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Discussion

Discussion: ''Analysis of the Working Process and Mechanical Losses in a Stirling Engine for a Solar Power Unit'' (Makhkamov, Kh. Kh., and Ingham, D. B., 1999, ASME J. Solar Energ. Eng., 121, pp. 121–127)

J. I. Prieto
Ing. Naval, Dr. Ing. Ind., Department of Physics,
University of Oviedo, Spain

Stirling engine based units are considered among the most effective alternatives for future solar applications at low power range. In order to analyze and to improve the performance of the three main subsystems of those units, namely, the solar receiver, the thermodynamic gas circuit, and the drive mechanism, simulations codes are under development worldwide. Therefore, the authors must be congratulated not only on the quality of their paper, but also on its current interest.

The authors claim that there is a good agreement between the calculated performance and the experimental results. Unfortunately, however, there is hardly any reference to the influence of velocity on either indicated power or mechanical losses. Yet, I have verified that widely accepted simulation codes can present very different degrees of accuracy depending on the operating point considered.

Organ [1] has introduced similarity criteria that evidence interrelations between the engine speed and other indicated performance parameters. Independently, Prieto and co-workers have derived the complete set of dimensionless parameters influencing the indicated performance and have proposed a method to apply similarity to analysis and design. A wide variety of prototypes has been analyzed, and a general model of performance has recently been proposed to cover wide temperature, pressure, size, and power ranges (see, for example, [2]).

The influence of the Mach number, $N_{\mathrm{MA}}=nV_e^{1/3}/\sqrt{RT_c}$, a kind of dimensionless engine speed, on the dimensionless indicated power, $\zeta=N_i/(\overline{P}V_e n)$, can be expressed by means of:

$$\zeta=\zeta_0-\Phi N_{\mathrm{MA}}-\Psi N_{\mathrm{MA}}^2 \tag{1}$$

where Φ and Ψ are dimensionless factors of the indicated power losses, and the coefficient ζ_0, known as quasi-static simulation, represents the theoretical thermodynamic prediction assuming an ideal cycle without any thermal or mechanical irreversibilities. Approximately, ζ_0 can be computed by the well-known Schmidt's model.

The values $\zeta_{\max}$ and $N_{\mathrm{MA,max}}$ at the maximum indicated power point fulfill the following equations:

$$\tfrac{1}{2}\zeta_0\leqslant\zeta_{\max}\leqslant\tfrac{2}{3}\zeta_0 \tag{2}$$

$$N_{\mathrm{MA,max}}=\frac{\sqrt{\Phi^2+3\zeta_0\Psi}-\Phi}{3\Psi} \tag{3}$$

$N_{\mathrm{MA,max}}$ can be considered as an index of engine development level, i.e., it is not an independent design parameter but a function which depends on the same parameters influencing the indicated power.

If the authors could obtain experimental measurements of $\zeta_{\max}$ and $N_{\mathrm{MA,max}}$, coefficients Φ and Ψ could be derived from the following equations:

$$\Phi=\frac{2\zeta_0-3\zeta_{\max}}{N_{\mathrm{MA,max}}} \tag{4}$$

$$\Psi=\frac{2\zeta_{\max}-\zeta_0}{N_{\mathrm{MA,max}}^2} \tag{5}$$

On the other hand, I have recently verified that the dimensionless power of the mechanical losses, $\zeta_{\mathrm{mech}}=N_{\mathrm{mech}}/(\overline{P}V_e n)$, is correlated to a series of dimensionless variables among which the Stirling number, $N_{\mathrm{SG}}=\overline{P}/(\mu n)$, where μ is the working fluid viscosity, stands out. N_{SG} evidences the influence of forces, viscosity, and velocity on mechanical power losses and it could be considered as a variation of a classical parameter in Tribology, usually known as the Sommerfeld number (see, for example, [3]).

ζ_{mech} and N_{SG} could be correlated by combining experimental brake power measurements and indicated power maps based on Eq. (1), which could confirm the accuracy of both the assumptions $n=1200\ \mathrm{min}^{-1}$ and $\mu_g=\mu_s=\mu_{sh}=0.4$ for helium at the operating point specified.

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Closure to "Discussion: 'Analysis of the Working Process and Mechanical Losses in a Stirling Engine for a Solar Power Unit'" (Prieto, J. I., 2000, ASME J. Solar Energ. Eng., 122, p. 207)

Kh. Kh. Makhkamov
Physical-Technical Institute of the Uzbek Academy of Sciences, Mavlyanova 2-B, Tashkent, 700084, Uzbekistan

D. B. Ingham
School of Mathematics, The University of Leeds, Leeds, LS2 9JT UK

Prieto et al. [1] propose a generic equation which should be applied to a wide variety of known kinematic Stirling Engines for the determination of the dimensionless value of the indicated and brake power as a function of the speed of the engine and of some dimensionless parameters Φ and Ψ for different operating conditions. The magnitudes of Φ and Ψ, in turn, depend on the parameters involved in the working process and the design dimensions of the machine. Prieto suggests that the approximate value of ζ_0 in Eq. (1) in the above discussion may be found from the Schmidt's model and further, the parameters Φ and Ψ should be calculated with the use of the experimental data obtained at the point when the engine operates with the maximum indicated power.

The above approach is only a small part of the extensive amount of work performed by these authors on deriving a complete system of dimensionless groups in order to represent the performance of different kinematic Stirling Engines. This approach is also known as the full dynamic similarity-scaling approach for the analysis and design of Stirling Engines (see [2–4]) and it has been used by many researchers in the development of new engines and for the evaluation of their performance.

The Laboratory for Stirling Engines at the Physical-Technical Institute, Tashkent, Uzbekistan, has developed a wide range of kinematic Stirling Engines of different types and configurations for operation with the use of solar energy and fossil fuels and in our paper we have described some of the methods and the simplest computer simulation model which we use in the engine development process. It has not been our aim to define the influence of the speed of the engine on the indicated (or brake) power and on the mechanical losses in the frame of this publication.

We appreciate the importance of the dynamic similarity-scaling approach for the analysis and design of Stirling Engines. The use of these methods is, undoubtedly, very useful in the development of new machine designs. Unfortunately, our experience is that the above method may only be employed in the initial stages of the design and for the preliminary evaluation of the performance of the prospective engine. Extra precautions should be taken when new machines are under consideration which are not of a similar configuration to those that have been built and tested.

In our activity, we give preference and more reliance to an approach when an individual numerical simulation is performed for every engine we are working on. In doing so, different order of mathematical models are usually used in a sequential fashion. Such an approach allows us, for example, to take into account and analyze the influence of the working process parameters, geometrical dimensions, and the material properties of the guiding and sealing rings, etc. for the determination of the mechanical losses.

In our next paper, which we hope will follow this discussion, we will describe the use of CFD modelling for the analysis of the working process and the determination of the performance of the Stirling Engine.

Clearly, the individual numerical simulation, with the detailed analysis of the work of the Stirling Engine, and the use of the series of complex mathematical models is a time consuming process but in the end it gives more accurate predictions. In our opinion, it is essential to follow this approach when it concerns the costly development of a sophisticated piece of machinery such as Stirling Engines.

References

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