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Screw expander: The expansion solver

S. Plánička[a], Z. Rendlová[a], J. Švígler[a]

[a] *NTIS, Faculty of Applied Sciences, University of West Bohemia in Pilsen, Univerzitní 8, 301 00 Plzeň, Czech Republic*

The most efficient energies utilization will be essential in all fields of human activities in the nearest future. For the making use of waste heat, for example in small industrial facilities, the possibility of screw motors application was studied, where the tasks of our department were primarily to analytically describe the screw motor geometry and secondarily to solve the expansion of the working medium within. An introduction of initial ideas of the expansion process solver is the main object of presented conference paper.

Benefits of the analytical description of a screw engine working chambers geometry lie in their usability for possible modifications of the working chambers geometry design, which prospective impact on engine efficiency should be evaluate appropriately. Resultant power of torque produced in a screw engine by working medium could be used as a design evaluation criterion, this requires calculations of expansion phase thermodynamics and especially the solution of pressure in the working space during the screw engine working cycle. In order to handle aforementioned calculations effectively, utilization of complete CFD for simulations of fluid flow in a screw engine is almost impossible due to its extreme computational demands. More suitable approach to handle these tasks could be creation of an own simplified and computationally fast solver of expansion processes. Such program code should be coupled with the geometrical code to acquire input geometrical data and to calculate the resulting forces as an integral of the pressure acting on screws surfaces.

Let me note that the proposed screw engine was originally intended to work with an organic medium in organic Rankine cycle (ORC). Both the ORC with phase changes and the working medium with a low speed of sound required the development of a nontrivial flow solver with complex constitutive relationships. Later, the working gas has been changed to air, consequently entire working cycle of the engine was shifted to the area of superheated vapor of air (inlet pressure $p^{IN} \lesssim 15$ atm and interior temperature $t \in (-50; 200)$ °C). Detailed analyses of partial test cases carried out on simplified geometry of single working chamber (e.g. study of inertia effects, propagation of expansion waves, friction losses, turbulence effects etc.) showed that a simple zero-dimensional model based on the laws of the ideal gas isentropic processes is sufficiently accurate to capture the air expansion in working space. Additionally, to lubricate the compressor and to seal small gaps, a small amount of warm oil is injected together with the compressed air into the working space. The resulted model of the working medium expansion was developed taking into account the following assumptions:

- There are no leakage flow losses (idealized analytical geometry with perfect contacts).
- Behavior of air is described by the ideal gas law (this assumption is true and of sufficient accuracy under operating conditions).
- Expansion of gas is adiabatic (fast processes, without heat exchanges).
- Oil is taken as an incompressible fluid, which is separated from air (its volume reduces the working space volume free for air expansion).

- At one moment pressure has the same value in the entire working space (instantaneous propagation of pressure changes, without significant fluid flow).
- Pressurization of the working space is immediate (from the opening until the closing of the inlet port, the working space is pressurized to the inlet parameters values).

Following aforementioned simplifications, the fundamental part of the model, i.e. the equation of the expansion phase pressure, is described by a simple algebraic equation

$$p(V) = p^{IN} \left(\frac{V^{IN}-V_{oil}^{IN}}{V-V_{oil}^{IN}}\right)^{\gamma},$$

where V is volume of working space variable during the expansion, p is corresponding pressure, p^{IN} is inlet pressure, V^{IN} is volume of working space at the moment of inlet port closing, V_{oil}^{IN} is total volume of injected oil to working space and γ is heat capacity ratio of air. The algorithm based on this simplest model is very computationally fast and obtained results are sufficiently accurate if the above assumptions are valid. A similar models were used in some computational software commonly, see [1]. The solution of proposed model can be seen in Fig. 1 (red dashed line), considering the ideal geometry of chosen screw engine and inlet pressure p^{IN} = 2.992 bar. For comparison is there shown a blue line, which corresponds to the data measured using experimental stand operated at the same inlet pressure in Technical University of Applied Sciences in Amberg.

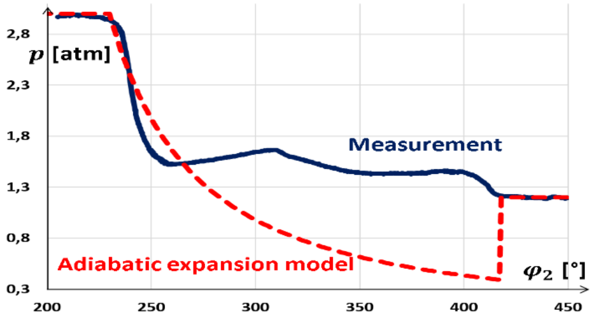

Fig. 1. Solution of the simplest 0-D model (red) in comparison with measurement data (blue)

After numerical experiments and followed by validation using experimental data, some shortcomings of the simplest 0-D model became apparent. The major inaccuracy of the presented model lies in the geometric representation, because our model considers strictly perfect contacts, but in general a leakage flow through gaps can occur and rapidly decrease the pressure gradient and accordingly negative affect efficiency of screw machines. The second imprecision of the basic model is unrealistic filling of the working space with compressed air, when the rapidly enlarging working space is still totally filled to the inlet pressure value through the closing inlet port. The third improper assumption of basic model is contained in approach of the adiabatic expansion of air. The experimental measurements on test stand clearly showed the significantly higher outlet temperature compared to predictions of the adiabatic expansion model. The only relevant explanation of such phenomenon may reside in air re-heating during the expansion process. The modified solver, which is able to handle with the all above-mentioned inconveniences will be detailed presented in the conference talk.

Acknowledgements

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References

[1] Stosic, N., Smith, I., Kovacevic, A., Screw compressors – mathematical modelling and performance calculation, Springer Berlin Heidelberg New York, 2005. ISBN-10 3-540-24275-9