THE STUDY OF THE IRREVERSIBILITY OF THE OPERATIONAL PROCESS OF THE EXTERNAL COMBUSTION ENGINES WITH HEAT REGENERATORS

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Abstract. The study, integrated in a wide interest field, Energy-Environment, deals with an important issue nowadays, that is the study of the irreversibility of Stirling external combustion engine and extending this to internal combustion engines. The theoretical researches will be done analytically and graphically and the result will be validated after comparing them with the experimental values of the actual engines.
Keywords: Stirling, cycle, losses, efficiency, regenerator, heat, transfer, experimental validation.

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The group of work will make and present, for the first time in the world, both the ideal cycle and the theoretical cycle that is the real one, for at least two types of Stirling engines.

We will make a study for sensitivity with the computing diagram for Sterling engines with the temperature optimized at warm source. Three sources of irreversibility will be taken into consideration: ΔT at heat sources, $\Sigma\Delta p$ – pressure drops due to finite speed in the regenerator, on the pistons and internal friction, and X – imperfect regeneration.

In the determinations it will be taken into account the specific heat varying with the temperature, for the working agent (air, hydrogen, helium). More computing diagrams will be made to obtain a computing diagram that should give the identical results with those of the actual engines considered as reference. Foe each computing diagram a sensitivity study will be made, on a wide range of parameters *E* – compression ratio, *W* – piston speed, *TH1S* – temperature of the warm source, *X* – imperfect regeneration, *Pmed* – medium pressure in the engine, working agent (air, hydrogen, and helium).

It will be taken into consideration that the pistons have a sinusoidal movement and, separately, of the pressure losses from the regenerator at the respective medium temperatures and pressures.

If for a certain engine it is made a code where to be used (as for the NASA Code), 9 (nine) parameters, we want that the computing diagram we will make to have the most two parameters. We will keep the two parameters constant, so practically we will use o formula and we are sure that the analytically obtained results will be identical with the real ones both for classical engines and for those with free pistons that is solar ones.

In the following step we will determine a number of 5 computing formulas for *X* but it should be taken into consideration that *X* to be a function to depend on a very large number of characteristic parameters of the regenerator, so that to be taken into consideration as many irreversibilities as possible. A sensitivity study will be done according to different parameters.

Evidently it is expected that *X* to depend of a series of constructive and functional factors. Only the analytical knowledge of such dependence can lead to optimization of Sterling engine even from the drawing stage.

The main idea of this computing diagram is to show that similar as more *Δp* generate losses, so more Δ*T* generate losses (that was discovered by Carnot). Unfortunately, if the intuitive explanation of the mechanism of more Δ*p* generate mechanical work or mechanical power losses is relatively simple, the way in which more internal Δ*T* (for example even inside the Regenerator) generate finally mechanical work or power losses is much more subtle. We will start from making an intuitive diagram that will try to describe the processes in the Regenerator, so a diagram to describe the variation in time of temperature distribution in the Regenerator. Based on this diagram we will go on to estimating *X*, applying the first principle of thermodynamics in the Regenerator. The properties of the Regenerator will be estimated meaning the equivalent weight and area that will become functions of constructive and functional parameters. Then, a computing relation is drawn for α – convection coefficient that will be function of properties and geometric parameters of the engine and regenerator but also of the physical properties of the working agent.

So, *X* will be function of all the above factors. The next step is validation of the 5 computing relations for *X*.

Taking into consideration that the combining computing diagram and the computing diagram for *X* has been validated, these diagrams will be combined in one and then it will be validated on real engines produced in Germany, Russia, Japan, USA etc. and this will be called global computing diagram, meaning that we will have the computing relations for *P* power and η output. A sensitivity study for the global computing diagram will be done for *X* and α. The fluctuation of the power and the output will be checked, the fluctuation of *X* and α for different parameters and finally for all the parameters enumerated in the context of presenting the project. It will be concluded that the global computing diagram (for power and output) correctly includes all the irreversibility that take place in the engine.

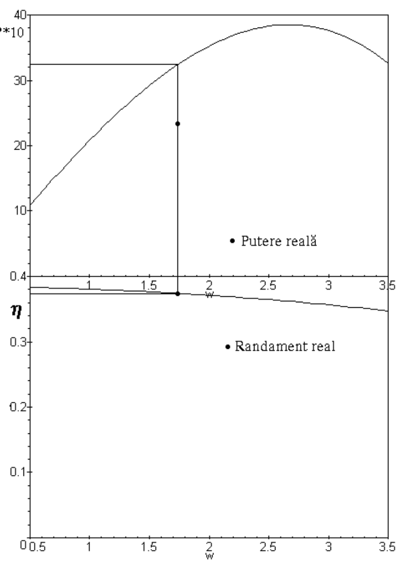

Fig. 1

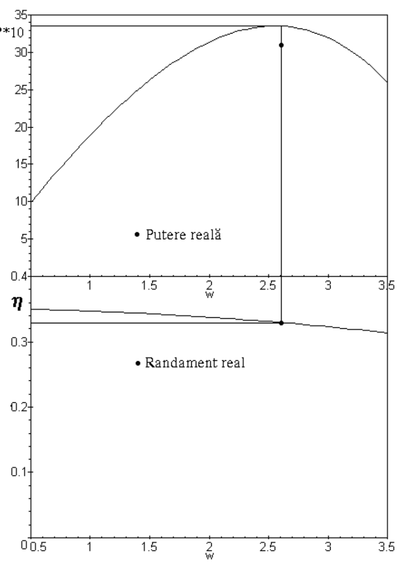

Fig. 2

During the project original computing diagrams will be made which as will be shown in their practical application are according to the reality based on comparison with the results of the experiments obtained in the Stirling engines made with the highest technologies (Japanese, American, Swedish, German and Russian).

Both the global computing diagram and the multitude of diagrams obtained from sensitivity studies function of a very great number of parameters, offers a powerful computing instrument in the drawing activity and optimization of Stirling engines, and on the other hand using the determined computing relations it will be eliminated the phase of making the prototype (that means some good years of designing, research, experimenting etc.) going straight to making the engine.

Because the prototype phase is eliminated, the costs of these engines will be considerable reduced.

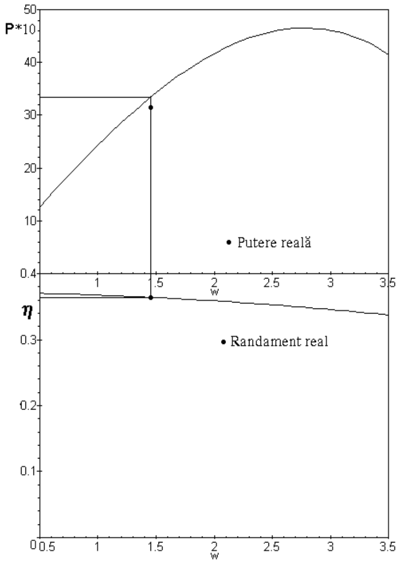

Fig. 3

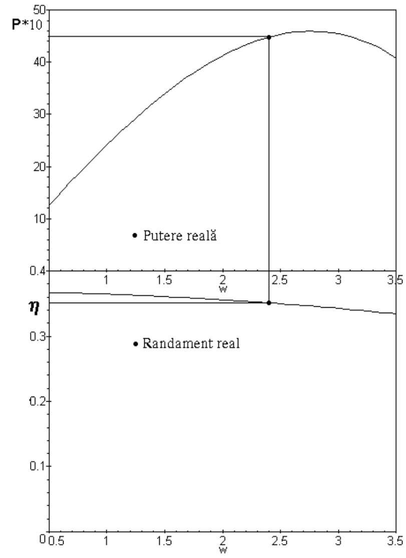

Fig. 4

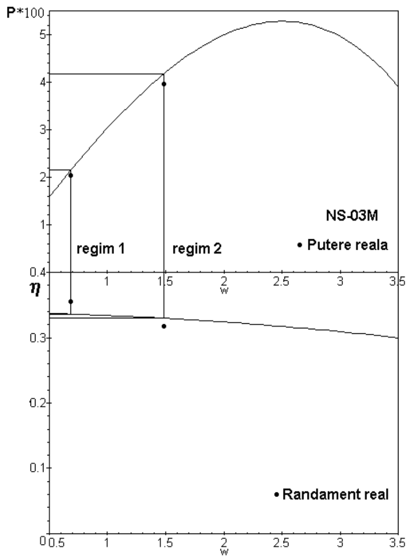

Fig. 5

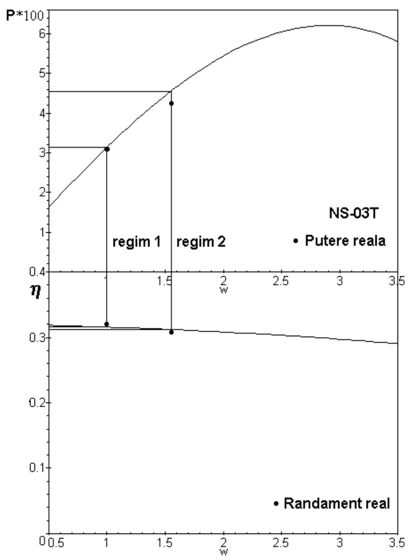

Fig. 6

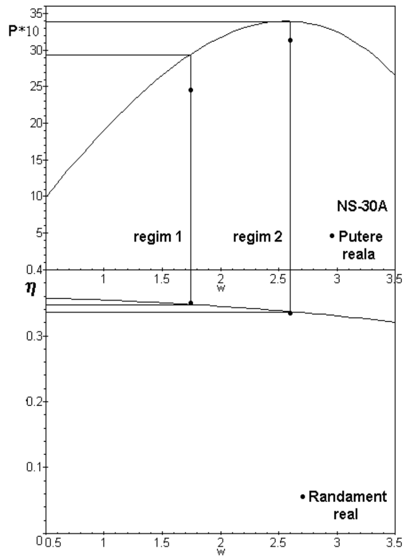

Fig. 7

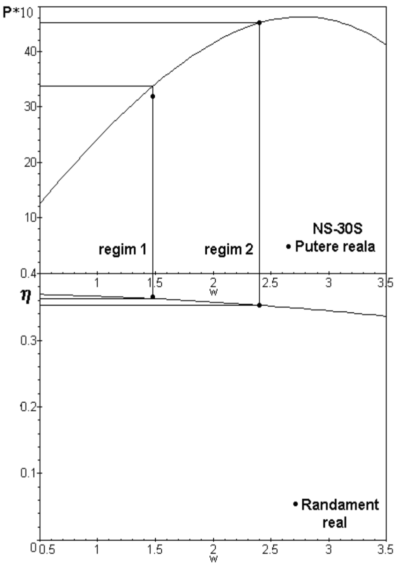

Fig. 8

Then, the working group, including specialists in engines, with a solid and real bases in dimensioning, designing of the engines that use heat regenerators on the one hand, and on the other based on studying about 200 books, manuals, scientific research etc. from the last 10 years, will go to another stage, meaning increasing the power and output for the existing internal combustion engines, by regeneration of heat.

The working way will be similar to that of Stirling engines. We will take into consideration several constructive solutions like:

– piston mounted regenerator (fig. 9);

– regenerator mounted on the common inlet-exhaust manifold (fig. 10);

– dead space mounted regenerator (fig. 11), and many others. In the computing relations will be included geometric and functional parameters of the working agent etc:

$$\begin{cases} n_r = 122 \text{ rot/min}; \\ T_o = 313 \text{ K}; \\ T_L = T_o + 25 \, [\text{K}]. \end{cases} \tag{1}$$

$$\begin{cases} j = 0.71; \\ m_g = 23.02902 \text{ kg}; \\ c_R = 0.46 \text{ kJ/kg} \cdot \text{K}; \\ c_v = 0.718 \text{ kJ/kg} \cdot \text{K}; \\ c_p = 1.049 \text{ kJ/kg} \cdot \text{K}. \end{cases} \quad (2$$

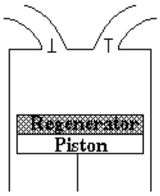

Fig. 9

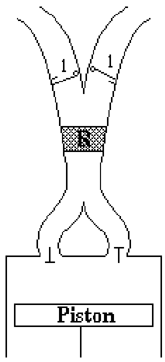

Fig. 10

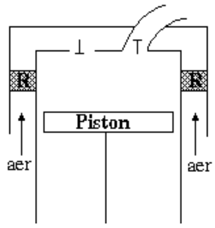

Fig. 11

$$\eta_{MS}=\left(1-\frac{T_0}{T_{H,S}}\right)\cdot\frac{1}{1+\sqrt{\frac{T_0}{T_{H,S}}}}\cdot\frac{1}{1+\frac{\left[j\cdot\frac{1+2R+e^{-\gamma}}{2(1+R)}+(1-j)\frac{R+e^{-\gamma}}{1+R}\right]\left(1-\sqrt{\frac{T_0}{T_{H,S}}}\right)c_v(T_m)}{R\ln\varepsilon}}\cdot$$
$$\cdot\left(1-\frac{\left(\frac{w}{w_{S,L}}\right)K\cdot(\ln\varepsilon)\cdot\left(1+\sqrt{\tau}\right)+2\cdot\left(\frac{w}{w_{S,L}}\right)^2 N_S+\frac{(0{,}94+0{,}045w)\cdot 10^5}{2p_4}}{2\eta'\tau\ln\varepsilon}-\right.$$
$$\left.-\frac{\left(\frac{w}{w_{S,L}}\right)K\cdot(\ln\varepsilon)\cdot\left(1+\sqrt{\tau}\right)+8\cdot\left(\frac{w}{w_{S,L}}\right)^2 N_S+\frac{(0{,}94+0{,}045w)\cdot 10^5}{p_4}}{2\eta'\tau\ln\varepsilon}\right) \tag{3}$$

$$P=\left(1-\sqrt{\frac{K}{RT_H}}w-y\frac{7.5T_L(\varepsilon-1)\left(w\frac{D_c^2}{Nr_{reg}D_R^2}\right)^2 N_S}{KRT_H^2\varepsilon\ln\varepsilon}\right)\left(1-\frac{T_0}{T_{H,S}}\right)\frac{1}{1+\sqrt{\frac{T_0}{T_{H,S}}}}\cdot \tag{4}$$
$$\cdot\frac{1}{1+\frac{\left[j\frac{1+2R+e^{-\gamma}}{2(1+R)}+(1-j)\frac{R+e^{-\gamma}}{1+R}\right]\left(1-\sqrt{\frac{T_0}{T_{H,S}}}\right)c_v(T_m)}{R\ln\varepsilon}}\cdot$$
$$\cdot\left[1-\frac{y\cdot\left(\frac{w}{w_{S,L}}\right)K(\ln\varepsilon)\left(1+\sqrt{\tau}\right)+8y\cdot\left(\frac{w}{w_{S,L}}\right)^2 N_S+\frac{(0{,}94+0{,}045w)10^5}{p_4}}{\left(1-\sqrt{\frac{K}{RT_H}}w-y\frac{7.5T_L(\varepsilon-1)\left(w\frac{D_c^2}{Nr_{reg}D_R^2}\right)^2 N_S}{KRT_H^2\varepsilon\ln\varepsilon}\right)\cdot\tau\eta'\ln\varepsilon}\right]\cdot$$
$$\cdot mRT_H(\ln\varepsilon)\frac{n_r}{60}$$

$$P = 2.743 \cdot 10^6 \text{ W} \quad (5)$$

$$\eta_{MS} = 0.405. \quad (6)$$

We consider that after validation we will obtain increase in power of 8-12% and of the output of 5-7%.

The research will be done on a wide range of engines with power between 45 kW and 10,000 kW. A lower power engine will be used experimentally.

It should be underlined that neither the displacement nor the compression ratio or any other value of the engine will be modified because the number of meshes is relatively reduced but the main point consists in the diameter of the mesh thread that has values of 0.04-0.06 mm. So, for an engine with a stroke of 100 mm, if we introduce 3 meshes, the stroke will be reduced with maximum 0.18 mm, while for a high power engine such as K6SZ 90/160 if a regenerator with 100 meshes is mounted, it means that from the 1600 mm stroke, the most 6mm will decrease.

The cost of a regenerator is minimal in comparison to that of an engine taking also into account the improvement of the engine characteristics.

Even if we do not seem too modest, the working group, will be able to enhance the characteristics of any type of existing engine with a minimum of costs or the new classical engines will be provided with heat regenerators when they are made, which means worldwide an extremely rich and valuable material for research, optimization and drawing internal combustion engines.

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