Lubrication-installation of screw engine applied in an Organic Rankine Cycle

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1 Introduction

A Rankine cycle using organic fluids as working medium, called organic Rankine cycle (ORC), is potentially capable of recovering low temperature heat sources - it means first of all waste heat - from different industrial and communal processes. The theoretical efficiency of the ORC-Cycle primarily depends on the temperature difference between the heat source and the natural environment (cooling medium). The low efficiency (due to the low temperature of the heat source) requires increased power plant equipment size (turbine, condenser, pump and boiler) that can become cost-prohibitive. Another aspect is the optimisation of the subprocesses, especially expansion in the turbine or other devices, which impacts the total efficiency of the real plant with its energy losses caused by deviations from the theoretical conditions. One of the technical possibilities is using a screw engine as effective expansion device. The principle of a screw engine has been used for the first time as compressor and can be adopted and used in reverse (expansion). This rearrangement requires many modifications and changes of the installation, in order to use the general principle effectively.

This paper presents some practical aspects of using screw engines as expansion devices, especially a novel lubrication installation adopted from a compressor and modified for the requirements of expansion machine.

2 Two-Stage ORC-Concept for waste heat recovery

A novel concept for optimising CHP-units with combustion engines (especially biogas plants) by converting the waste heat into electricity in an ORC process at medium or low temperature was developed and investigated theoretically within a former research work published in [5].

The concept comprises two heat input stages and two expansion stages. The two temperature levels of heat input correspond to the heat transfer temperatures and ratios in the exhaust gas heat exchanger of a combustion engine – specifically a gas motor in a biogas plant, and in the cooling system of the engine. High-pressure expansion is carried out in a micro-turbine, and the residual expansion is coupled to the expansion of the working fluid from the low-temperature heat input in a screw engine. Although this complicates the system as a whole, it permits better operational exploitation of the options provided by the two expansion devices. The general overall concept for the ORC system is shown in Fig.1.

Figure 1: Overall concept for a two-stage ORC-System
It is a relatively complicated and cost-intensive solution due to the investment involved but in many practical applications it is the only conceivable alternative if seeking to improve the efficiency. More details about the concept and thermodynamic calculations and optimization were published in previous works [5,6].

Both expansion devices can be used in optimal ranges of thermal parameters (temperatures and pressure ratios) but one of the biggest technical problems in the practical application is the use of a screw rotor engine as expansion device.

3 Test Bench

Because of the implementation of a screw engine, there are many extra possibilities which can be achieved due to its advantages. Before advancing with a 2-stage ORC process like this, more research is required for the implementation of a screw engine in an ORC process. Therefore this present research concentrates only on the implementation of a screw engine in the ORC test bench and has chosen a one-stage ORC process with one screw engine. For this purpose a Variscrew VMY 046 refrigerant screw compressor has been used, chosen from the product range of “Aerzen”. This concept, which has already been built, is shown in Fig. 2.

![Figure 2: The one-stage ORC test bench with a screw engine](image)

Screw engines have some special features which turbine engines do not have [8,9]. In order to operate screw compressors as an expanders, only their direction of rotation has to be reversed. Unlike with turbine engines, design differences to optimize them for either function are minimal. Rotor tip speeds of screw engines are roughly one order of magnitude less than those in turbine engines. Therefore screw engines can usually be directly coupled to normal 2- and 4-pole generators which reduce transmission losses. Because of the low fluid velocities, the presence of liquid in the working chamber does not damage the rotors, so the screw engine can expand in wet vapor as well. This allows for more possibilities to run the process, which can result in more efficiency of the total process. Since a screw engine is resistant to fluid in the working chamber, this fact can also improve performance by sealing the gaps with a fluid and acting as a lubricant. In most situations this fluid is lubricating oil which fulfills the viscosity requirements.

4 Lubrication-installation of screw engine

The screw engine is a displacement rotary engine which works based on the Lysholm principle. The Lysholm principle has been economically used in the 1950s for the first time as a screw compressor [7]. The principle is similar to the workings of piston engines. Both have a closed working chamber, only the one based on a Lysholm principle changes cyclically instead of oscillating. The cyclical change thus leads to an in- or decrease of energy content of the fluid in the chamber.

Lubrication in a machine has three main effects, namely:
- reducing friction,
- cooling,
- sealing gaps.
Reducing friction is important to maintain a high lifespan. Friction mainly occurs between the rotors and between the bearings. Since cooling has a negative effect on the efficiency of an expander, this effect of lubrication has to be prevented from occurring as far as possible. When lubricating the rotors the rotor gaps are better sealed and thus the usable pressure release is increased, which in turn has a positive effect on the efficiency of the screw engine.

For lubrication the system needs some adjustments to operate correctly as a screw engine. Since screw engines are mainly used as a compressor, well-known lubrication systems are only available for screw compressors. Therefore the lubrication system of a screw compressor is taken as an example for the lubrication in the test bench. The system is similar, but the necessary adjustments have been made. A simplified diagram for the lubricant flow in a typical screw compressor is shown in Fig. 3.

![Figure 3: Lubrication flow in a screw compressor](image)

Like in Fig. 3, most screw compressors have 4 main lubrication inlets: one for the bearings at the inlet side of the compressor, one for the bearings at the outlet side of the compressor, one for the shaft seal and one for the oil injection to the rotors. Since high temperatures lead to lower viscosities of oil, it is recommended to cool the oil if it gets too hot because of the compression. A lower outlet fluid due to cooling the oil has a positive impact only on the compressor efficiency. Therefore, mostly a cooling heat exchanger is placed after the oil pump. The injected oil will finally be released together with the working fluid. To prevent the oil from stacking in the working fluid tank or in the evaporator, an oil separator is placed directly after the outlet of the screw compressor. After that, the oil from the oil separator can get stored in the oil tank which can further be used for the lubrication again. A useful feature of this design of lubrication is that in some situations an oil pump is not necessary. This is because of the high pressure that exists in the oil separator, which can be used to get a continuous flow to inject the oil at the lower-pressure side of the screw compressor.

Almost the same system as used in figure 6 is employed in the lubrication of the screw engine in the test bench. Due to the negative impact of lower temperatures on the efficiency of a screw engine, the oil-cooling heat exchanger is removed from the concept diagram. The oil separator which is directly installed after the screw engine has now a low pressure instead of a high pressure as with a screw compressor. Therefore the oil pump is now necessary in order to pump the oil up again to its high-pressure inlet; this pressure has to be higher than the pressure of the refrigerant. An outlet was also added to the lubrication diagram for the Variscrew VMY 046. This outlet is a drain outlet (connection “p”) which can function as a bypass for starting the screw engine. A simplified diagram for the lubricant flow of the test bench screw engine is shown in Fig. 4.
In order to operate the screw compressor, the correct pressure and volume rates have to be maintained, and the pressure losses in the lubricating pipelines have also to be calculated. The biggest pressure loss is in the outlet bearing pipe (t). Therefore the minimum pressure of the total oil system has to be 1.74 MPa and the maximum 2.19 MPa. In order to get correct values for all pressures, the valve of the main oil injection \((x_1, x_4)\) can probably be fully opened. The valves to the bearings \((s, t)\) and the valve to the shaft seal \((z)\) have reduce the pressure to 1.65 MPa.

The volume flows that are given by the manufacturer sum up to 60 l/min. These are high values that are suitable for the operation as a screw compressor, but are probably over- dimensioned to ensure its security. Therefore one has to find out in the test bench how low a volume flow the system can possibly handle. This is important because the less heat losses due to lubrication occur, the higher the efficiency will be.

When a lower volume flow is set, it has to be ensured that the viscosity the lubricant will still be sufficient. Because when the temperature of the oil then rises, the viscosity will decrease. According to the specifications of the producer (“Aerzen”), the allowed viscosity during operation lies between 12 and 50 mm\(^2\)/s. This can be realized by choosing the right lubrication oil.

5 Conclusions

The application of a screw engine as expansion device in ORC-installations for waste heat recovery could be a very effective measure and a chance to increase the efficiency of the system. This statement is particularly valid when referring to the novel two-stage concept presented in chapter 1, because of its prevailing pressure and temperature rates. The mature technology of screw engines as compressors can be adopted and used in reverse (expansion) but not without technical challenges and problems. The most important goal and challenge is the design and construction of lubrication system, which has to perform only two tasks (reducing friction, and sealing gaps). First of all the cooling effect and requirement of oil is not the same when using an expansion device (opposite direction of mass flow and pressure conditions) and the oil mass flow can be reduced, namely without disturbance of other functions.

An novel oil installation of the screw engine has been designed and installed in the ORC-test bench, which enables the experimental investigations to find an optimal solution and to assure the appropriate working conditions of the machine and the whole installation.
6 References