Inversion of the twin rotary screw compressor to an expander

Cite as: AIP Conference Proceedings **2118**, 030027 (2019); https://doi.org/10.1063/1.5114755
Published Online: 27 June 2019

Jiri Linhart, Zdenka Rendlová, and Jaromír Švígler

Inversion of the Twin Rotary Screw Compressor to an Expander

Jiri Linhart[1, a)], Zdenka Rendlová[2, b)] and Jaromír Švígler[2, c)]

[1]*University of West Bohemia in Pilsen, Faculty of Mechanical Engineering, Department of Power System Engineering, Univerzitni 8, 301 00 Pilsen, Czech republic*
[2]*Univeristy of West Bohemia in Pilsen, Faculty of Applied Sciences, Department of Mechanics, Technicka 8, 301 00 Pilsen Czech republic*

[a)]Corresponding author: linhart@kke.zcu.cz
[b)] zrendlov@ kme.zcu.cz
[c]svigler@kme.zcu.cz

Abstract. The screw compressor inversion is carried out in cooperation of the university UWB in Pilsen with the firm ATMOS Chrast and OTH Amberg-Weiden (Bavaria-Czech Cooperation Project). ATMOS produces screw compressors flooded with oil, which, unlike non-oiled, where only bearings and gears between screws are lubricated, have a more thorough oil machinery. Its importance rises with the expander. The oil must be thoroughly separated from the working medium behind the expander, where it has lower pressure and temperature than in the expander input. Since the oil must return to the expander inlet, both parameters need to be increased by the oil pump and in the heat exchanger to the inlet level in order to prevent cooling of the working medium and hence efficiency reduction. This creates an auxiliary oil cycle in addition to the main cycle with organic medium (ORC). The inversion of the compressor to the expander is not only about turning the rotation of the screws and the direction of flow, but also about optimizing the shape of the screwing to achieve acceptable efficiency. This problem is solved by numerical simulation, the results will be verified experimentally. From a structural point of view, it is necessary to solve a number of details that will prevent the unacceptable release of working organic media into the environment. This applies mainly to the expander and the circulation pump, where shaft seals cannot completely prevent leakage of liquid or gaseous phase of organic matter. An important design task is the perfect filtration of the lubricating oil from organic liquid substance. The cyclone commonly used here must be supplemented with another fine filter equipped with scavenge line. There is also a problem with the research facility how to manage electricity produced by the electrodynamic brake of the order of 100kW. It can either be returned to the power grid (expensive investment) or to the electric boiler of the organic cycle, or liquidated in resistive coils by heat conversion.

DESIGN OF EXPERIMENTAL EQUIPMENT

The research facility is a model of a waste heat recovery system from high-performance power plants or small and medium-sized enterprises, such as farms that produce low-calorific thermal energy by burning biomass. The source are also geothermal springs. Turbine cycles are generally used to evaluate the low grade heat. Steam turbines are not entirely suitable, they are complex, expensive, prone to vibration and thus have a shorter lifetime. Opposite features should have screw motors if they work with a suitable medium. Such are some organic substances, for example pentafluoropropane R245fa, whose admissive saturated steam has a temperature of 108°C at 15b and a condensation temperature of 40°C at 2.5b, see Fig. 2. Water or atmospheric air can be the condenser coolant in the European climate even in summer. The Organic Rankine Cycle (ORC) consists of a main cycle, three auxiliary cycles and an electrical branch. Pentafluoropropane is non-flammable, slightly toxic and should not leak from the device.

In operation of a screw compressor sometimes arises a power outage and compressor stops to work. The compressed air starts to flow in the opposite direction and moves the rotors in spite of the fact that it does not have a

38th Meeting of Departments of Fluid Mechanics and Thermodynamics
AIP Conf. Proc. 2118, 030027-1–030027-5; https://doi.org/10.1063/1.5114755
Published by AIP Publishing. 978-0-7354-1858-5/$30.00

suitable design for the expander function. Thus, the inversion of the compressor to the expander appears real, but adjustments are necessary to achieve greater efficiency.

Screw compressors are available in two versions:

a) With external gear between the two rotors, which do not require intensive oil lubrication of the screws in addition to the bearings. This is an advantage, but compensated by the larger clearances between the screws and between them and the housing, which cause air to penetrate into the neighboring spaces and so reduce machine efficiency.
b) Twin rotary screw compressor without external gear, the driven screw transmits rotational motion to the second rotor by direct contact. The clearances between the gears are smaller, the efficiency higher, but at the cost of intensive lubrication of the rotor space in the compressor. Just with such a compressor will be performed inversion to expander.

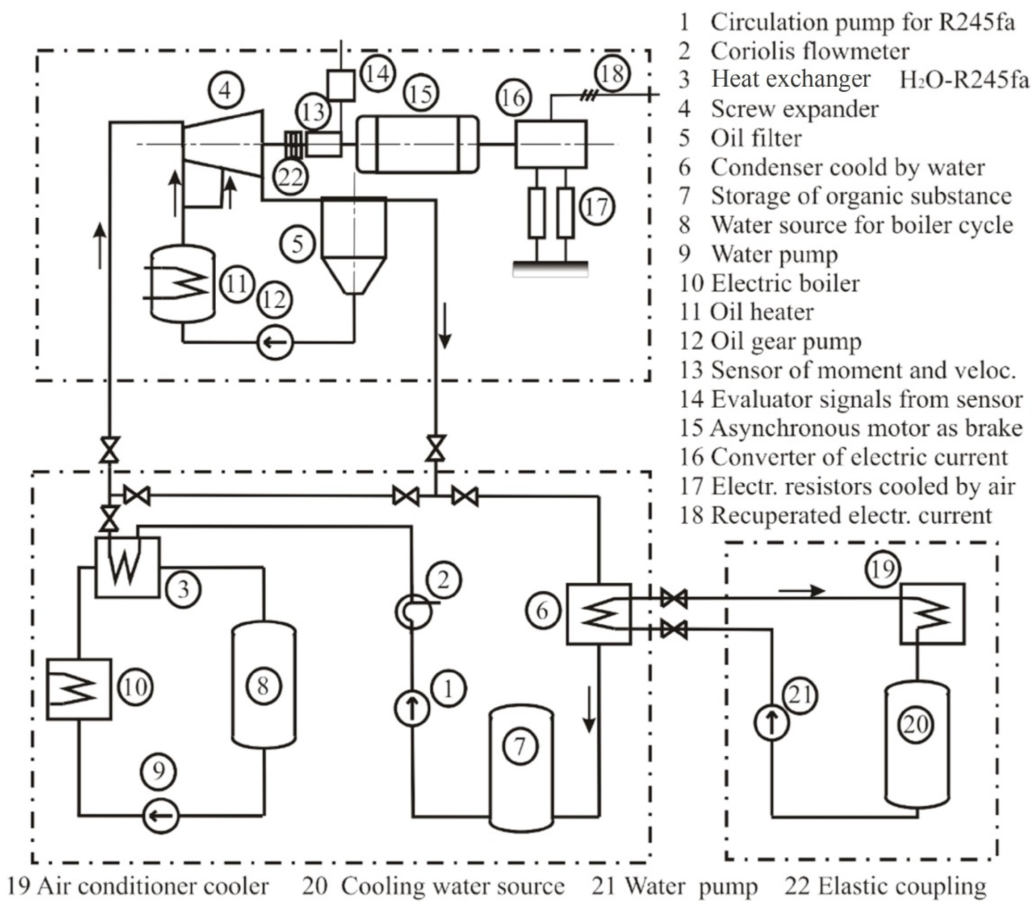


FIGURE 1. Schematic sketch of the research experimental equipment with oil-lubricated expander.

The heat cycle diagram of the test apparatus is shown in Fig. 1 and in pressure-enthalpy diagram Fig. 2 The Organic Rankine Cycle (ORC) consists of a main cycle, three auxiliary cycles and an electrical branch. The main cycle is formed by a circulation pump (1), a Coriolis mass flow meter (2), an R245fa evaporator for saturated or wet steam (3), an expander (4), an oil filter (5), a condenser (6), and a liquid working fluid reservoir (7). The boiler circuit is water, composed of a liquid water reservoir (8), a pump (9), an electric boiler (10) and the aforementioned exchanger H2O - R245fa of about 100kW of transferred heat. There is only a liquid phase throughout this circuit to avoid a boiling crisis.

The oil circuit separates the oil from the working organic medium and returns it to the expander after its heating to the inlet temperature of expander. Cold oil would lower the working fluid's inlet temperature and thus the expander output. Filtration takes place in a cyclone (5) with a built-in cleaner, the separated oil is conveyed by a gear pump (12) to a heating tank (11) and then to the expander. The third auxiliary circuit is part of the condenser. The cooling water, after suction from the reservoir (20) by the pump (21), passes through the condenser tubes to a connected air conditioner cooler (19) equipped with two fans and located in front of the laboratory building.

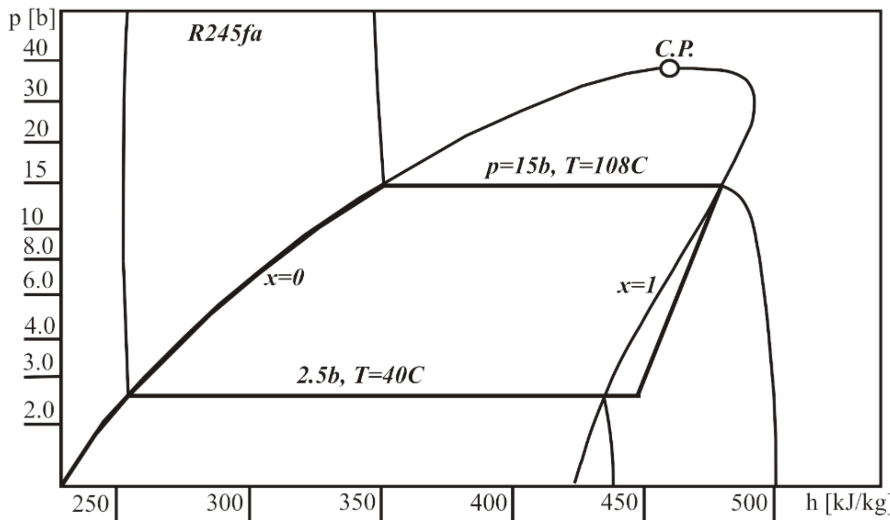


FIGURE 2. Drawing of the proposed pentafluoropropane cycle in the pressure-enthalpy diagram.

The branch for measurement the turning velocities and the expander torque moments together with utilization or depreciation of the produced electricity is connected to the expander shaft via a high quality coupling (22) not transmitting vibration. Behind coupling is an instrument (13) detecting the mentioned values. The obtained electrical signals are led to an oscilloscope (14), from which data are transferred to the evaluation computer. The asynchronous motor (15) is used as an electrodynamic brake and the electric current produced here is fed to the converter (16). There are basically three ways to deal with the electricity produced. It can be recuperated to a 3x400 Volt network, requiring a difficult phasing process. Furthermore, the electric current can be used as a supplementary heat source in the electric boiler. In short-term tests, the produced current is possible to convert into heat in coil resistances cooled by natural air circulation.

In addition to the meters mentioned, the experimental equipment is equipped with a number of other sensors for measuring pressures and temperatures, mainly in the expander area, which is the core of the research.

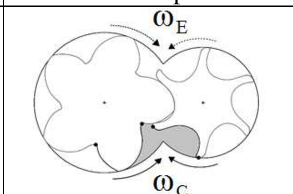
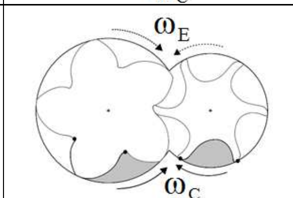
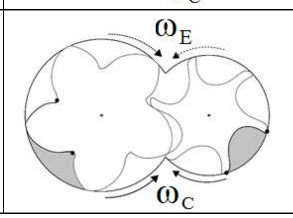
MECHANICAL AND STRUCTURAL SOLUTIONS

The implementation of the project to convert a screw compressor into an expander by modification of the screws shapes consists of two main steps. The first step is to build the machine from existing screw compressors and make the necessary calculations and measurements. In a subsequent step, adjustments will be required to improve the efficiency of the device. These adjustments will include, among other things, efforts to reduce leakage losses and endeavour to adapt the expander workspace by modifying the shape of the rotor tooth profiles. According to the information available, this option has not been examined.

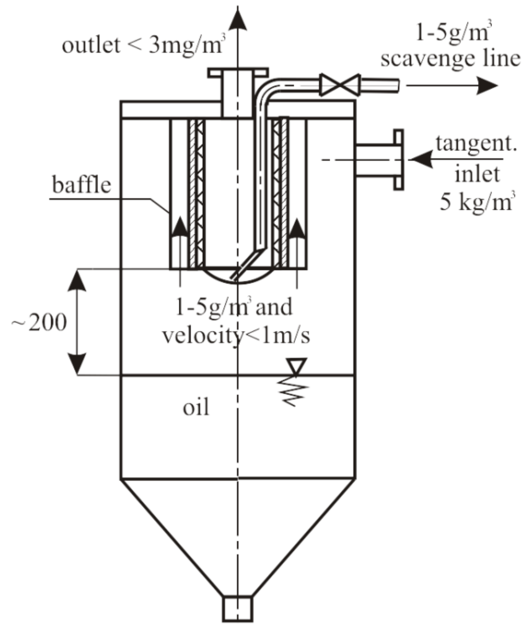
To construct a mathematical model of a screw motor, it is necessary to create a computational model of the working space formed by the teeth of the screw rotors. Tooth profiles are created by the envelope principle, which is mathematically described by transformation equations and the condition of mutual contact, which forms perpendicularity of normal vectors and relative profile velocities at the point of contact. The theoretically correctly together working tooth profiles are shown in Fig. 3 (a). The profile shapes can be different and currently the profile shown in the figure is most used, and it also has various modifications. The figure shows the rolling of the rotors in the front plane or the front cross sections of the rotors along the axis of rotation. The surfaces between the teeth form in the longitudinal direction the working chambers of the screw machine which form the individual working spaces. At an expander this spaces must increase in direction of the working medium flow.

The selection of the most suitable rotor profiles is based on the numerical calculation of the flow (CFD) in the area of the moving screws. The flow computation gives the pressure distribution on the surface of the expander rotors, from the pressures will be computed forces acting on the rotors, their moments, and the output taken away by the shaft. In doing so, the escape amount of the organic medium through the slots between the rotors, between the rotors and the housing will be respected. Experimental verification is necessary.

Majority of commercially available screw expanders are of „dry design". It means, that no oil is used for lubricating and sealing of screw rotors. This attitude results in less efficient machine, featuring also high speed of rotor revolutions, limited life time and higher emitted noise. Because introduced project works with oil lubricated screw expander, the utmost attention must be rendered to oil circuit itself. After designing of screw expander as a reversed version of screw compressor, ATMOS is now concentrating on oil injection to screw stage.

l=0	Expander	Rotation of profiles	Compressor
L_{in1}	t=0 (Suction)		$t+4\Delta t$ (Discharge)
L_{in2}	$t+\Delta t$		$t+3\Delta t$
L_{in3}	$t+2\Delta t$		$t+2\Delta t$

(a)



(b)

FIGURE 3. (a) Rolling of rotors in the compressor front plane or in a series of cuts along the machine axis, (b) Cyclone for spinning oil droplets, including internal cleaning line.

The oil circuit should be as closed as possible to minimize oil carry-over to the main ORC circuit. To ensure this, the separation process of mixture of oil and air has been studied and several different approaches pre- engineered. An oil separator is shown in Fig. 3 (b).

On the contrary to the standard oil lubricated screw compressors, which are utilizing downstream pressure cascade to the run oil flow through the circuit, in screw expander situation, the flow should be driven by pumps. The most suitable one are gear pumps both on main oil flow stream, as well as on scavenge line. To collect more detail knowledge regarding the oil separation process, the testing rig is being designed. The goal is to study the relations between pressure drop and oil pre-separation in pressure vessel, as well as fine separation on separation element. The right values of oil flow, should be tested and determined to ensure proper operation of expander element, which efficiency is also influenced by volume of oil injected.

ACKNOWLEDGMENTS

The project "Inversion of the screw compressor" takes place within the "Target 2014-2020" Cross-Border Cooperation Program Czech Republic – Bavaria and is funded by the European Regional Development Fund.

REFERENCES

1. I. K. Smith, N. Stosic, A. Kovacevic, *Power Recovery from Low Grade Heat by Means of Screw Expanders,* (Woodhead Publishing Limited, Cambridge, 2014).
2. K.Kauder, BWK Bd **37**, 1-13 (1995).
3. N. Stosic, I. K. Smith, A. Kovacevic, "Combined screw compressor-expander in fuel cell application", in *Proceedings of IMechE Conference on Compressors and Their Systems* (Professional Engineering Publishing, 2003), pp. 369-378.