Visualization of Flow in Scroll Compressor by Radiography

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ABSTRACT

Saving energy and resources in the air conditioning industry is required in order to protect the global environment. To save resources, miniaturization of the compressor in air conditioners is necessary. This miniaturization will increase the oil circulation rate (OCR) of the compressor because the oil separation space will be reduced. To improve the oil separation efficiency, it is necessary to understand the appearance of the flow of oil and refrigerant in the compressor chamber. This paper reports a technique to visualize the flow by using neutron radiography and X-ray radiography. Furthermore, a method to measure the oil concentration by carrying out image processing is described.

1. INTRODUCTION

The air conditioning industry has made much progress in replacing refrigerants with substances that do not damage the ozonosphere and in developing energy-saving components in line with aims to protect the global environment. The compressor is one such component that has undergone substantial improvements in efficiency since it accounts for most of the energy consumption of air conditioners.

For further resource saving, it is important to reduce the size and weight of compressors. However, miniaturization of the compressor results in a higher oil circulation rate (OCR) due to the smaller capacity of the oil separation space inside the compressor. A high OCR reduces the efficiency of the refrigeration cycle. It is therefore necessary to increase the efficiency of separating oil and refrigerant in a small separation space. To reduce the OCR, it is important to understand the appearance of the flow of oil and refrigerant in the compressors.

This paper describes a method to visualize the flow in the scroll compressor for a package air conditioner by using neutron radiography and X-ray radiography.

2. STRUCTURE OF SCROLL COMPRESSOR

Figure 1 illustrates the structure of the scroll compressor used with refrigerant R410A. It is an inverter driven compressor with a 3.75-kW rated motor input. The compression mechanism part is in the upper main chamber and the direct current brushless motor (DC-BL motor) is in the lower main chamber. The pressure in the main chamber is the same as the discharge pressure. The main part of the compression mechanism consists of an orbiting scroll, a fixed scroll, a frame and a crank-shaft. The orbiting scroll and the fixed scroll form the compression chambers between each scroll wrap with an involute curve. The crank-shaft is supported by the main bearing in the frame and the sub-bearing located below the motor. The orbiting scroll is connected to the top of the crank-shaft by an orbiting scroll bearing. The orbiting scroll is driven by the crank-shaft and revolves without rotating. As the orbiting scroll revolves, the volume of the compression chambers decreases, and the fluid in the compression chambers is compressed.

The back-pressure chamber is located in back of the orbiting scroll in order to push the orbiting scroll to the fixed

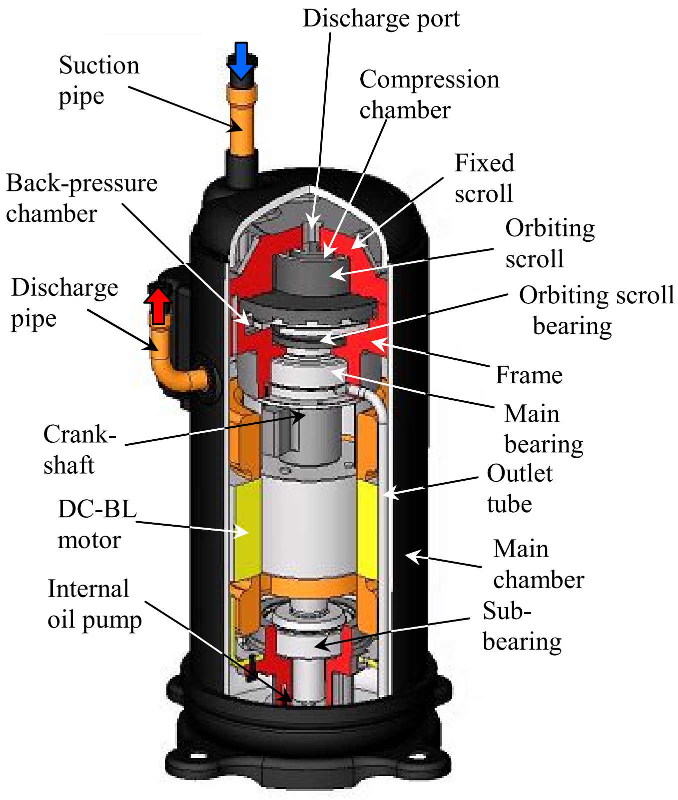

Figure 1: Scroll compressor for R410A

scroll.
The oil supply structure circulates oil with an internal oil pump and an outlet tube. This structure is advantageous in that it can control the amount of oil supplied to the bearings and to the compression chambers independently. The oil accumulates at the bottom of the main chamber. The internal oil pump that is connected below the crank-shaft pumps the oil to the upper bearings through a passage that penetrates the crank-shaft. The oil lubricates the sub-bearing, the main bearing and the orbiting scroll bearing. Most of the oil returns to the bottom of the main chamber through the outlet tube, but some of the oil flows into the back-pressure chamber by means of an oil supply structure that transports the oil from the space filled with the oil to the back-pressure chamber.
The oil in the back-pressure chamber flows into the compression chambers and seals the minute gap in both scrolls. The oil in the compression chambers is discharged with refrigerant from the discharge port of the fixed scroll. Most of the oil is separated from the refrigerant as it collides with various parts in the main chamber and drops to the bottom of the main chamber. The oil that could not be separated from the refrigerant flows into the refrigeration cycle with the refrigerant and reaches the heat exchangers. The ratio of this oil to the refrigerant is referred to as the OCR. When there is a large amount of oil in the heat exchangers, namely when the OCR is high, the oil prevents the refrigerant in the heat exchangers from condensing or evaporating. The efficiency of the refrigeration cycle then decreases. Moreover, if too much oil flows out from the compressor, the reliability of the compressor decreases because there is no oil at the bottom of the main chamber to lubricate the bearings. It is therefore important to reduce the OCR to improve the efficiency of the refrigeration cycle and to maintain the reliability of the compressor.

3. RADIOGRAPHY

Radiography technology makes it possible to observe the internal structure or the internal flow of an object by using the difference in material penetration strength with radiation such as neutron beams and X-rays. This method enables us to observe the inside of an object without contact and destruction.
Neutron radiography has been a topic of focus as an innovative tool for visualizing and measuring fluid phenomena.

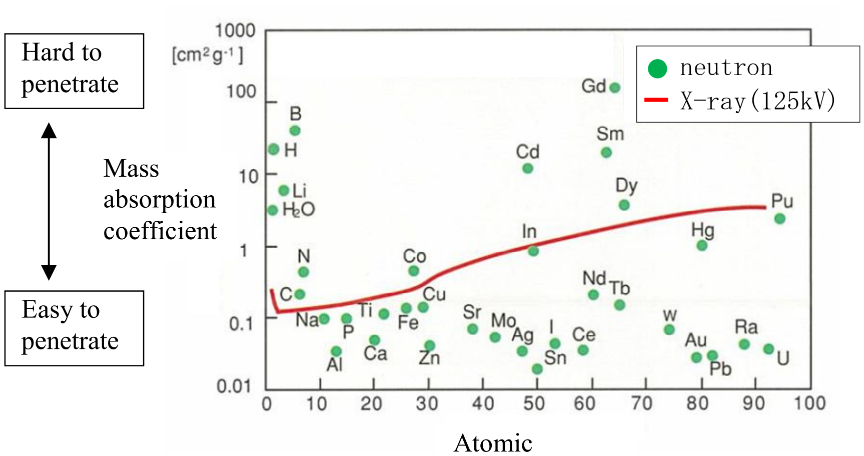

Figure 2: Relationship between atomic number and mass absorption coefficient

As shown in Figure 2, neutron beams can easily penetrate metals (the absorption coefficient for metals is small) but have difficulty penetrating certain elements such as hydrogen compounds (the absorption coefficient for hydrogen compounds is large). Because of the large difference between two absorption coefficients, hydrogen compounds inside a metal container can be viewed clearly by using neutron radiography. The disadvantage of neutron radiography is that experiments must be done on a large scale in order to use a nuclear reactor.

In contrast, X-ray radiography is simple to use in experiments. However, the difference in absorption coefficients between metals and hydrogen compounds is not as large as in neutron radiography because X-rays have a linear characteristic between absorption coefficients and atomic numbers. When the atomic number increases, the absorption coefficient also increases. Moreover, the absorption coefficients for metals such as iron are larger than that of neutron radiography, so the penetration strength for metals is weaker than that of neutron radiography.

We used a thermal neutron radiography device of the Japan Atomic Energy Agency (JAEA) in our experiments. We used an imaging plate for the neutrons in order to obtain a static image. The image was 300 x 200 mm in size and 25-50 μm in resolution. We used a neutron television system consisting of a fluorescent converter and a high sensitivity television camera in order to obtain a movie of the flow. The resolution of the movie was 100 μm, and the frame rate was 30 fps.

We also used an X-ray radiography device from Hitachi Engineering and Services (HES) for the X-ray radiography. This device allows us to obtain not only a static image but also a movie by irradiating the X-ray continuously. The X-ray source in the device was 100-300 kV. The size of the flat panel was 250 x 200 mm, the resolution was 400 μm, and the frame rate was 30 fps.

4. VISUALIZATION OF FLOW

Figure 3 shows a sample image of the movie obtained by neutron radiography, which shows the internal flow of the scroll compressor during operation. The parts that were recorded are the motor and its top space. In order to make the movie visible, the white and black color tones were reversed. The driving condition was the ARI (Air-conditioning and Refrigeration Institute) condition as indicated in Table 1. We analyzed the movie in a steady state and also at the time of starting and stopping the operation of the compressor; the analysis revealed that the brightness of each image changed at the upper space of the motor (part A in Figure 3). When the compressor was not operating, the brightness of part A was comparatively white. From the time of starting the operation of the compressor to the time that the compressor reached a steady state, the brightness of part A was observed to gradually turn black. This is because some of the oil that is accumulated at the bottom of the chamber changes to fine particles of oil as the rotational speed of the compressor increases, and then the particles of oil with refrigerant flow inside the compressor.

We carried out image processing to quantitatively evaluate the change in brightness during each state. Figure 4 plots the change in the brightness ratio from a steady state to the time the compressor was stopped. At the moment of stopping the compressor, the brightness ratio clearly changes. After stopping the compressor, the brightness ratio

gradually decreased. These findings indicate that particles of oil with refrigerant flow during the steady state, and after stopping the compressor, the particles of oil drop to the bottom of the main chamber. As time passes, the floating fine particles drop to the bottom gradually and the brightness ratio gradually decreases.
This indicates that there is a relationship between the brightness ratio and the concentration of oil, which greatly effects the OCR. By carrying out the image processing, the concentration of oil in the operating compressor can be measured.

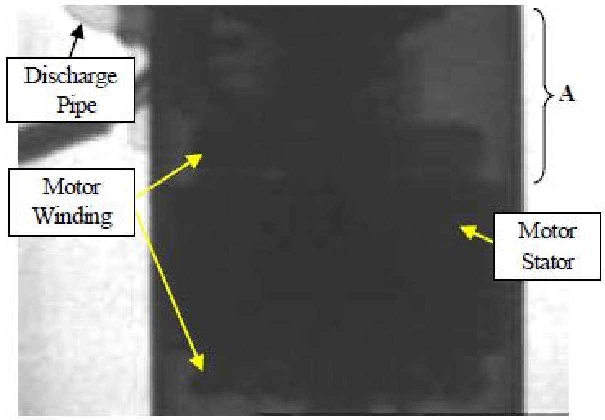

Figure 3: Neutron radiography image

Table 1: Driving condition of compressor

Suction pressure	Discharge pressure	Suction temperature	Rotational speed
1.00 (MPa)	3.38 (MPa)	18.3 (deg C)	60 (1/s)

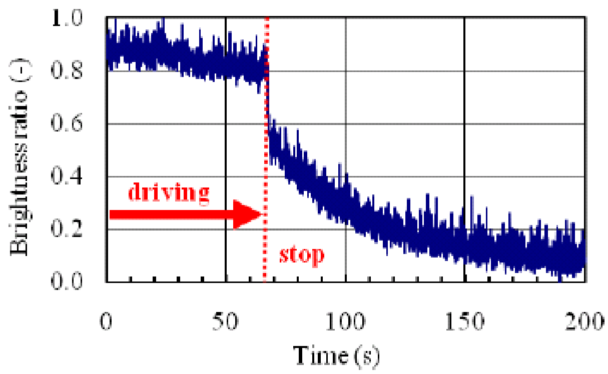

Figure 4: Variation in brightness ratio

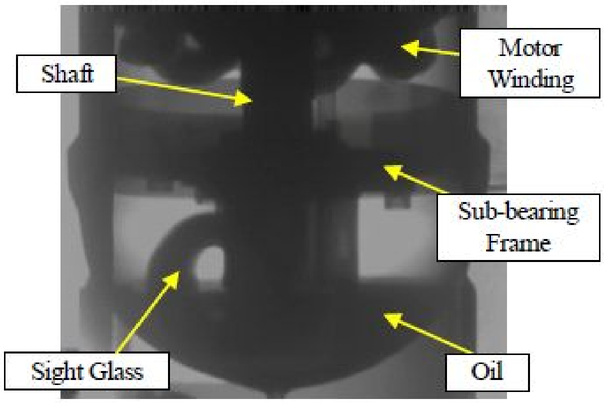

Figure 5: X-ray radiography image

Next, Figure 5 shows the sample image of the movie in which the internal flow of the scroll compressor was shot during operation by X-ray radiography. The lower part of the compressor was shot under the ARI driving condition. The particles of oil with refrigerant could not be observed by X-ray radiography in this movie. However, the oil surface at the bottom of the main chamber is clearly apparent, and the behavior of the oil surface shaking at the bottom can be observed.

5. CONCLUSION

The internal flow of a scroll compressor during operation was visualized and measured by neutron radiography and X-ray radiography, in which the absorption coefficient for each element differs.

- Neutron radiography revealed a correlation between the brightness and the concentration of oil, which has a great influence on OCR. Thus, it was possible to measure the concentration of oil in the operating compressor by executing the image processing.
- X-ray radiography, which is simple to use in experiments, was effective for observing the oil surface and its behavior.

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