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NUMERICAL INVESTIGATION OF THE SPRING CONSTANT IMPACT ON THE WORK OF A STIRLING-RINGBOM ENGINE WITH AN ELASTIC ELEMENT

Assist. Prof. Tsvetelina Petrova, PhD
College of Energy and Electronics (CEE)
Department of Energy and Mechanical Engineering,
Technical University of Sofia, Sofia, Bulgaria
Tel.: +359895 589913
E-mail: tzvetelina.petrova@tu-sofia.bg

Assoc. Prof. Detelin Markov, PhD
Department of Hydroaerodynamics and Hydraulic Machines,
Technical University of Sofia, Sofia, Bulgaria
Tel.: 02/965 3305
E-mail: detmar@abv.bg

Prof. Emil Ratz, DSc
Department of Electrical Machines,
Technical University of Sofia, Sofia, Bulgaria
Tel.: 02/965 2153
E-mail: erra@tu-sofia.bg

Abstract: *Current work deals with numerical simulation of the behaviour of a Stirling-Ringbom engine with an elastic element that assists the displacer piston movement from its top dead centre toward its bottom dead centre. The variation of the atmospheric pressure and the temperature of the hot source influence engine operation. Therefore, the goal of this material is to identify the character and the extent of this influence. This paper shows that by variation of the spring constant it is possible to achieve stable operation of the engine concerned under variation of the environment parameters within certain intervals.*

Keywords: *Stirling-Ringbom engine, Elastic element, Sping constant, Engine behaviour*.

INTRODUCTION

Stirling engine is patented in 1816 by Robert Stirling as a new type of engine with external heat source. The main parts of this engine are two connected cylinders with different cross sections, in which the pistons are moved by the working fluid. The pistons of the first machine are both binded to a flywheel. The Striling engine is still object of investigations and modifications 200 years after its invention.

Here is investigated the behaviour of a modification of the Stirling engine the so-called “hybrid” Stirling-Ringbom engine. It is termed like this because the bigger piston (the displacer) moves freely, while the power piston is linked to a flywheel (Senft, J., 2008). Efficient operation of this engine, which depends strongly on a great number of parameters, may be reached only when those parameters vary in narrow intervals (Petrova, Ts., Markov, D., & Naydenova I., 2016). For breaking these limitations, an elastic element is included in the engine (Fig. 1) that assists the movement of the displacer from its upper dead centre (UDC) toward its bottom dead centre (BDC). The principal goal of the paper is to investigate numerically the impact of the elastic element on the performance of the engine. The hypothesis of the study is that efficient operation of the engine under varying parameters can be ensured by adjustment of the spring constant.

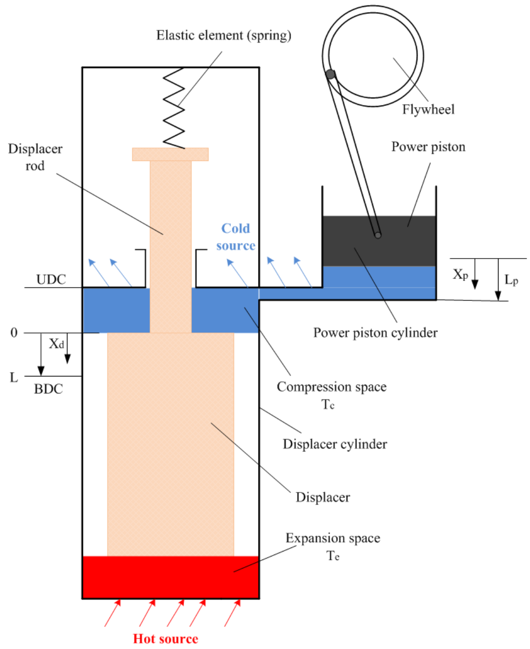


Fig. 1. Sketch of a Stirling-Ringbom engine with an elastic element

EXPOSITION

Computtional details

For the needs of this study is used the TUS-SRSim simulator, which is developed in Matlab/Simulink environment. The full mathematical model of the Stirling-Ringbom engine, which is developed following (Senft, J., 1985) is described in (Petrova, Ts., Markov, D., Velichkova, R., & Simova, I., 2017).

In Table 1 are sumarised the design parameters of the investigated Stirling-Ringbom engine with an elastic element.

Table 1. Design parameters

№	Parameter	Symbol	Unit	Value
1	Mass of the displacer piston assembly	M_d	kg	0.53
2	Displacer piston cross-section	A_d	m^2	0.2124
3	Displacer rod cross-section	A_r	m^2	0.00785
4	Displacer half-stroke	L	m	0.08
5	Power piston cross-section	A_p	m^2	0.0314
6	Power piston half-stroke	L_p	m	0.13
7	Spring constant	D	N/m	700
8	Expansion space temperature	T_e	K	373
9	Compression space temperature	T_c	K	289
10	Mean temperature of the working fluid	T_{mean}	K	331
11	Atmospheric pressure	B	Pa	95000

Along the cycle, under design conditions, the pressure of the working fluid in both the expansion space and compression space varies around the atmospheric pressure (B). Hence, B is both a design parameter and the main operative parameter. To each atmospheric pressure corresponds a mass of the working fluid ($M_{F,B}$, evaluated at T_{mean}), which allows the engine to generate maximum possible mechanical work, (Petrova, Ts., Markov, D., Velichkova, R., & Simova, I., 2017). The operative conditions under which the engine operation is studied are presented in Table 2.

Table 2. Investigated cases

Case	Ambient pressure B, Pa	Working fluid mass corresponding to B - $M_{F,B}$, kg
ESR01	93000	0.042265
ESR02	93500	0.042493
ESR03	94000	0.042720
ESR04	94500	0.042947
ESR05	95000	0.043174
ESR06	95500	0.043402
ESR07	96000	0.043629
ESR08	96500	0.043856
ESR09	97000	0.044083
ESR10	97500	0.044311
ESR11	98000	0.044538

Results and discussions

The importance of the spring constant for a stable engine operation and for the new work of the engine is demonstrated on Fig. 2 and Fig. 3. On Fig. 2 is presented the pV-diagram of the engine cycle for case ESR01 and three values of the spring constant D - 400, 700, and 1300 N/m. On Fig. 3 is presented time variation of displacer position (X_d) under the same conditions.

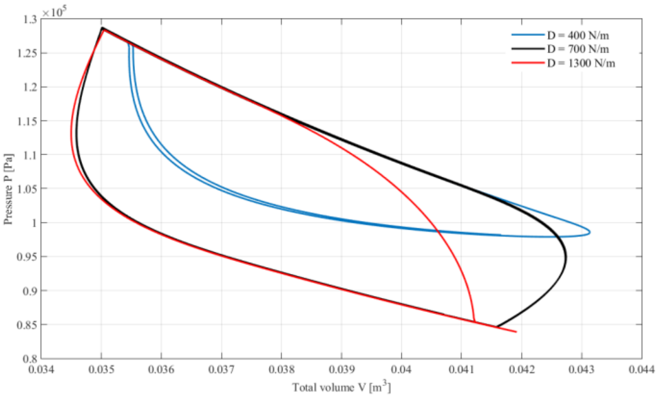


Fig. 2. pV diagrams for case ESR01 and three values of the spring constants D

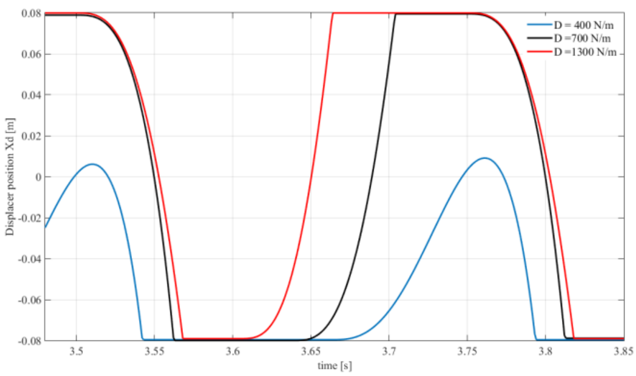
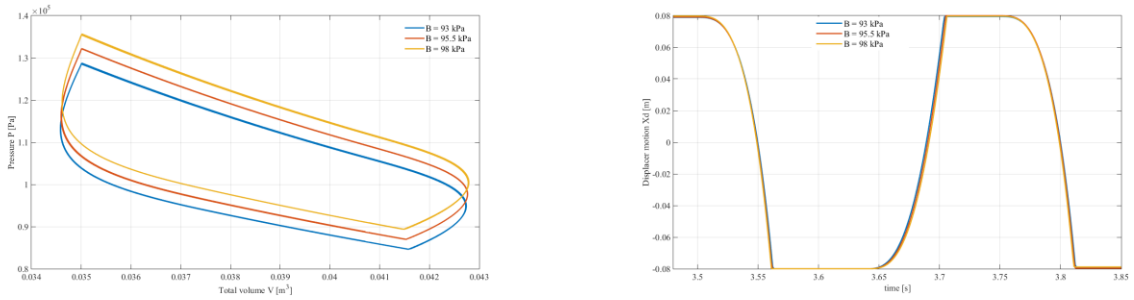


Fig. 3. Displacer position Xd at ambient pressure B = 98 kPa and different spring constants D

Displacer motion $X_d(t)$ (Fig. 3) depends strongly on the spring constant. The design value of the spring constant ensures stable operation of the engine. When the spring constant differs from the design value (D = 700 N/m) displacer motion bacames irregular. When D is smaller than the design value (D = 400 N/m) displacer could not reach its BDC, and when D is greater that the design value (D = 1300N/m) displacer hold on time at the BDC is greater than under design conditions.

The investigated Stirling-Ringbom engine with an elastic element is able to work normally, as under design conditions, at different atmospheric pressure (B) when the working fluid mass (M_F) is equal to $M_{F,B}$. This is demonstrated on Fig.4.a, where is presented the pV-diagram of the investigated engine for three cases – ESR01, ESR06, and ESR11. It is clearly seen, Fig 4.b, that for these cases displacer motion is the same. The hold on time at UDC is slightly longer than at the BDC. Though the engine works normaly under various B when $M_F = M_{F,B}$ engine pressure time variation has different shape as it can be seen from Fig. 5 for cases ESR01, ESR06, and ESR11. The shapes of the pressure variation along the cycle, shown in Fig. 5, differ from the pressure variation shape of the kinematic Stirling engine (Kolin, I., 1998). This difference is caused by the different way of synhronising the movement of the two pistons for the investigated engine and for the kinematic Stirling engine.



a b

Fig. 4. Variations in the behavior of the Stirling-Ringbom engine with an elastic element

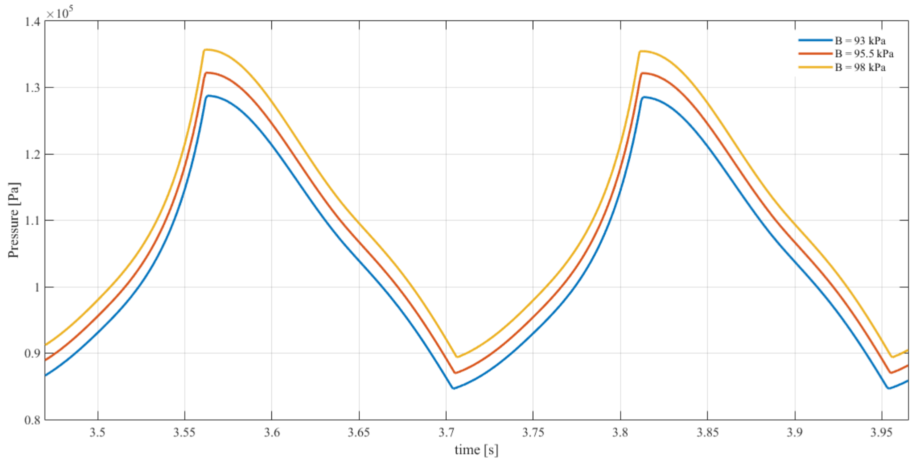


Fig. 5. Engine pressure variation along the cycle

The cycle net work (W_{net}) of the engine depends strongly on the variation of several operative parameters - atmospheric pressure (B), working fluid mass (M_F), spring constant (D), hot source temperature (T_e), and cold source temperature (T_c). On Fig. 6 is demonstrated the impact of the spring constant D variation, it is varied in the interval 400 – 1300 N/m with a step of 100 N/m, on the net work of the engine for case ESR01. The variation of W_{net} under this condition is characterized with a flat maximum in the interval D = 550-750 N/m. On Fig. 7 is demonstrated the impact of the hot source temperature variation (T_e), it is varied in the interval 353 – 408 K with a step of 5 K, on the cycle net work of the engine for case ESR01 (with D = 700 N/m). The variation of W_{net} under this condition is characterized with a flat maximum in the interval T_e = 385-395 K.

On Fig. 8 is demonstrated the combined effect of the variations of the atmospheric pressure B and of the spring constant D on the variation of cycle net work of the investigated engine at T_e = 373 K and $M_{F,B}$. The atmospheric pressure is varied in the interval [93, 98] kPa with a step of 0.5 kPa and the spring constant D in the interval [400, 1300] N/m with a step of 100 N/m.

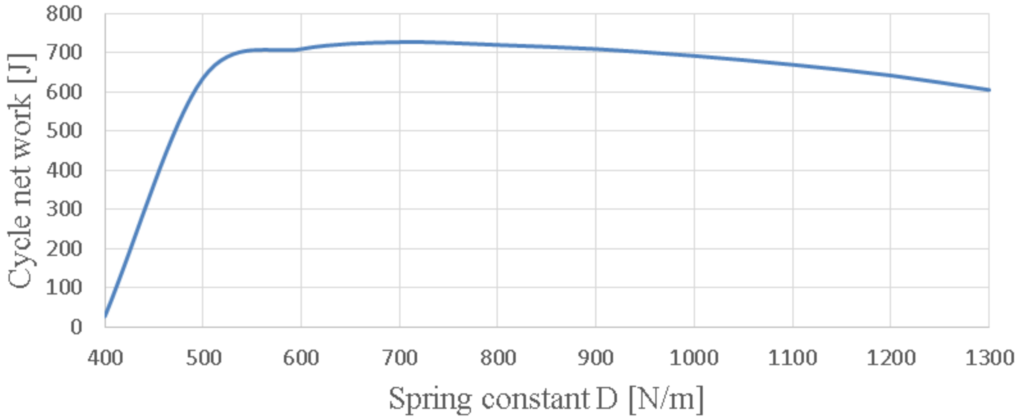


Fig. 6. Cycle net work variation with the spring constant D for case ESR01 (and T_e = 378 K)

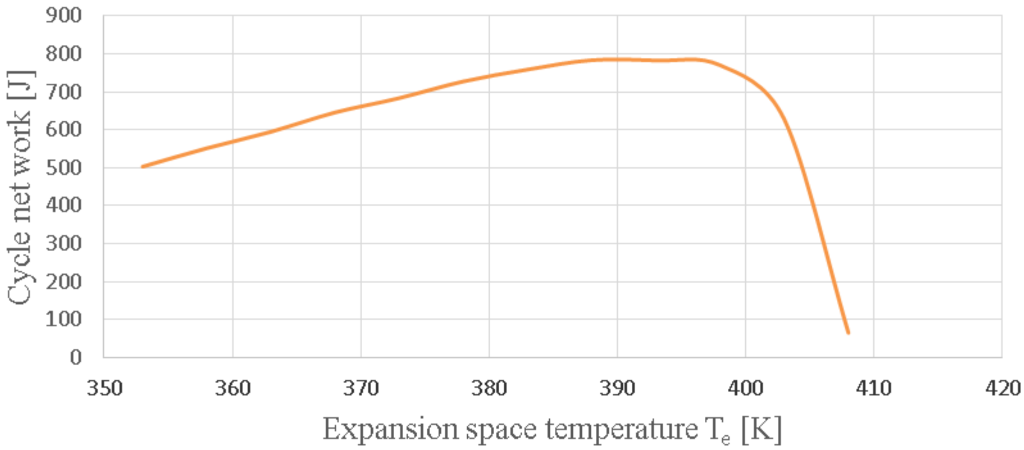


Fig. 7. Cycle net work variation with the hot source temperature for case ESR01 (D = 700 N/m)

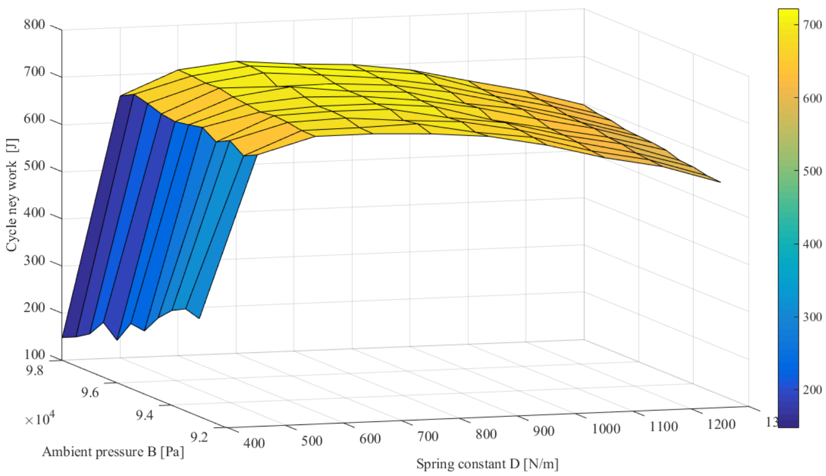


Fig. 8. Cycle net work variation with the variations of atmospheric pressure and spring constant

On Fig. 9 is demonstrated the combined effect of the variations of spring constant D and hot source temperature on the variation of cycle net work of the investigated engine for case ESR11. Spring constant D is varied in the interval [400, 1300] N/m with a step of 100 N/m and hot source temperature is varied in the interval [353, 408] K with a step of 5 K. When the expansion space temperature, equal to the hot source one, increases and spring constant is with small values, the investigated engine does not work. By increasing both the spring constant and the expansion space temperature the engine reaches good operation characteristics with a high level of the cycle net work.

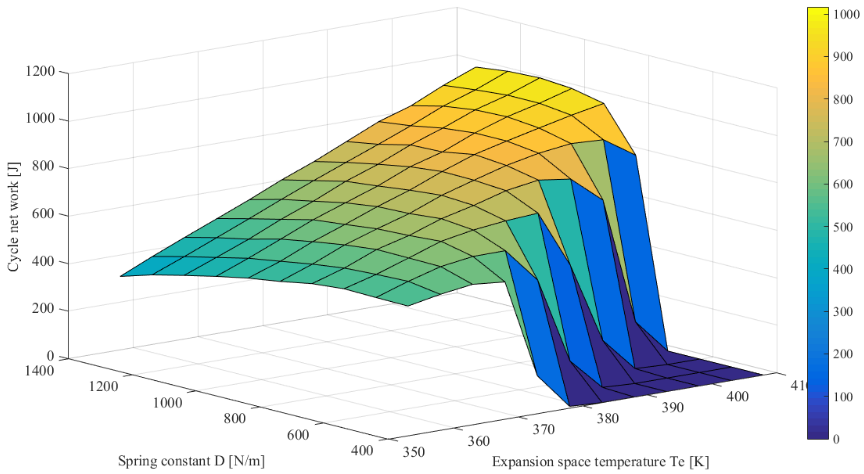


Fig. 9. Cycle net work variation with the variations of spring constant and hot source temperature

CONCLUSION

The operation of the Strirling-Ringbom engine with an elastic element is investigated numerically with the aim to reveal how it is influenced by the variations of the spring constant (D), ambient pressure (B) (at working fluid mass $M_{F,B}$), and expansion space temperature T_e. The results obtained prove that the examined parameters strongly influence the cycle net work of the engine.

The presence of a flat maximum in the variation of the cycle net work of the investigated engine as a function of the studied influencing parameters is a prerequisite for a stable operation of the engine because:

- by adjusting of the value of the spring constant of the elastic element it is possible to compensate the negative impact of the variations of atmospheric pressure, when $M_F \neq M_{F,B}$, and hot source temperature on the operation of the engine;
- under small changes of the characteristics of the elastic element, due to fatigue, engine performance will remain unchanged at its maximum.

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