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Numerical study on oil supply system of a rotary compressor

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HIGHLIGHTS

- A CFD method for analyzing the oil supply system of rotary compressor is presented.
- Leakage through the roller end clearances depends on the operating condition.
- Groove shape and inclination angle are the main design parameters of spiral grooves.
- A parabolic interface of oil and gas can be formed in the gallery of the shaft.
- Single-flow model and steady solver can be applied to the oil supply system.

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ABSTRACT

The oil supply system is a crucial reliability issue for rotary compressors. This paper provides a general method for analyzing the oil supply system of a rotary compressor by using computational fluid dynamics (CFD). The process includes establishing the physical model, dividing computational grid, setting boundary conditions, calculating leakage rates through the roller end clearances, translating the dynamic issue into the static issue and so on. Validation of the rationality of the oil supply system model has been made by the measurement of the main bearing oil flow rates. The effects of operating conditions of the compressor, the oil level height of the oil sump and the main design parameters of the oil supply system on the oil supply characteristics are analyzed by numerical simulation. It is found that the main bearing oil flow rate varies circularly along with the rotation of the shaft. The shape and inclination angle of the spiral groove also influence the main bearing oil flow rate. The oil leakage rates through the roller end clearances depend largely on the operating conditions. In addition, the oil level height of the oil sump has a huge effect on the total oil flow rate.

1. Introduction

Rotary compressors are widely used in room air conditioners. The quantity of production or sales is about 100 million. Designing the oil supply system of rotary compressors rationally cannot only improve the reliability of rotary compressors, but also greatly affect the energy conservation. Appropriate lubricating oil contributes to generating oil films on bearings, reducing friction losses and lowering wear of bearings. On the contrary inadequate lubricating oil leads to several alterations, including the increase of the lubricating oil's temperature and bearings, the decrease of lubricating oil's viscosity and also the increase of shaft wear and bearings, leading to the declination of the compressor's performance and reliability. Meanwhile, excessive lubricating oil increases the oil discharge rate (ODR), which will reduce both the heat exchange efficiency of the condenser and evaporator in the air conditioner system and the capillary flow efficiency, leading to the poor performance of the system.

The oil supply system of the rotary compressor is quite complex as it involves a lot of design parameters. Early studies on the oil supply system of the rotary compressor mainly focused on local simulated experiments. Thereafter one-dimensional empirical equations applied in oil supply network-electrical analog method was used to analyze the oil supply system. However, many hypotheses and empirical parameters were involved in the one-dimension empirical equations and the empirical parameters depend on the concrete structure of the oil supply system, the rotate speed of the compressor, the refrigerant used in the compressor and etc.

Toshiba Corporation firstly studied the oil supply characteristics of the rotary compressor's bearings in 1984 [1]. In theoretical analysis, the flow in the radial holes was simplified into a one-dimensional flow. Also, the flow in the spiral groove was taken as

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the linear superposition of the flow caused by the rotation of the shaft and the flow caused by the pressure difference between the inlet and outlet of the spiral groove. Gravity was neglected in the analysis process. In 1992, Nagoya research and development center of Mitsubishi Heavy Industries Ltd. analyzed the elements of an oil supply system theoretically and experimentally. Meanwhile, a computer program was developed to evaluate the oil supply system [2]. University of Inchon studied individual lubrication elements of the oil supply system theoretically and experimentally, suggested to express the flow of every lubrication element with equations involving some empirical coefficients, and adopted an analogous electrical circuit to model the whole oil supply system in 2000 [3]. In 2003, University of Inchon modeled the whole oil supply system by adopting an analogs electrical circuit. The empirical coefficients of the individual lubrication elements were obtained by experiment and theoretical calculation. The effects of design changes in individual lubrication elements on the oil flow distribution were detected by the simulation program [4].

In recent years, CFD method has been applied successfully to the analysis of the oil supply system of hermetic scroll compressors and reciprocating compressors used in refrigerators by many researchers [5–10]. As the oil supply system of rotary compressors is much more complex than that of scroll compressors and reciprocating compressors, it brings difficulties for researchers to explore it with CFD method, especially mesh the model. Therefore, quite few studies on the oil supply system of rotary compressors using CFD method have been published.

The structure and the research emphasis of the oil supply system of rotary compressors are different from those of scroll compressors and reciprocating compressors. In scroll compressors and reciprocating compressors, the cylinder is set above the electric motor and the main bearing is far away from the oil sump. The time required for the oil reaching the main bearing as soon as the compressor is started, is the main influence on the compressor's reliability, which is the main research emphasis. Therefore, the volume of fluid (VOF) method and the unsteady solver are usually employed to study the oil supply system of scroll compressors and reciprocating compressors. The studies are focused on the rising process of the oil following the compressor start-up. The simulation process consumes longer time.

In rotary compressors, the pump body is set under the electric motor. The cylinder and the sub bearing are submerged by the oil in the oil sump. The main bearing is close to the oil sump. The time required for the oil to reach the main bearing is quite short. However, the structure of the oil supply system of rotary compressors is very complex. The oil flow rates of the bearings of rotary compressors are easily affected by the difference between the suction and discharge pressure, while those of scroll compressors and reciprocating compressors are not. For rotary compressors, the oil flowing into the gallery not only supplies the bearings, but also seals the roller end clearances. The oil flow rates through the roller end clearances are closely related to the operating conditions of the compressor. Thus the research emphasis of the oil supply system of rotary compressors is the oil flow rates of the bearings when the compressor operates steady. Therefore, the single-flow model and the steady solver are employed to simulate the oil supply system of rotary compressors using CFD method in this paper.

2. Modeling

A rotary compressor, as shown in Fig. 1, comprises a cylinder, a main bearing, a sub bearing, a roller, a shaft, a muffle, a motor, a shell and etc. A schematic diagram of the oil supply system of rotary compressors is shown in Fig. 2. One side of the shaft is immersed in the oil sump at the bottom of the shell. An oil pick-up is installed at the inlet of the oil gallery inside the shaft. On the shaft wall, three radial feeding holes are drilled. As the shaft rotates, the oil in the oil sump is drawn into the oil gallery and delivered into various bearing surfaces via the radial feeding holes. Some portion of the oil delivered into the relief groove of the main bearing flows into the spiral groove to lubricate the main bearing, and the other flows into the upper cavity inside the roller. The oil delivered into the relief groove of the sub bearing is directed into the straight groove to lubricate the sub bearing, and then flows back to the oil sump eventually. The oil fed through the middle radial feeding hole flows into the upper and lower cavity inside the roller to lubricate the eccentric bearing. Some portion of the oil in the roller chamber leaks to the suction and compression chambers through the roller end clearances. Under some certain operating conditions, the oil flows out from the top of the oil gallery.

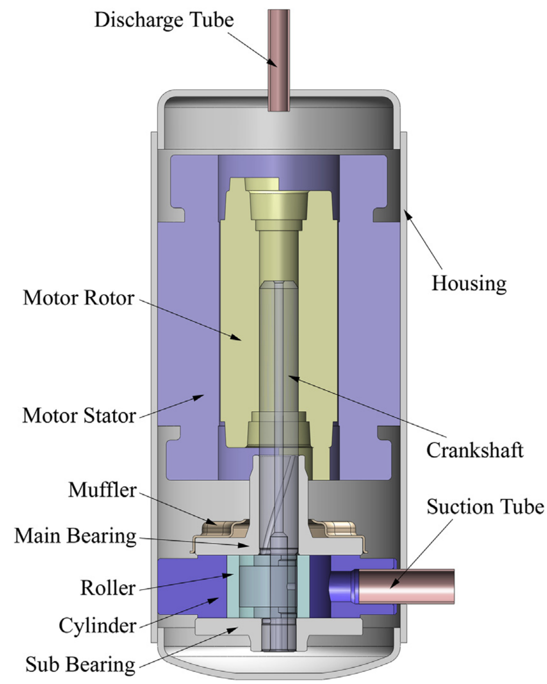

Fig. 1. Sectional view of a rotary compressor.

2.1. Physical model

The geometry of the oil supply system is illustrated in Fig. 3(a). The oil flows continuously in the oil supply system. The flow can be

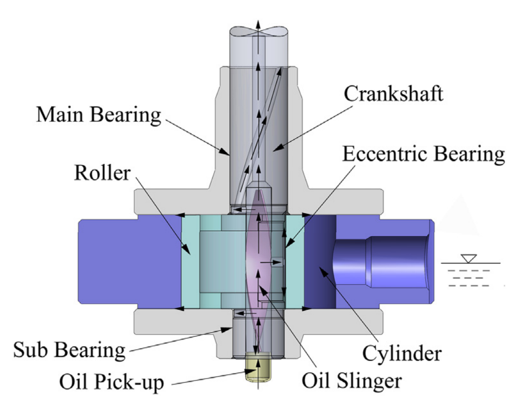

Fig. 2. Schematic of oil supply system.