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SCROLL EXPANDERS FOR LOW-POWER ORC

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Abstract: One of the possibilities how to realize expansion in organic rankine cycles (ORC) is to use the scroll expanders. These expanders seem to be perspective for low-temperature low-power ORC. The article deals with the basic principles and features of scroll expanders, limits of the use of this type of engine for practical application and specifies recommendations for the use of this expander in ORC.
Keywords: scroll expanders, low-power ORC, microcogeneration

1. INTRODUCTION

Increasing demands for economical use of energy lead to consideration of the use of low-potential heat sources to produce electricity. Such a source may be, for example waste heat from industrial production. In these cases, it is often the relatively low heat input from tens to hundreds of kW. One of the ways to use the waste heat, is the deployment of organic Rankine cycle (ORC). This cycle is basically identical to the classical Rankine cycle, working substance is suitably selected organic compound which has better properties at lower temperatures. One of the many problems that are currently solved in the area of organic Rankine cycles is the way how to realize expansion. Today the expansions are carried out in dynamic machines - turbines. To ensure good efficiency the speed of such machines have to be very high. There are many problems associated with this - an expensive production, necessary precision balancing, use of gearboxes with a high reduction ratio or expensive high-speed generators, as well as relatively expensive lubrication systems [1]. Therefore positive displacement expanders appear more appropriate. They can be directly connected to conventional electrical generators, when properly designed. The screw expanders which have found commercial application in the ORC units GreenMachine of company ElectraTherm seem to be perspective. Also vane and scroll expanders seem to be interesting. However these types are still waiting for commercial application in organic heat cycles.

2. PRINCIPLE AND CONSTRUCTION

Scroll expanders construction can be derived from the construction of scroll compressors. Their principle was patented as early as 1905 in the U.S. [2], however, the practical application was enabled much later thanks to the progress in manufacturing technology. Scroll compressors are mostly used in refrigeration systems and heat pumps. They can be hermetic, semi-hermetic or non-

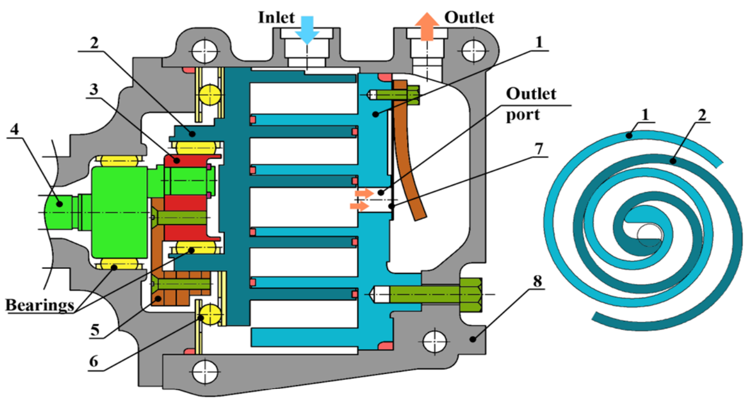

Figure 1. Schematic section of a scroll compressor [5]

hermetic. They are produced in series and are easily accessible. For this reason, many research teams used for experimental work modified scroll compressors to realize the expansions. A schematic section of a scroll compressor is shown in Figure 1.

The main element consists of two plates, which carry the vertical spiral walls (1), (2). These spirals are identical, but they are rotated to each other by 180°. One of the spiral is always fixed (1), while the other is movable (2). The movable spiral does a circular translational motion around the center of the fixed spiral. This movement is ensured by an eccentric mechanism (3). The whole mechanism is driven through a shaft (4). Balancing of rotating masses caters counterweight (5). Rotation of the movable spiral is unacceptable, otherwise the mechanism would not work. To prevent rotation serves for example Oldham coupling used by Copeland [3]. In Figure 1 there is a solution of Sanden company for automotive air conditioning scroll compressors. In this case the proper motion is ensured by the bearing balls, placed in a metal ring with circular holes (6). There is also the check valve (7) placed in the body of the compressor (8), which prevents the reverse rotation of compressor. However, it must be removed to use the compressor in the reverse - expansion mode. The principle of expansion is inverse to compression and is shown in Figure 2.

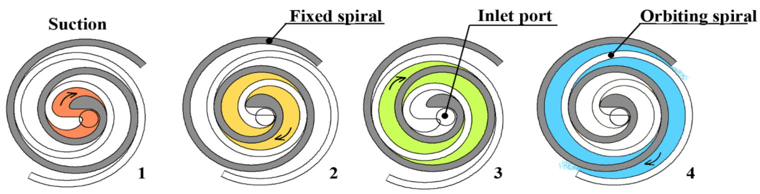

Figure 2. The principle of expansion

Due to the close proximity the spirals form work spaces, which increase during rotation. Working medium flows through the inlet in the center of machine (1). Due to the expansion of working medium, the movable spiral rotates the direction indicated in figure 2. Suction phase is completed when the movable spiral closes the inlet connection (2). This is followed by expansion (3), which continues until the distance between the tip of the orbiting spiral and the fixed spiral increase, allowing the working substance to leave work spaces. As it can be seen in figure 2, the expansion process is continuous. When are the work spaces between the spirals closed from entering the working substance, other spaces are already filled. This ensures smooth and balanced operation.

3. CHARACTERISTICS OF SCROLL EXPANDERS

The scroll expanders are currently not manufactured, so their characteristics can be only derived from the characteristics of scroll compressors or from measurements of these compressors in the reverse expansion mode. Such experiments were carried out on an experimental track in the labs at CTU in Prague. Scroll compressors are characterized by a slightly complicated design. For proper operation they require precise eccentric mechanism, eccentrically positioned rotating plate with the spiral must have counterbalance. In order to achieve good volumetric efficiency, it is necessary to ensure high accuracy of their manufacturing - especially the spiral blades. Mentioned design complexity can be fully applied to the scroll expanders. On the other hand, the production of scroll compressors is managed also in large series. For this reason the production costs can be very low. Scroll compressors are characterized by reliability, high efficiency, low noise and vibrations [4]. Also these properties can be applied to expanders without larger doubts. It is necessary to know, that the value of expander and compressor efficiency will differ. Volumetric efficiency of scroll compressor reaches the values from 0.89 to 0.98 [4]. In contrast, the automotive air conditioning compressor, that we measured in the expansion mode showed a maximum value of 0.7 [5]. Low values of volumetric efficiency was also mentioned by Aoul and Clodic (0,63) [6], Lemort [4] and others. Moreover, volumetric efficiency is one of the main factors that

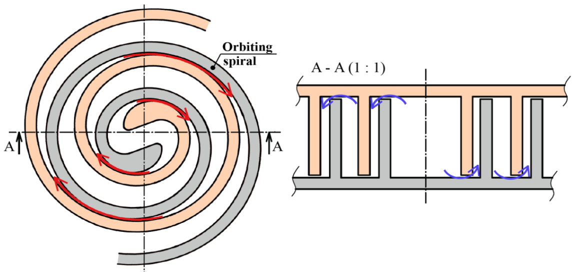

Figure 3. Ways for working substance to escape from work spaces

affect the overall efficiency of the expander. There are two different ways for the working substance to escape from work spaces during suction and expansion (see Figure 3).

The tangential leakage (shown in red) occurs between the sides of the spiral blades. They can be caused by imperfect spiral shape, by tilting the plate with the spiral blade due to different pressures, or intentional clearance between the sides of spirals. These leaks can be reduced for example by presence of oil in the working substance. In case of using a scroll expander in the Rankine cycle, next option is the expansion of wet steam, or injection a small amount of liquid phase, etc. The radial leakage (shown in blue) occurs between the plate and the edge of the spiral. The reasons are basically the same as in the case of tangential leakage. To reduce the radial leakage scroll compressors usually have milled a groove in the spiral blades into which is placed a plastic seal. Ways to prevent radial leakage are basically the same as in the case of tangential leakage. Decrease of volumetric efficiency in the expansion mode partially explains Peterson in his work [7]. In his opinion the oil in the expansion mode tends to wash out from the work spaces. This is probably due to the same direction of acting of the pressure in the work area and rotation. In contrast, in case of compressor the oil wash out tendency is compensated with the opposite direction of rotation of orbiting spiral. In case of compressor oil leaching tendency contrary compensated in the opposite sense of rotation of spiral blades. Scroll compressors are compressors with a built-in pressure ratio. If equipped with a discharge valve, it is possible to achieve even higher pressure. In case of expander, the expansion ratio is given by the geometry of the machine. Expansion ratio can be affected by the length of spirals – the longer spirals are, the greater expansion ratio can be achieved. The length of spirals can not be increased arbitrarily. We are particularly limited by technological capabilities of their manufacturing. Spirals should be in contact on all the proper places. For long spirals there is a problem to hold the required dimensions and tolerances. If the spirals are in a poor contact, it will negatively affect volumetric efficiency. Volume of the work spaces increase linearly depending on the rotation angle of the output shaft. This trend is shown in figure 4 for common automotive air conditioning scroll compressor which was within the experiment operated in the expansion mode. The expansion ratio is approximately 2.4.

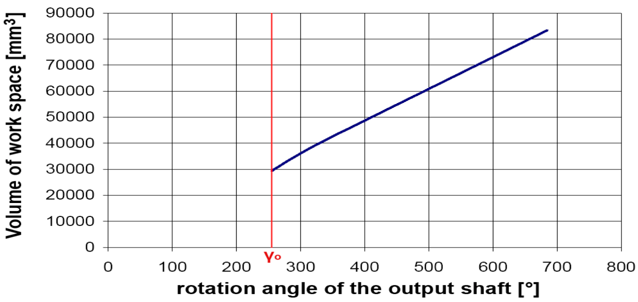

Figure 4. Volume of work spaces with the rotation af the output shaft

4. APPLICATION IN ORC

As already mentioned, scroll compressors are most commonly used in refrigeration systems and heat pumps. In these thermal cycles they operate with refrigerants - organic substances. Similar (or exactly the same) substances are used in the ORC. Motor power to drive scroll compressors is anywhere in range of one to tens of kW. From this we can conclude that the mechanical performance of scroll expanders could be in a similar power level. These facts show that scroll compressors and expanders may not be very different. Scroll expanders can be designed to maximum utilization of existing technology for mass production of scroll compressors. In order to operate scroll expanders with high efficiency, performance and long life, it is important to design their operating parameters correctly. Very important is the correct determination of the required volumetric flow. It can be based on the theoretical flow determined by geometry of the machine but it si not possible to ignore the influence of volumetric efficiency. As mentioned, it has considerable influence on the overall efficiency of the machine. The value of volumetric efficiency can be increased by the presence of oil in the working substance. Oil seals work spaces of the machine while having a positive impact on mechanical losses. Another way to increase the volumetric efficiency could be an injection of liquid phase of working fluid directly into the work spaces. However, there is necessary to keep an eye on the overall efficiency of the heat cycle. Good influence can also have operating the expander at optimum temperatures. The scroll compressor is limited by temperature difference between inlet and outlet, which can reach values of more than 90 K. Of course, such a difference may greatly affect the geometry of the spiral blades and reduce the volumetric efficiency. In case of expander, the temperature difference across the whole machine is much smaller. Therefore, it is only necessary to keep an eye on the warming rate to avoid mechanical damage to the expander due to different dilation of the parts. Further reduction of temperature differences across the machine could be created for example by isolating it. This would again have a positive effect to hold the correct geometry of spiral blades during operation. With regard to Saitoh experiment [8], who successfully operated automotive air conditioning scroll compressor in reverse mode at temperatures up to 136°C, we can assume the right temperature for the expander at about 160° C or slightly higher. Scroll compressors are designed to operate the pressures greater than 1,5 MPa. This value is sufficient for the operation of ORC. The advantage of scroll compressors is the fact that their speed is about 3000 RPM. Therefore the derived scroll expander could be directly connected to an electrical generator. Of course this has a positive effect on mechanical losses. The overall efficiency of proper designed scroll expanders should be greater than 0.6 [5].

5. CONCLUSION

Scroll expanders seem to be very perspective for realization of expansions in organic cycles with a heat ouptut of tens to hundreds of kW. Their deployment in such cycles is not very different from deployment of scroll compressors in refrigeration cycles. Used working substance may be similar or identical, the temperature and pressure range of expanders is also similar to compressors. The big advantage is that the design of scroll expanders can be derived from current mass-produced scroll compressors and use the existing manufacturing technology. Of course, it would be necessary to make minor design changes. Attention should be further focused on ways how to improve volumetric efficiency, which has a major impact on the overall efficiency of the expander. One of the possibilities is for example to mix a small amount of oil in the working substance, which would better seal the work spaces and also due to its lubricating properties has a positive effect on the mechanical losses. The overall efficiency of well-designed scroll expanders should be above the value of 0.6.

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