2014

The Scroll Compressor With Internal Cooling System In Cryogenics Applications

Józef Rak
Wroc?aw University of Technology, Poland, jozef.rak@pwr.wroc.pl

S?awomir Pietrowicz
Wroc?aw University of Technology, Poland, slawomir.pietrowicz@pwr.wroc.pl

Zbigniew Gnutek
Wroc?aw University of Technology, Poland, zbigniew.gnutek@pwr.wroc.pl

The Scroll Compressor With Internal Cooling System In Cryogenics Applications

Jozef RAK[1]*, Slawomir PIETROWICZ[2], Zbigniew Gnutek[3]

[1]Wroclaw University of Technology, Department of Thermodynamics,
Wroclaw, Poland
jozef.rak@pwr.edu.pl

[2]Wroclaw University of Technology, Department of Thermodynamics,
Wroclaw, Poland
slawomir.pietrowicz@pwr.edu.pl

[3]Wroclaw University of Technology, Department of Thermodynamics,
Wroclaw, Poland
zbigniew.gnutek@pwr.edu.pl

* Corresponding Author

ABSTRACT

In order to decrease the energy cost of a compression process the cooling system has to be applied. Based on the modified vanes geometry the new cooling system for the scroll machines was proposed. The distinctive trait of the new vane is a significant space where the cooling system is possible to install. Applying internal cooling may contribute to decreasing outlet temperature thus increase the efficiency of the process. Based on the initial CFD results a large heat extraction scroll compressor prototype will be build and tested in cryogenics applications. The paper presents the simulation process describing the model assumptions, boundary conditions, taking cooling into account, and the postprocessing. It has been demonstrated that internal cooling system has an impact on compression process by making it more isothermal.

1. INTRODUCTION

The scroll compressors are widely used in the ventilation and air conditioning systems. There are other possible applications for such devices in medical or cryogenic industries where the distinctive scroll benefits (reliability, smooth and quiet work) may be utilized. The very important feature is also a possibility to build an oil-free machines. It enables to refrain from using oil separation systems and gain pure medium from simplified construction. It is especially useful in an aseptic environment or when small amount of space is available. Unfortunately oil is an important element in preventing leakage losses and heat removal. Without a dedicated heat removal system, the pressure ratio of the compressor is limited by the outlet temperature according to Equation (1).

$$T_2 = T_1 \left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}} = T_1 \left(\frac{v_1}{v_2}\right)^{\gamma-1} \quad (1)$$

If outlet temperature is too high, the thermodynamic efficiency is low and the device may even overwhelm due to seizure (Lee, et al., 2013). The last problem is connected with a thermal expansion of the vanes and it is the most intense in the discharge area where the temperatures are the highest (Jang, et al.,2006). The temperature increase is caused by two main phenomena: friction and compression process itself. The friction occurs in the axial sealing on top of the vane and in the vanes common points. Both of the friction types take place constantly.

In order to decrease the discharge temperature a new vanes shape has been developed, with a place for an additional chiller (Fig. 1). In the Fig. 2 a patent pending, nr P 398244, is presented. Filled in 02.27.2012 by S. Pietrowicz and J. Ciesla and it is a practical approach to the subject. The most important novelty proposed is utilizing the free space in the vane. Exploiting the fact that one of the scrolls is stationary, a chiller may be introduced. Cooling device would be matching the empty space and transferring the heat from working chambers and the scroll. It could be driven externally from the back of the compressor, what would not much complicate the unit. Such application would generate asymmetry to the system but, as it was mentioned before, the temperatures before discharge are predicted to be relatively lower and also chambers from both sides of the suction are rotating around the machine.

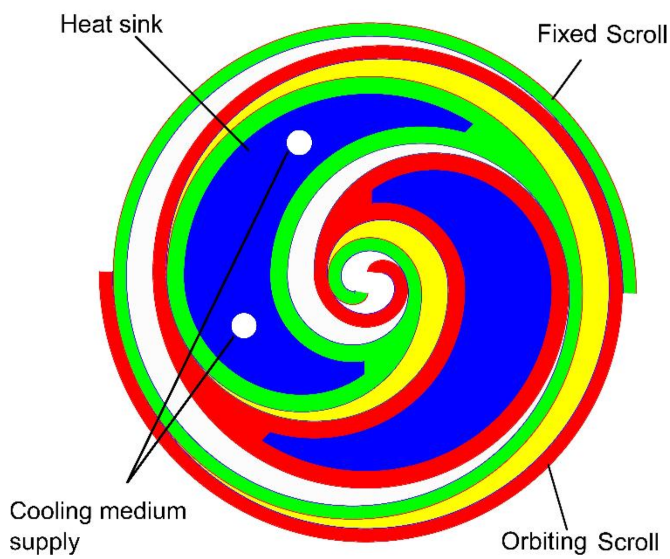


Figure 1: Hybrid vanes scroll compressor

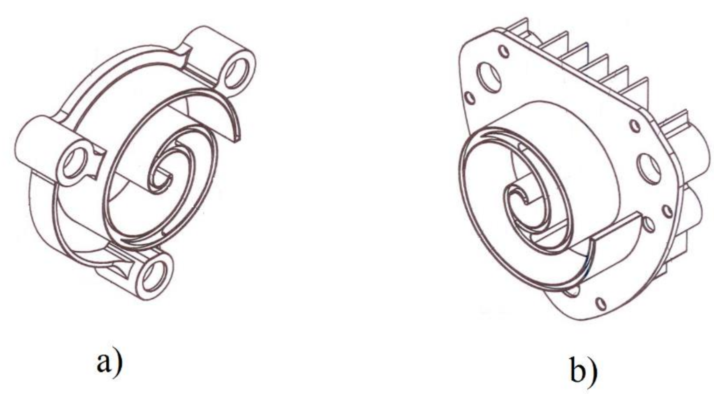


Figure 2: Scroll compressor, illustration from: *S. Pietrowicz, J. Ciesla, patent pending nr P 398244*

The vanes are build based on the involutes in suction and discharge areas, with a curve designed in complex numbers plane (Pietrowicz, 2003) which may be expressed as in Equation (2) (Bush et al., 1994):

$$\vec{P} = R_s(\psi)e^{i\psi} + R_g(\psi)e^{i(\psi+\frac{\pi}{2})} \tag{2}$$

In the proposed geometry the vanes edges length is reduced by 42% compared to an involute with preserved performance. In result the seal area, and the friction heat, is concerned to be lower. A distinctive feature of this geometry is a limited the number of working chambers and vanes common points, resulting in further friction reduction. Furthermore a chamber volume before the discharge is higher (Fig. 3) what implies more compression work in the central area and lower temperatures around it.

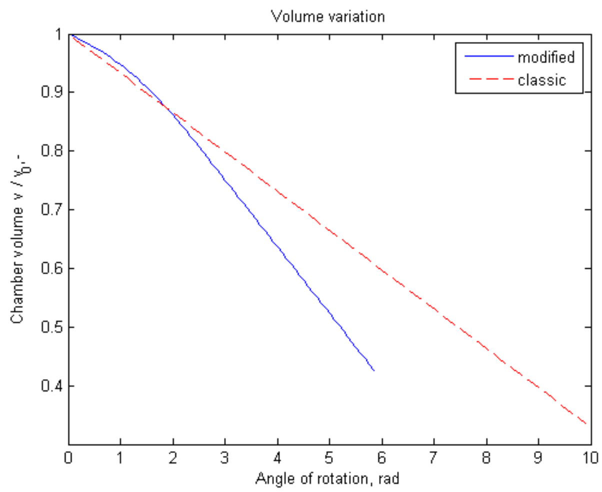


Figure 3: Volume change rate comparison for classical and modified vanes

2. JOULE-THOMPSON CIRCUIT

One of the applications for a scroll compressor with internal cooling may be compact Joule-Thompson cryocooler. The use of a modified compressor unit may emphasize scroll main advantages which are low noise, low vibration and continuity of the process. Proposed cryogenic setup with the scroll compressor is presented in the Fig. 4. In the concept with an oil-free compressor there is no need for oil supply or separation system. It simplifies the unit and allows for greater temperature range since an oil freezing temperature is not a concern. Also the cycle efficiency is expected to rise because of much lower pressure drop due to lack of filtering system.

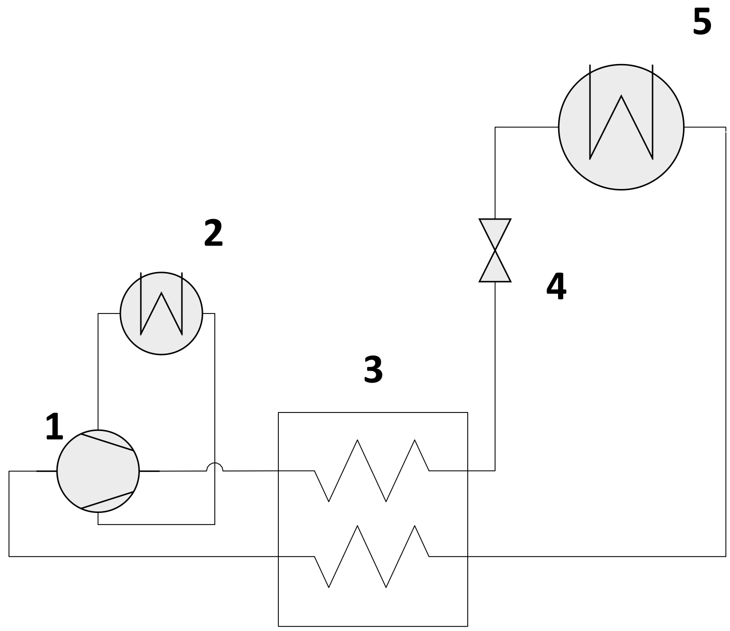


Figure 4: Joule-Thompson cryocooler cycle. 1) scroll compressor, 2) scroll cooling system, 3) heat exchanger, 4) J-T expansion, 5) evaporator

3. MODEL ASSUMPTIONS

The preliminary calculations, with the use of Finite Volume Method, were performed in order to estimate the possible cooling result and temperature field in the machine. In the two-dimensional steady-state model a conjugate heat transfer was solved within four fluid and two solid domains. Each domain was meshed independently (Fig. 5) with hexahedral elements and connected with corresponding interfaces. Since the compression process causes a gas temperature increase the heat of compression had to be modelled. In order to do so a heat sources were applied to the fluid domain heat transfer equation. In Equation (3) the sources were selected in the way that they reflect isentropic enthalpy growth in the medium with regard to the x chamber rotational angle.

$$S = (i_0 + c(T_x - T_0)|_{s=idem})\rho \tag{3}$$

Having the source term defined for each chamber a following boundary conditions and assumptions (Table 1) were applied:

Table 1: Model assumptions

Medium	air, ideal gas
Ambient and suction temperature	300 K
Suction pressure	1 atm
Inner chambers pressure	2.35 atm
Scroll material	aluminum, $k_{t=20^oC} = 297\frac{W}{mK}$
Shaft is stationary	$\frac{d\Theta}{dt} = 0$

Two simulations were performed: with no internal cooling (adiabatic free space walls) and with cooling (stationary scroll cooler wall as a heat sink $Q = -100\ W/m^2$). The adiabatic boundary condition for the empty space is justified since heat transfer coefficient is much higher for aluminum than for air inside the free area. In the both cases the heat is being transferred out of the machine through the outer walls of the vanes.

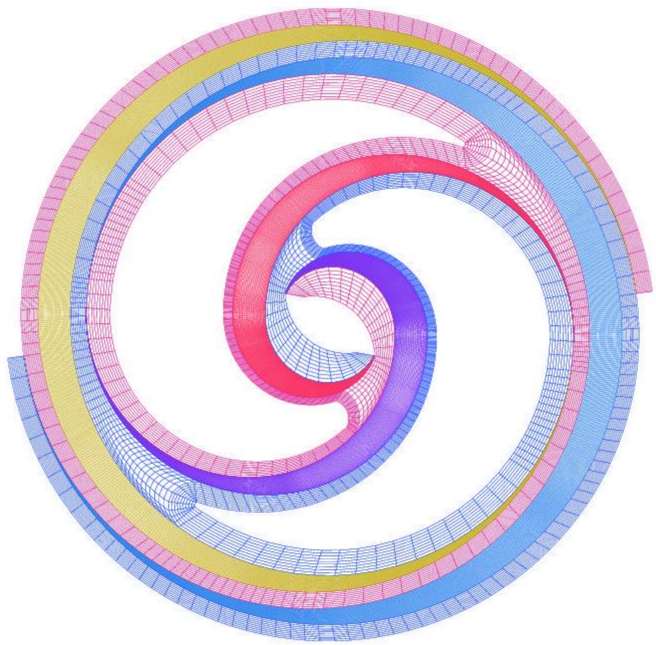
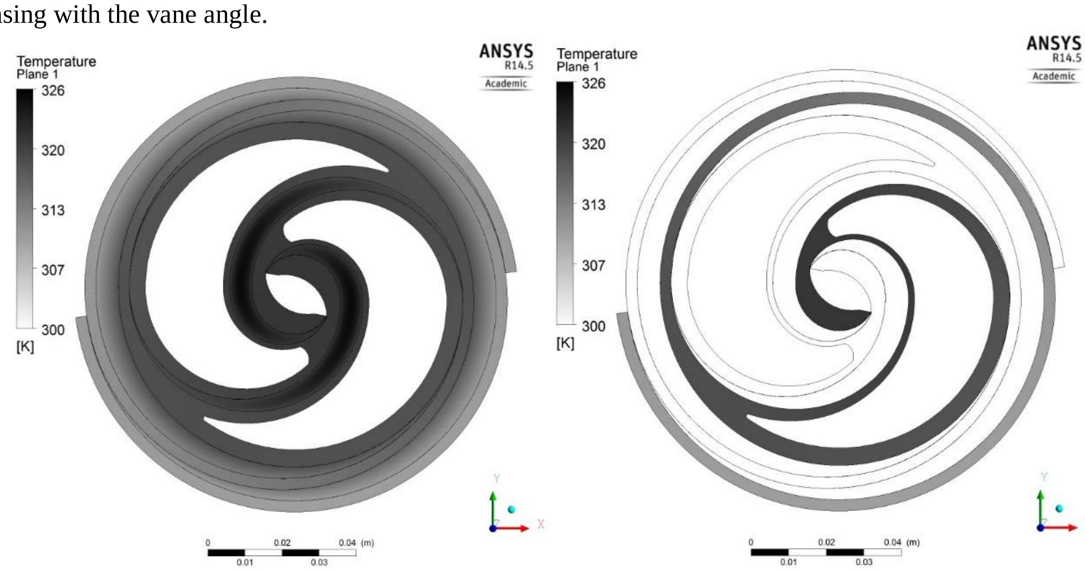


Figure 5: Numerical meshes of the working chambers and scroll vanes

4. Results and discussion

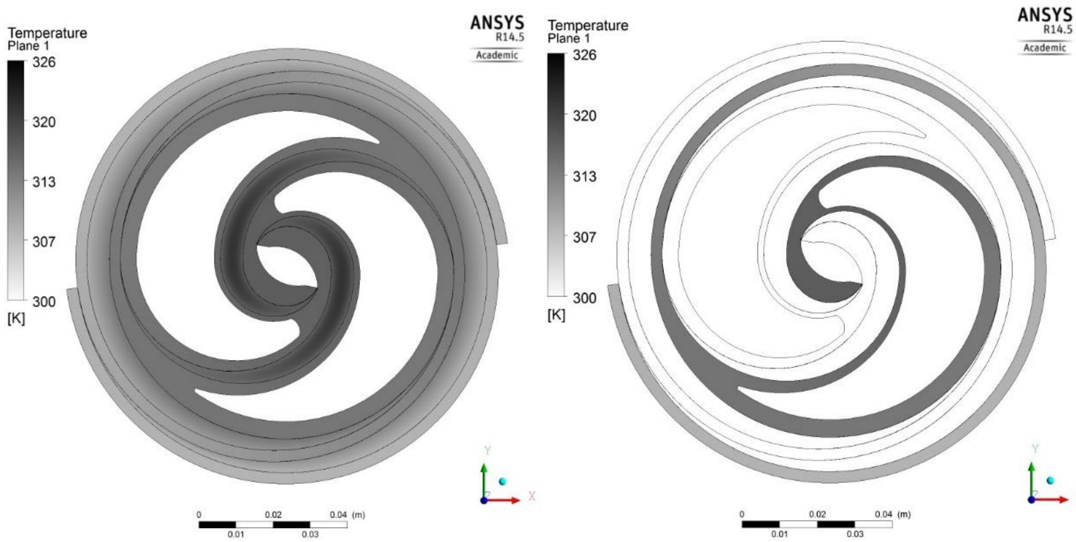
The simulations end was when temperature fields stabilized and the system reached its equilibrium. In the Fig. 6 a solution for a system with no additional cooling is presented. Maximum temperature of the medium is 326 K and the mean temperature in the central working chambers is both 322 K. The temperature field in the scroll is gradually decreasing with the vane angle.



a) b)

Figure 6: Temperature distribution without heat removal system

The second simulation was performed with the cooling system applied inside the static scroll. The converged results presented in the Fig. 7 show that the temperatures got lower compared to the previous ones. The maximum air temperature decreased to 321 K and the mean temperature of the central chamber fell to 317 K. There is no significant difference between opposite chambers mean temperatures and no further asymmetry was noticed in the scrolls.



a) b)

Figure 7: Temperature distribution with the use of heat removal system

5. Summary

The concept of hybrid geometry oil-free scroll compressor with internal cooling system was presented. The anticipated benefits are twofold. Modified vanes shape, with shorter length, may reduce the friction heat generated. It also changes the compression process nature by decreasing pressure, and so the temperature, before the discharge chamber. Another part of the concept was applying the internal cooling system inside the stationary vane. It became possible since the hybrid curve was used. The numerical procedure was developed in order to estimate the possible thermal effect of such solution. The simulations confirm the temperature reduction in all of the working chamber and in the scrolls. Taking this into account the modifications may result in higher efficiency and reliability of the compressor.
The proposed solution may find use in cryogenic applications where high pressure ratio is needed or in any process where high output medium purity and low temperature is essential.

NOMENCLATURE

c	heat capacity	(kJ/(kg K))
k	thermal conductivity	(W/(m K))
i	specific enthalpy	(kJ/kg)
p	pressure	(Pa)
P	vector	(-)
R_g, R_s	vectors	(-)
S	heat source	(kJ/m^3)
t	time	(sec)
T	temperature	(K)
v	specific volume	(m^3/kg)
γ	heat capacity ratio	(-)
θ	shaft angle	(rad)
ρ	density	(kg/m^3)
ψ	parameter	(-)

REFERENCES

Bush, J. W., Beagle, W. P., Housman, M. E., 1994, Maximizing Scroll Compressor Displacement Using Generalized Wrap Geometry, *International Compressor Engineering Conference*, Purdue, p. 204-210.

Lee J., Lee K., Jeong S., 2013, Experimental study of a mixed refrigerant Joule–Thomson cryocooler using a commercial air-conditioning scroll compressor, *Cryogenics*, vol. 55–56, Pages 47-52

Jang K., Jeong S., 2006, Experimental Investigation on Convective Heat Transfer Mechanism in a Scroll Compressor, *International Journal of Refrigeration*, vol 29, Pages 744-753.

Pietrowicz, S. 2003 The modelling of thermal – flow processes in scroll machines, Ph.D. Thesis, Wrocław University of Technology,Wrocław 2003 (in Polish).

ACKNOWLEDGEMENT

Calculations have been carried out using resources provided by Wroclaw Centre for Networking and Supercomputing (http://wcss.pl), grant No. 278.