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**TRANSIENT THERMAL ANALYSIS OF SCREW COMPRESSORS,
PART III
TRANSIENT THERMAL ANALYSIS OF A SCREW COMPRESSOR TO
DETERMINE ROTOR-TO-ROTOR CLEARANCES**

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ABSTRACT

This paper is the third installment in a series of three papers intended to report on the implications of transient thermal phenomena in the operation of oil-flooded refrigeration screw compressors. In the interest of designing an oil-flooded refrigeration screw compressor with both high efficiency and reliability, a comprehensive understanding of the clearances between moving parts in the operating compressor is key, both at steady-state operation and in the transients that occur during normal operation.

Four factors: bearing bore locations (in thermally deformed housings), bearing deflections, rotor bending, and thermally deformed rotor shape all act together to produce the rotor-to-rotor clearances experienced in a running screw compressor. For the transient thermal analysis case considered in Part I and Part II, the intermesh clearances from rotor to rotor are calculated throughout the time range. A three-dimensional rotor clearance calculation code is utilized to perform the calculations. Relative influence of the four factors is investigated.

1. INTRODUCTION

It is already noted in Parts I (Sauls *et al*, 2006) and II (Weathers *et al*, 2006) that there is a desire to manage the clearances between moving parts in the operating screw compressor for performance and reliability concerns. Part II proceeded to describe the finite element analysis work done to determine temperature distributions throughout the compressor for transient and steady state cases so that compressor part thermal deflections could be determined and then clearances between screw rotors and rotor bores could be calculated. The clearance distribution between the rotors themselves—intermesh rotor clearance—was calculated separately with special purpose software that worked with precise rotor profiles and is the subject of this paper. The general behavior of the screw rotor, like the major compressor housings can be determined for the nominal case—perfectly machined housings. The next step was to combine the effects of real world production variation with the thermal effects and see how they compare. For the rotors, we need to consider all the components that make up their true physical state:

1. Manufacturing variation—machined location and size of the bearing bores in the housings.
2. Thermal displacement of the bearing bores in the housings.

3. Machining variation of the rotor profiles.
4. Profile distortion due to thermal effects.
5. Whether or not the rotors are crowned.
6. Rotor bending due to gas forces.
7. Bearing deflections under load.

2. MESHLINE

In order to discuss the rotor-to-rotor clearances, it is important to have an understanding of what defines the “contact” of the rotor set. The meshline refers to the locus of points that are along the flanks of the male and female rotors and represent the points that are at closest approach between the two rotors from one end of the rotor bodies to the opposite end. These points define a sealing edge of the compression pockets contained by the rotor lobes and the housing rotor bores. If the points along the meshline are also located within the design contact band of the rotor profile, they may or may not actually touch, depending on the orientation of the rotors with respect to each other and the various modifications to the profiles that are the subject of this paper.

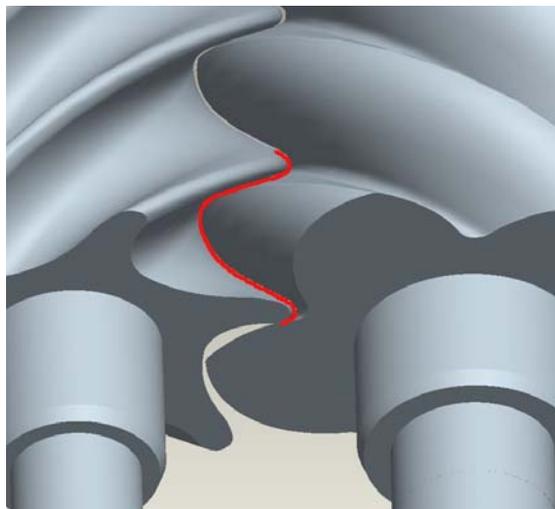


Figure 1: Portion of Meshline

Figure 1 shows a representation of a section of the meshline that is visible when two rotors are paired outside the rotor housing. If the meshline is plotted in space coordinates without physical geometry in the way to obscure the locus of points, it would look like the representation in Figure 2, where views from x,y , y,z , and x,z are shown. An oblique view of the meshline, (like the isolated section shown in Figure 1) is shown in Figure 3.

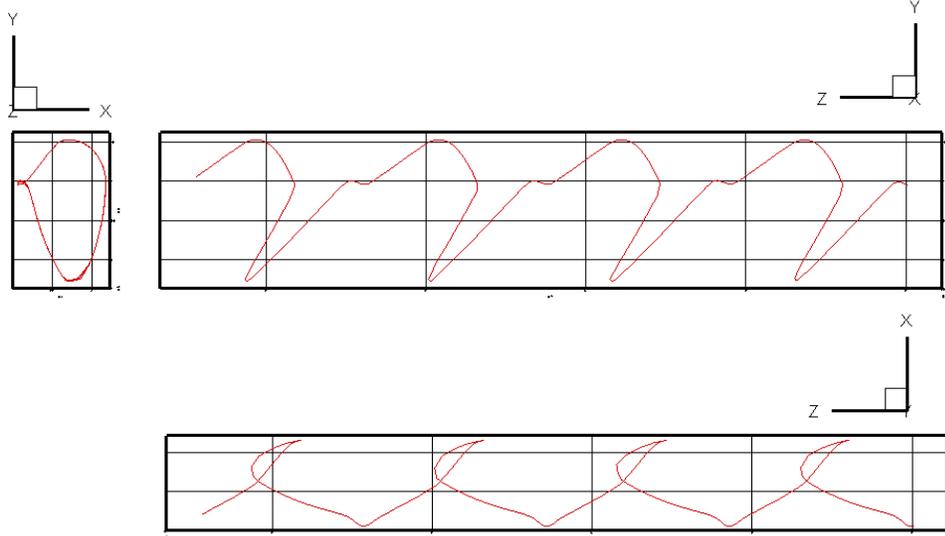


Figure 2: Multiple Views of Meshline

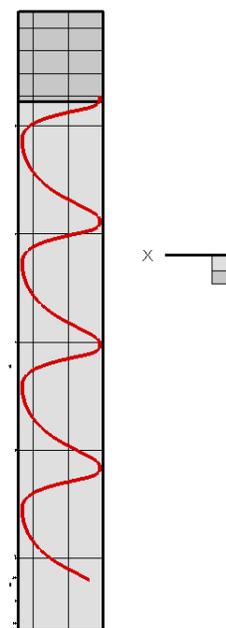


Figure 3: Angled View of Meshline

We are most concerned with the clearance between the two rotors, so that would mean calculating the closest approach of the two opposing rotor flanks as we travel along the

meshline. With the understanding of what the meshline looks like in 3-D space, perhaps an easier way to visualize the clearance between the rotors is to use the meshline length as a parameter, and look at clearance as a function of position along the meshline. Figure 4 shows an example of the clearance calculated for two rotors with nominal size, shape and positions within a screw compressor. It is apparent from the example that there are four regions of contact between the male and female rotor possible under these conditions. For all clearance plots, the clearance is

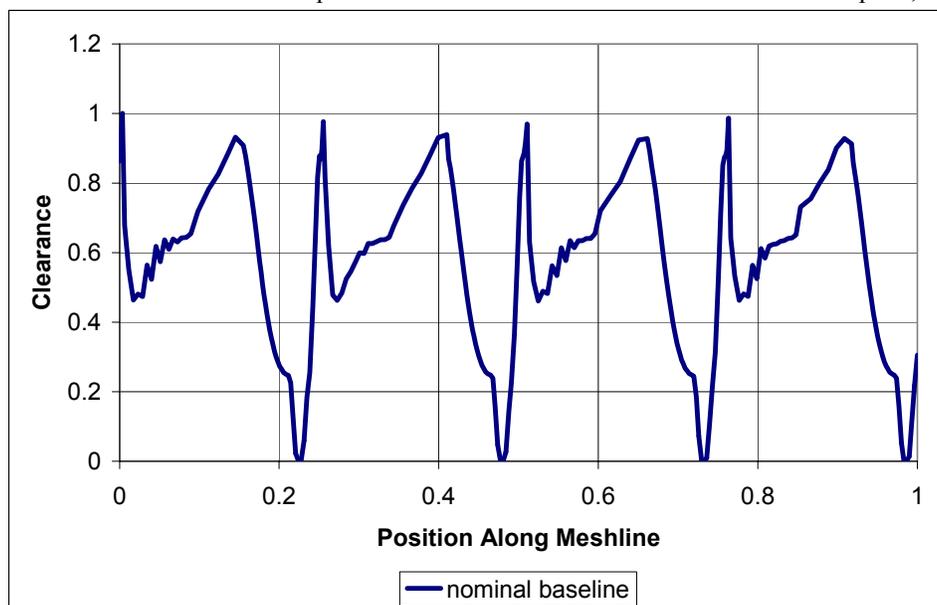


Figure 4: Baseline Clearance Along Meshline

scaled by the maximum clearance in this baseline case and is plotted at a fraction of the position along the meshline from the suction end of the rotors.

3. MANUFACTURING VARIATION

A primary source of variation in the as-assembled rotor-to-rotor clearance is the orientation of the rotor shafts with respect to each other. The shaft orientation is determined by the design of the compressor housings that contain the suction and discharge end bearings, as well as the capability of the machining process for those housings. A

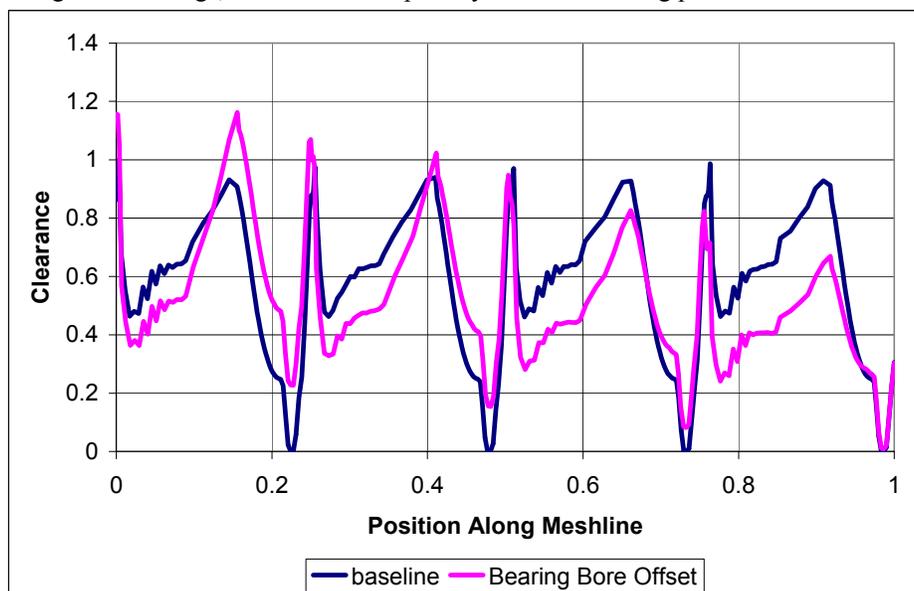


Figure 5: Clearance with Bearing Bore Position Offset

compressor with only variation in the positions of the rotor orienting bores could result in clearances like those in Figure 5, which compares shifted axes to the nominal case. Axes are shifted the maximum that would be expected given design tolerances for bearing bore position.

4. THERMAL DISPLACEMENT OF THE BEARING BORES

Another factor controlling the position of the shaft-positioning bearing bores in the housings is the thermal analysis

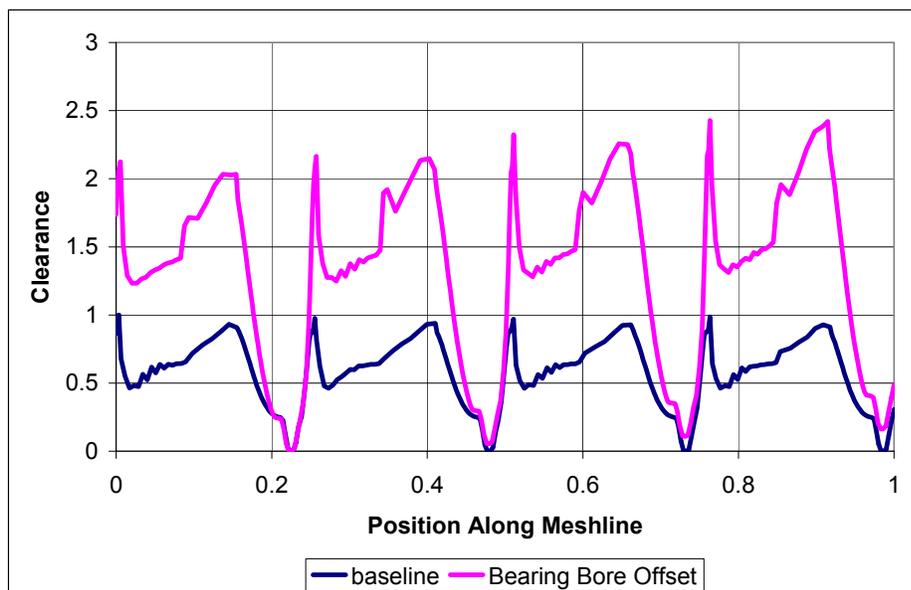


Figure 6: Thermal Effects on Bearing Bore Locations

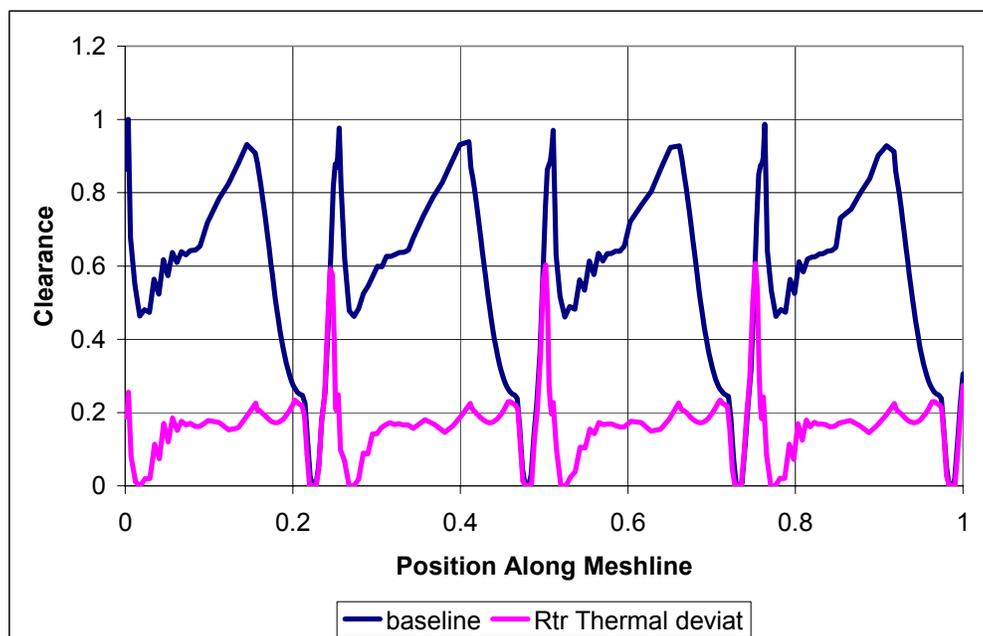
reported in Part II of this report (Weathers *et al*, 2006). The heating of the housings predicted by the thermal analysis tends to act in differing amounts at the suction and discharge ends of the compressor. The effect on rotor clearances due to the change in bearing bore positions from the thermal effects for the case studied in Part II is shown in Figure 6. This clearance change could be considered very significant.

5. VARIATION OF MACHINED ROTOR PROFILES

The processes used to manufacture the rotor body profiles also play a part in the actual physical state of the rotors within the compressor. Profile deviations from manufacturing are due to a variety of causes such as machine setup, tool condition, rotor material issues (type of material and amount of stock to be removed), etc. In the end, it comes down to the specification that is applied to the screw rotor profiles. The resultant clearance from variation of rotor profiles acts to impact the character of the clearance distribution somewhat, but magnitude of manufacturing variation is much smaller than the magnitude of variation due to thermal distortion discussed in section 6 and is not considered further.

6. THERMAL DISTORTION OF ROTOR PROFILES

As was done with the housings and the resultant bearing bore positions, the thermal analysis conducted by Weathers *et al* (2006) was used to determine the thermally deformed shape of the rotor profiles. This thermal component of the changes applied to the rotors as a result of the actual running conditions of the compressor results in changes to the rotor mesh clearance. Considering only the changes on the rotor profiles, the resulting mesh clearance can be seen in Figure 7. This is a significant change from the baseline clearance.



7. ROTOR CROWNING

Another factor that affects rotor-to-rotor clearance is any modification of the basic profile shape over the length of the rotor. Crowning is a technique that modifies the tooth profile along the rotor length, relieving the profile (removing more material) towards the ends of the rotor body, while the middle of the rotor body may have an unaltered nominal profile shape. Obviously, a changing profile along the rotor length will impact the rotor-to-rotor clearance along the rotor. Figure 8 shows a comparison of the rotor clearance along the meshline for a set of rotors with and without crowning.

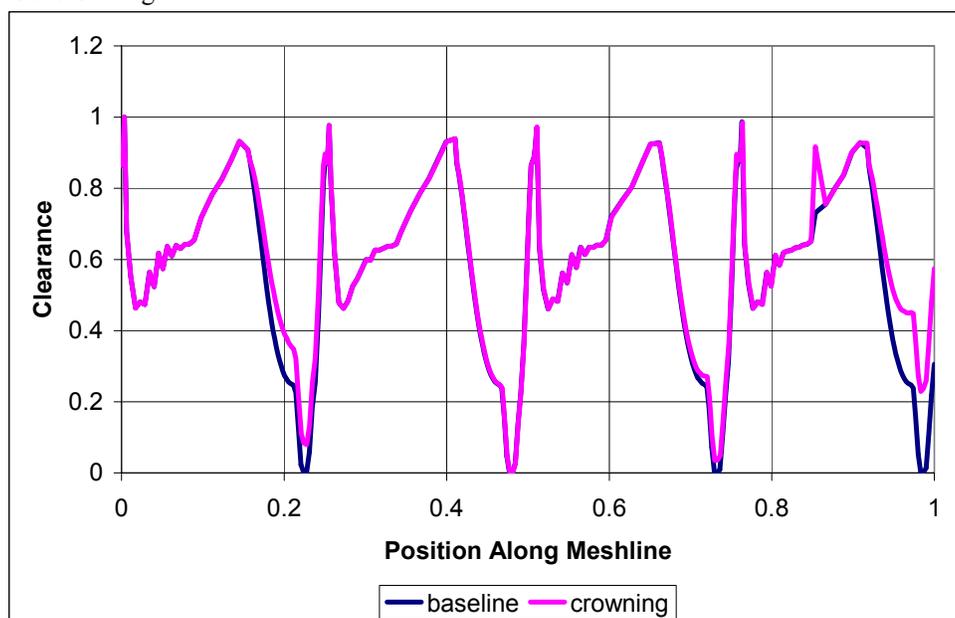


Figure 8: Effect of rotor crown on mesh clearance

8. ROTOR BENDING

The effect of the gas forces on the rotors and bearing deflection is not as dramatic an effect. Figure 9 shows effects of rotor bending on mesh clearance for the load case of interest.

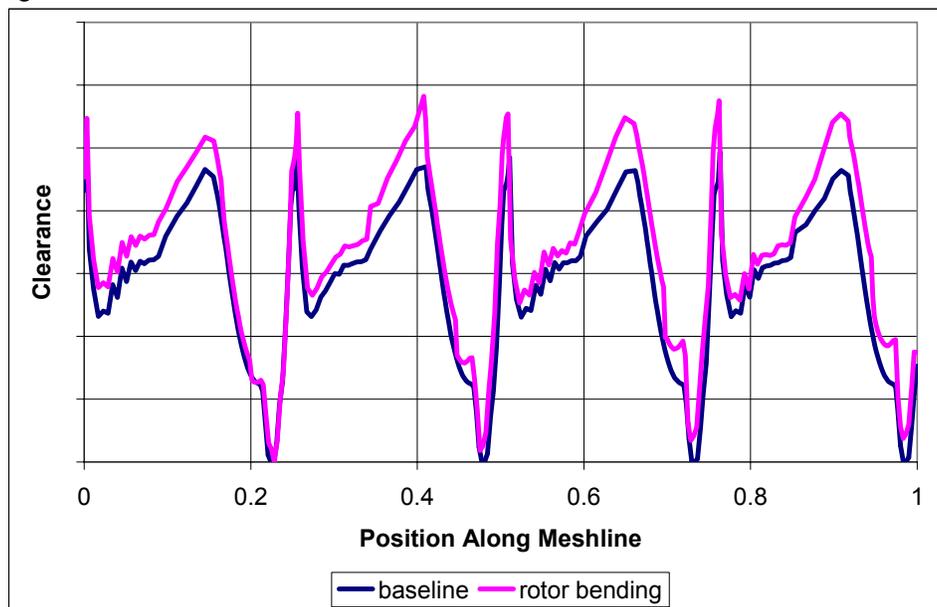


Figure 9: Clearance effects from gas loads

9. SUM OF THERMAL DEVIATIONS

When the effects of thermal deviations on the rotors and housings are combined, the picture is not as bleak, since the effects on rotors and housings tend to counteract each other. The growth of the rotor bodies is contained by the expanding housings. Figure 10 shows the comparison of thermal effects with the baseline case.

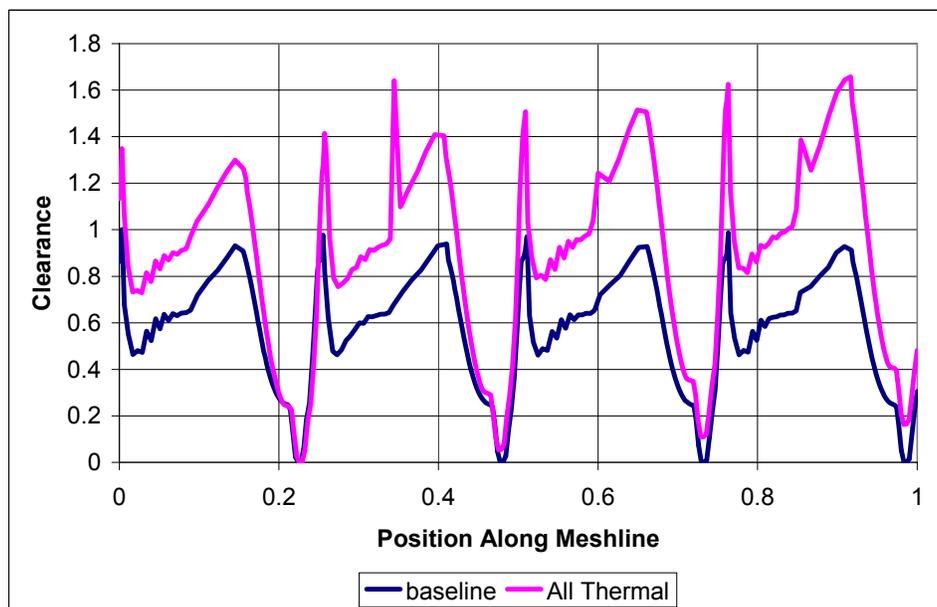


Figure 10: Mesh clearance change from thermal effects on rotors and housings

10. FACTORS NOT CONSIDERED

Some other factors that would play a part in the total picture for the rotor-to-rotor clearances would be individual tooth deflections due to loads. Each rotor tooth (male rotor lobes are typically very massive in relation to the female lobes, so would have a smaller effect than female lobes) deflects due to the gas loads imposed on it by the compressed fluid present in the compressor. In addition, for untimed rotors in a direct drive arrangement, rotor lobes would deflect as a result of the loads transferred from one lobe to the next as they contact. The oil flooded refrigerant compressor currently being considered has relatively low contact forces and low torque transmission so they are not considered.

11. CONCLUSIONS

- Thermal deflections in compressor housings and rotors are a significant factor in the variation seen in compressor mesh clearances during operation.
- Thermal deflections in the compressor parts are a larger source of clearance variation than manufacturing induced variations.
- A piece of welcome knowledge is that the running mesh clearances do not appear to have a minimum lower than that experienced in the cold, non-operating mode.

REFERENCES

- Kauder, K., Janicki, M., von Unwerth, T., 2001, Workshop: Simulation of screw-type machines, Private communication, University of Dortmund.
- Kauder, K., Keller, G., 1995, Wärmeübergangsrandbedingungen für Schraubenmaschinen, Schraubenmaschinen – Forschungsberichte des FG Fluidenergiemaschinen Nr. 13, Universität Dortmund: 5-19.
- Sauls, J., Powell, G., Weathers, B., 2006, Transient Thermal Analysis of Screw Compressors, Part I -- Use of Thermodynamic Simulation to Determine Boundary Conditions for Finite Element Analyses, Proceedings of the 2006 International Engineering Conference at Purdue, Purdue University.
- Weathers, B., Sauls, J., Powell, G., 2006 Transient Thermal Analysis of Screw Compressors, Part II Transient Thermal Analysis of a Screw Compressor to Determine Rotor-to-Housing Clearances, Proceedings of the 2006 International Engineering Conference at Purdue, Purdue University.

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