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Screw expander: Working chamber analysis to maximize transmitted torque

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1. Introduction

A screw expander is a device that is structurally based on the principle of operation of a screw compressor. The main idea is to interchange the input of the screw compressor for the output and, while simultaneously changing the direction of rotation of the twin rotors, use the energy of the working medium to drive another device. In order to develop such a device and subsequently ensure its operation with the greatest possible efficiency, it is therefore necessary to know the working characteristics of a machine. These are affected not only by the thermodynamic parameters of the working medium, but also by the shape and volume of the working chamber, which changes during the working cycle.

2. Working chamber model

In the first step, it is necessary to describe the shape of the monitored working chamber. Since the working chamber is defined by the inner space of the compressor housing and the outer surface of the rotors, it is necessary to create an analytical description of the shape of both rotors, the male rotor and the female rotor. This description is based on knowledge of the shape of the female rotor profile in frontal plane which is performed using a series of analytical curves (for example, lines, arcs etc.). Depending on this description, the profile of the male rotor is created using the envelope principle [1]. Due to the fact that the axes of rotation of both rotors are fixed with respect to the inner space of the housing, their positions do not change during the working cycle. Considering two adjacent cuts that are perpendicular to the axis of rotation of the rotors shifted by distance Δl, the corresponding angle of rotation of the profiles can be determined. Then it is possible to determine the size of the cross-sectional area $A_{i,k}$, which corresponds to the working chamber for a given angle of rotation of the female rotor. For two adjacent slices at a distance of Δl, the the elementary volume $V_{i,k}$ is computed using

$$V_{i,k} = \frac{A_{i,k} + A_{i,k+1}}{2} \cdot \Delta l \,, \tag{1}$$

where A_i and A_{i+1} are working chamber areas in slices i and $i + 1$, respectively. The index k represents chosen angle of rotation of female rotor from range $\varphi \in \langle 0, \varphi_5 \rangle$. The total volume V_k of working chamber is calculated as the sum of elementary volumes $V_{i,k}$ along total length of screws. The actual volume of the working chamber depends on the angle of rotation of the secondary rotor and changes with the angle of rotation, in particular in the case of a screw expander this volume increases.

3. Working cycle description

The operating cycle of the screw compressor can be divided into several phases. These phases can be defined with respect to the angle of rotation φ of the female rotor. In the first phase, the rotors are rotated from the reference position until the working chamber begins to form. This corresponds to the angle of rotation of the female rotor in the range $\varphi \in \langle 0\,, \varphi_1 \rangle$. Subsequently, the working chamber is formed in the range of the angle of rotation $\varphi \in \langle \varphi_1\,, \varphi_2 \rangle$. As soon as the angle of rotation becomes φ_2, the inlet port is opened and the working chamber is filled with the working medium (so-called filling phase). This phase takes place in the range of the angle of rotation $\varphi \in \langle \varphi_2\,, \varphi_3 \rangle$. Then, the inlet port is closed and the working chamber can be understood as an enclosed area into which the the specific amount of working medium has been introduced. Due to the rotation of the rotors, which occurs due to the action of the working medium on the surface of the rotors, the volume of the working chamber increases. Thus, the working medium in the working chamber expands (expansion phase). This phase takes place in the range of the angle of rotation $\varphi \in \langle \varphi_3, \varphi_4 \rangle$. Then there is a phenomenon when the working chamber no longer increases its volume and the angle of rotation varies within range $\varphi \in \langle \varphi_4\,, \varphi_5 \rangle$. Then the working medium leaves the space freely through the outlet port (exhaust phase).

4. Calculation of torque during the working cycle

Considering the elementary volume of working chamber given by two adjacent sections of the working chamber i and $i + 1$, the working media acts on the outer surfaces of the screws and on the inner surface of the housing. The pressure of working media is computed in isolated single working chamber with respecting of characteristics of working media at the inlet port. In the phase of expansion of the gas in the working chamber, the adiabatic law is respected. The aforementioned model of working medium expansion seems appropriate when a fast processes (adiabatic expansion of gas without heat exchanges) and an ideal geometry with ideal contacts (no leakage flow losses) are assumed [2].

5. Application

The described procedure was applied to a mass-produced B100 compressor produced by Atmos Chrást s.r.o. This compressor, the inversion of which is intended to obtain a screw expander, is equipped with rotors with a total length $l = 129.9$ mm and diameters of head circles $D_2 = 83.94$ mm for the female rotor and $D_3 = 106$ mm for the male rotor and the pitch angle $\gamma = 38.127°$. Both screws are mounted in the housing, the distance of the parallel axes of rotation of both screws is 73 mm, see Fig. 1. The working medium consisting of two separate phases, namely compressible gas (air) and incompressible liquid (oil).

6. Conclusion

In order to maximize the performance of the screw expander, an analysis of the working space was performed and the sizes of the surfaces on which the working medium acts were determined, thus generating a torque ensuring the rotation of the screws in the screw expander. From the performed analyzes, it seems advantageous to modify the screw profiles so that the active area on which the working medium acts is maximized while respecting the parameters of the housing. Another possible modification is to keep the existing tooth profiles of both rotors and insert screws with variable pitch angle into the housing.

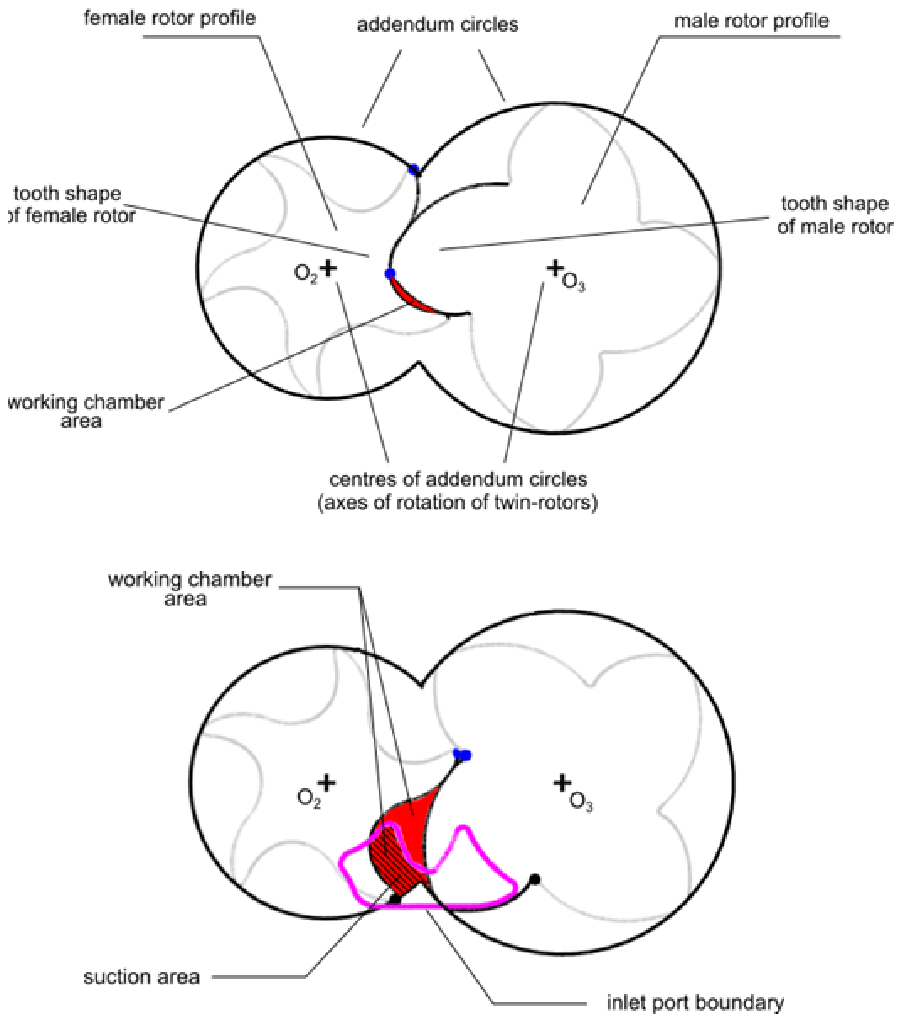

Fig. 1. Identification of the working chamber and the geometry of the suction opening for the selected angle of rotation of the female rotor

References

[1] Švígler, J., A treatise on the theory of screw machines, University of West Bohemia, Plzeň, 2010.

[2] Stosic, N., Smith, I., Kovacevic, A., Screw compressors: Mathematical modelling and performance calculation, Springer Berlin Heidelberg New York, 2005.