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Numerical Analysis of Screw Compressor Rotor and Casing Deformations

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Abstract:

Performance and reliability of screw compressors is highly dependent on their operational clearances. Compressor structural parts including rotors and the casing are affected both by pressure and temperature of the working fluid to which they are exposed. The standard approach when simulating performance is to neglect these deformations and assume rigid compressor elements.

In this paper a numerical solution which combines the solution of fluid field from Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) of solid elements is used to calculate deformations of the compressor elements. The temperature field obtained from CFD is extracted and applied to the surface of the solid parts where it was averaged in time and served as boundary conditions for solid body calculations. The FEM analysis performed in ANSYS showed encouraging results which can be used for analysis of changes in compressor clearances.

Key words: Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA), screw compressor, deformations.

1. Introduction

Screw compressor are positive displacement machines that comprises pair of helically geared rotors contained in a casing as shown in Figure 1. Relative motion of rotors and casing causes change in the volume of the compressor working chamber which increases the pressure and causes the compression process [1, 2]. Clearances must exist between rotating and stationary parts allow relative motion between rotors and casing. That in turn provides leakage gaps between rotating and stationary elements. The compressed fluid leaks through these leakage gaps and influences the efficiency of a screw compressor. The size of clearances is affected by the deformation of structural elements caused by pressure and temperature. If the compressor rotors deform due to the increase in temperature, there is a risk of contact between the rotating and stationary elements and therefore risk of damage or complete failure of a compressor. In order to avoid that contact, designers increase compressor clearances. This however causes higher leakage losses and in turn increase in the working chamber temperature which in turn further deforms the rotors [3]. Therefore it is desired to minimize the clearance. Due the fast development of manufacturing technologies in the past several decades it is now possible to manufacture screw compressor parts with high precision. Screw compressor rotors can now be produced at an economic cost with tolerances as small as 5 micrometres while casing bores can be manufactured with repeatability of 2 micrometres [4]. This gave possibility to manufacture screw compressor with low level clearances and avoid previously mentioned malfunctions.

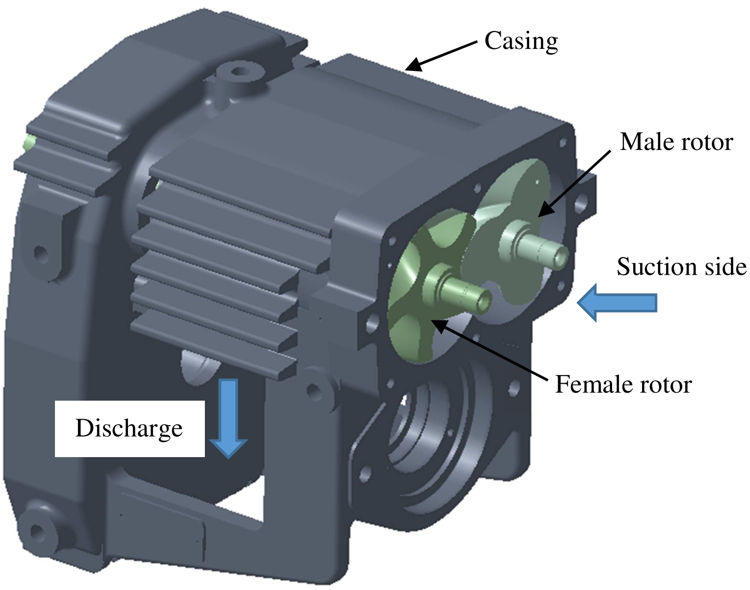

Fig. 1 Design of twin screw compressor

Despite the advanced manufacturing capabilities give a deterministic framework to the design process of screw compressors the thermodynamic process during screw compressor operation significantly affects changes in clearances. The increase in pressure and temperature will cause screw compressor parts to deform. Which of these two parameter will influence more on deformation depends mostly on the compressor type, i.e. is it oil free or oil injected [4]. Oil free screw compressors are mostly designed for low pressures of up to 3 bar but due to lack of cooling of the compressed gas, they usually have high discharge temperatures. In this case pressure loads are much less significant than the temperature loads.

Temperature loads in oil free screw compressors cause significant size and shape deformations which cause to clearance level changes. Typically, the inter-lobe and radial clearances on the discharges side of the compressor will reduce. To determine values of clearances under the working conditions especially under temperature changes, several steps have to be performed. Typically, the first step is to perform CFD calculations which will provide temperature distribution on the boundary of rotors and casing. Second step is thermal analysis which gives temperature load distribution in rotors and casing. Third step is structural analysis which gives deformations of rotors and casing. In order to perform such a process, due to complexity of screw compressor geometry simplification have to be taken into account. Different authors suggest different approach to solve this problem.

Sauls et al, 2006 proposed to separately calculate temperature field in the compressed gas and FEA analysis [5, 6, 7]. This process requires serious effort and time to perform calculation and transfer results in different software which is measured in months and is not practical for industrial use. Kovacevic et al, 2002 proposed use of Computational Continuum Mechanics (CCM) in which finite volume method is used to calculate fluid flow and solid structure, all in the same solver [4]. The results showed excellent results. The process is suitable for research but still requires significant effort to be implemented in industry. One dimensional analytical approach for local deformations proposed by Buckney et al, 2014 is applicable in industry as it is fast but takes into account some assumptions which cannot be always generally accepted [3].

It is important to emphasize that during thermodynamic process in screw compressor heat will transfer not just to the rotors and casing but to some other parts of compressor too. This means other parts will expend under temperature loads in the convenient ratio. Clearances mostly depend of the geometrical values of the rotors and casing and in this analysis all other deformations will be neglected.

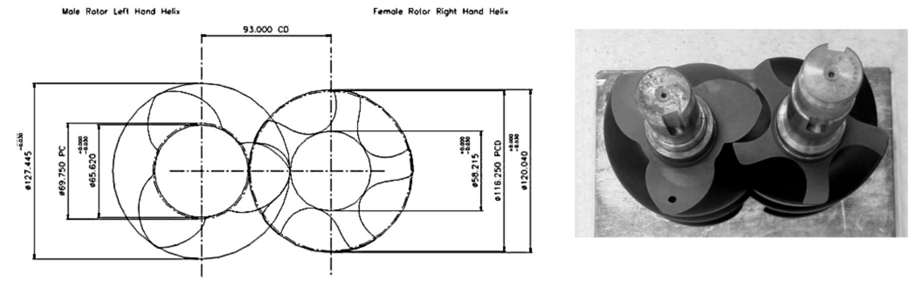

Fig. 2 Oil free screw compressor with 3-5 “N” rotors

This paper presents an integrated approach which uses results from chamber model and applies averaged temperature for the numerical analysis of screw compressor rotors and casing deformation using commercial solver ANSYS in order to estimate change in clearances. For this analysis oil free screw compressor with 3-5 “N” rotors showed in Figure 2 is used.

2. Thermal analysis of screw compressor rotors and casing

Chamber models are often used to calculate compressor performance and determine temperature change within the working chamber in time, i.e. with the rotation of rotors [1]. Such models are fast and reliable. Screw compressors are positive displacement machines in which change of the pressure is caused by the change in volume. Therefore it is reasonable to assume that parameters of the fluid trapped in the chamber such as pressure and temperature are the same for the entire chamber in one time instant. They change with rotation of the rotors in time as function of change in volume. Therefore, pressure and temperature values calculated by use of chamber model can be assigned to the part of the rotors and casing depending on the rotation angle. The computer code SCORG developed at City, University of London allows grid generation for CFD and calculation of preliminary thermodynamics. The grid generated in SCORG is exported to ANSYS – CFX for temperature and pressure calculations. State of fluid temperatures obtained from the chamber model and CFD simulation for one specific position can be seen in the Figure 3.

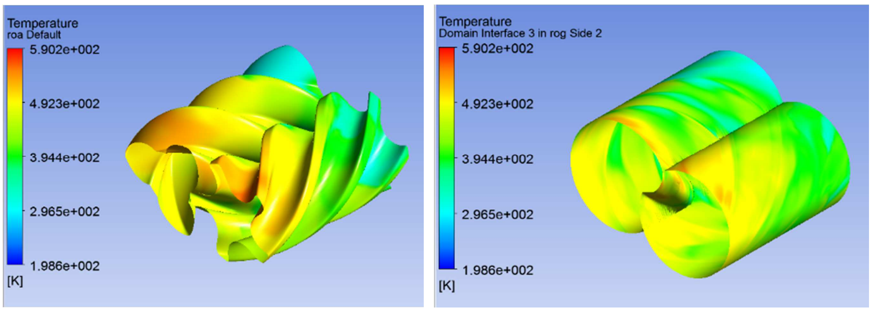

Fig. 3 Temperatures assigned to rotors (left) and casing (right) for specific rotor angle value

Figure 3 shows temperatures of fluid trapped in each chamber next to the rotors and casing surfaces for specific rotor angle. The temperature distribution over rotor and casing surfaces changes with the change in the rotational angle. Similar results are achieved by multi-chamber thermodynamic model built in SCORG. These results are used for calculation of rotor and casing deformations.

Due the cyclic characteristic of motion identical temperature distribution over surfaces are repeated after full cycle for rotors and after every lobe passing for casing. These temperatures are averaged along the rotors and casing which is shown in Figure 4 [3, 5].

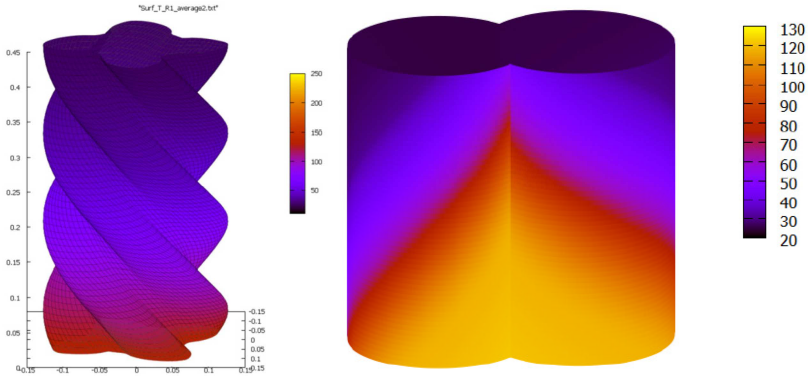

Fig. 4 Averaged temperature distribution on rotor (left) and casing (right)

Averaged temperatures are than used as boundary conditions in steady state thermal analysis of rotors and the casing. Figure 5 shows temperature loads on male and female rotors after steady state thermal analysis. For this analysis ANSYS software for steady state thermal analysis has been used. Temperature load values are changed from around 27 to 180 °C for rotors and casing but with different distribution over surfaces. Figure 6 shows temperature loads on casing.

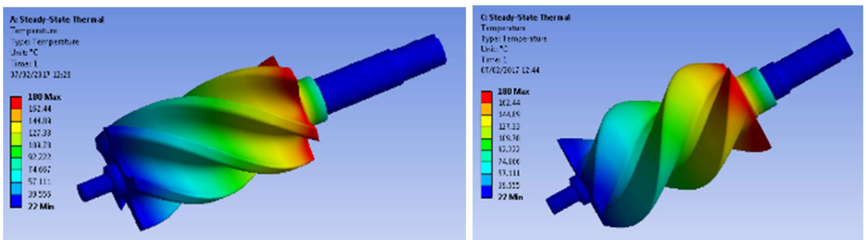

Fig. 5 Temperature loads on female (left) and male (right) rotors

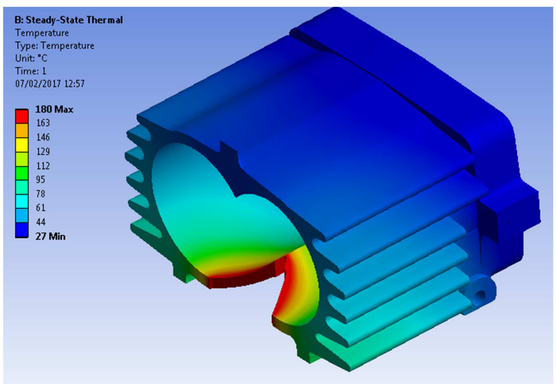

Fig. 6 Temperature loads on casing

Temperature values for the casing are highest around discharge port. Once the thermal steady state analysis has been performed it is possible to start with structural analysis of screw compressor rotor and casing under temperature load.

3. Structural analysis of rotors and casing

Computation of rotors and casing deformation has been carried out by Finite Element Method (FEM) in ANSYS software. Numerical analysis for each part is performed separately. Solid bodies of rotors and casing are divided into finite elements where female rotor comprises 185789 elements, male rotor 156228 elements and casing 50172 elements. Temperature loads are taken from steady state thermal analysis from the previous step. Rotors are restrained at bearings.

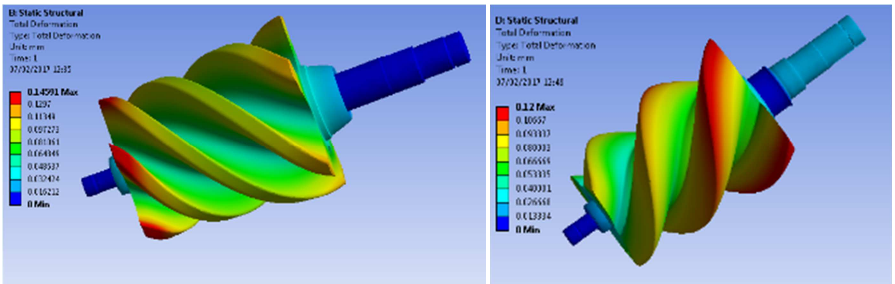

Fig. 7 Enlarged deformations of female (left) and male (right) rotors

Figure 7 shows deformations of the female and male rotors under temperature loads. Deformations are enlarged 130 times to be visible in the figures. From the results it can be seen that deformations are increased from suction side to the discharge side which means that the largest deformations are on the discharge side where temperature field has the highest values.

Values of the maximal deformations of 100 μm on the male and female rotors are significant. This means that projected clearances are changed. If only the rotor deformations are taken into account, this compressor would have contact between the rotors and the casing as well as between the rotors. In reality both screw compressor which rotors and casing will deform. Therefore the deformation of the casing needs to be included is the analysis.

Figure 8 shows the casing deformation. Deformation for casing are also enlarged 130 times to be visible.

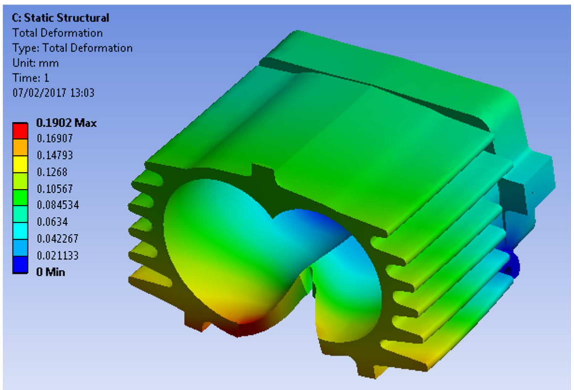

Fig. 8 Enlarged deformations of casing

As expected, the deformations of the casing are significantly different than the rotors deformations. The casing is not deformed symmetrically around the axis like in the rotors case which can be seen from the Figure 8. The largest deformations values for casing are around 200 µm and it occurs in the discharge zone. This result shows that casing expansion will make some free space for the expansion of rotors. The critical point is the top of the casing on the discharge side which sees deformations lower than the expansion of the rotors. However due to slight change in the position of rotor axes at the discharge the compressor elements will not come in contact and the compressor will continue working correctly.

The analysis shows that different regions have different levels of deformations. Deformations in the suction zone are significantly lower than in discharge zone which influences clearances to change differently along the rotors and casing.

4. Conclusion

A full 3-D simulation has been carried out to determine the flow field within the oil free screw compressor. The temperature to which rotors are exposed has significant influence on the change in operating clearances. Changes in the working clearances are consequence of the deformation of rotor and casing. It is shown that the results from CFD calculation or from chamber model can be used to average the temperature on the rotor surface and could be used for mapping the boundary conditions for the FEA analysis. The FEA analysis shows that due to the different nature of the deformation of rotors and casing, the operational clearances in different regions of the compressor will change differently. The work is continuing to define reliable and fast method for analysis of the effect of the clearance change on the performance of screw compressor.

5. References

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