator function. The original construction and materials used were unsuitable; hence it is necessary to construct new regenerator.

3 THE LOCATION OF COOLING HOLES BASED ON RESISTANCE PAPER ANALOGUE STUDIES ON A NEW REGENERATOR

The original construction of the plate of the regenerator is displayed in Figure 4. The passage of air and its regeneration is blocked by the size and location of cooling holes. Thus, there is a proposal for the construction of a new regenerator plate.

An effective method of properly locating cooling holes to achieve a uniform plate temperature has been suggested by resistance paper analogue measurements of the increase in effective resistance caused by the presence of the cooling holes. The disturbance of the current by the holes, and therefore the local increase in resistance, is schematically illustrated in [1, 2].

If one assumes that the plate will be cooled by rings of holes, with each ring containing an equal number of holes, we can divide the plate into sections bounded by the center lines of adjacent rings as shown in Figure 5. Model studies with resistance paper analogues can now be used to find the ratio of the resistance of such a band with holes, as against the resistance without holes. Over a wide range of variation of hole diameter, hole spacing, and band width as defined in Figure 5, the analogue studies yield the following surprisingly simple result for the ratio of resistances:

$$\frac{R_i}{R_{io}} = 2 \cdot \frac{S_{io}}{S_i} - 1 = K_i, \tag{1}$$

where $S_i =$ band surface area with holes,

$S_{io} =$ band surface without holes.

We can conveniently rewrite (1) in terms of the area removed for cooling: thus

$$K_i = \frac{1+\gamma_i}{1-\gamma_i} \quad ; \quad \gamma_i = \frac{S_{id}}{S_{io}} \quad ; \quad \alpha_i = \frac{a_i + \Delta a_i}{a_i} \quad ; \quad l = \frac{2 \cdot \pi \cdot a}{n} \tag{2}$$

where $S_{io} =$ area of band without holes,
$S_{id} =$ area removed from band for cooling,
$n =$ number of holes per ring,
$d =$ diameter of holes,
$a_i =$ radius of the inner ring of holes in the band.

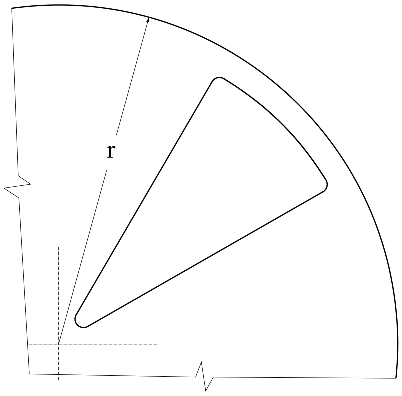

Figure 4: There is an illustration of the construction of the Stirling engine's original regenerator plate. The cooling holes consist of four incisions. The plates are turned to each other at 90 degrees and form an impassable layer.

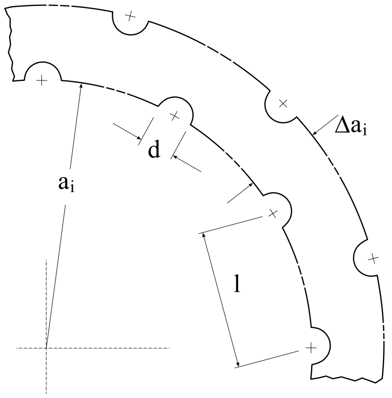

Figure 5: Definition of parameters for use in location of cooling holes. The i^{th} band of a Bitter plate defined by the center lines of adjacent rings of holes of diameter d, where each ring contains n holes.

The power in a band at a given voltage is simply V^2/R_i. Therefore, with the same amount of cooling surface available in each band (the number and diameter of holes in each ring is assumed constant), the heat flux will be constant if we choose the width of each successive band to give the same resistance per band. (This will not necessarily produce a constant gradient within the material, but the boundary-layer temperature rise almost invariably predominates over the temperature gradient, and a constant-heat-flux criterion will therefore yield very nearly a constant temperature.) Under conditions of nearly constant temperature (and therefore resistivity), then, each band will have a resistance:

$$R_i = \frac{K_i \cdot 2\pi \cdot \rho}{t \cdot ln \alpha_i} \quad ; \quad \alpha_i = \frac{a_i + \Delta a_i}{a_i} \tag{3}$$

where $\rho =$ resistivity,
$t =$ plate thickness,
$K_i =$ is taken from (2).

Therefore, to have a constant resistance in each band, we must choose each band so that:

$$\frac{ln\alpha_i}{K_i} = constant = C, \tag{4}$$

If we satisfy (4) for each band and if each band has the same number of equal-diameter holes, we will achieve a constant heat flux throughout the plate. The value of the constant C in (4) is set by the location of the first ring of holes. Each succeeding ring of holes can be located sequentially by letting the *OD* of the band just established be the *ID* of the next band and then by searching for the value of α which satisfies the already established constant C. The result is depicted in Figure 6. A set of these plates form the whole regenerator.

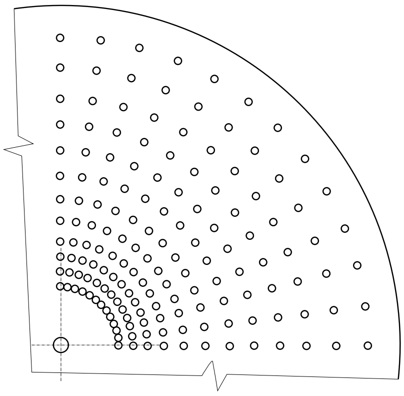

Figure 6: There is an illustration of the construction of the Stirling engine's new regenerator plate.

4 CONCLUSION

We analyzed the model of the Stirling engine to obtain its features. It was found that the unsuitable construction of regenerator made for poor regeneration or even its complete absence and, thusly, low power. Using the results of the resistance paper analogue studies, we made a proposal for the new construction of the regenerator. The model measurements by the computer system Ansys, followed by practical measurements are the next steps of our experiment.

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REFERENCES

[1] Brechna, H.: National magnet laboratory report NML-62-1 (1962).

[2] Fournier, J.: No. 61, Centre d'etudes nucléaires de Grenoble (June 1966).