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An Experimental Study on the Dynamic Behavior of Micron-Size Gap by Cylinder Pressure and Temperature Under the Rotary Compressor Operation

N. Matsumura
Mitsubishi Heavy Industries

K. Abe
Mitsubishi Heavy Industries

H. Machida
Mitsubishi Heavy Industries

TITLE : AN EXPERIMENTAL STUDY ON THE DYNAMIC BEHAVIOR OF MICRON-SIZE GAP BY CYLINDER PRESSURE AND TEMPERATURE UNDER THE ROTARY COMPRESSOR OPERATION

AUTHORS : NORIAKI MATSUMURA *
KIYOSHI ABE *
HIROSHI MACHIDA **
* NAGOYA RESEARCH & DEVELOPMENT CENTER
MITSUBISHI HEAVY INDUSTRIES, LTD. NAGOYA, JAPAN
** AIR-CONDITIONING & REFRIGERATION MACHINERY WORKS
MITSUBISHI HEAVY INDUSTRIES, LTD. AICHI, JAPAN

ABSTRACT

As for recent heat pump air conditioners, compressors are required to possess higher efficiency and higher reliability.

Since a rotary compressor has several gaps in the order of microns which affect its efficiency and reliability, it is necessary to understand the micron-size gap under the operation.

However, since the compressor is small, the installation of a sensor is difficult, and since the temperature and pressure conditions are severe in the refrigerant and oil environment, a measurement error is large due to temperature drift, and therefore an advanced sensor is needed for detailed measurement of gap.

This paper describes the compact size and low temperature drift eddy current type gap sensor which we developed, and an experimental study on the dynamic behavior of micron-size gap caused by cylinder pressure and temperature under the rotary compressor operation.

INTRODUCTION

Recently a rotary compressor for heat pumps is required to possess high performance.

A rotary compressor has several gaps in the order of microns which affect its performance. These gaps consist of various parts such as cylinder bearing, rotor, blade, and the like.

These micron-size gaps can change according to the deformation caused by assembling and the pressure as well as the temperature under the compressor operation.

The size of gap under the compressor operation can be different from a value which is assumed by single components. If the size of gap is larger

than the assumed value, it leads to lower performance by compression gas leak. If the size of gap is smaller than the assumed value, it leads to lower perfomance by increasing mechanical loss.
It is required to understand the micron-size gap under the compressor operation to prevent such disadvantages.

The measurement of such micron-size gap requires a sensor which assures accuracy of several microns. The gap sensors on the market can not meet such accuracy under the compressor operation.

There are various sensors such as a inductive type (eddy current type), a capasitive type, a ultrasonic type, a optic type to measure a gap in the order of microns. There are refrigerant and oil in a gap. The characteristic of a sensor should not be affected by refrigerant and oil. The sensor which can meet such requirements is presumably a eddy current type sensor.

This paper describes the eddy current type gap sensor which we developed. It is compact, and have low temperature drift and heat proof. The paper also describes the dynamic behavior of micron-size gap under the rotary compressor operation.

EDDY CURRENT TYPE GAP SENSOR

No commercial gap sensors can satisfy requirements in size, heat proof, and measuring accuracy. In order to measure the micron-size gap under the compressor operation we need the sensor which is compact (dia.5 mm or less), and have heat proof (200℃ or more) and lower temperature drift (0.1μm/℃ or less).

A prototype sensor and measuring equipment

The prototype sensor is shown in Fig.1, which comprises a bobbin on which coil wire is wound and adhesive with which the coil wire is fixed to the bobbin. Material of the bobbin and the adhesive is ceramics because it has heat proof and lower deformation by heat. Coated copper wire with higher heat proof was used. The copper wire of 60μm in diameter was wound about 40 turns on the bobbin. Characteristics of sensor by calculating given by the difference of the coil shape are shown in Fig. 2. (reference(1),(2).) As the ratio of $\frac{D-d}{2H}$ in the coil becomes larger, the sensitivity will incease. The ratio of $\frac{D-d}{2H}$ was set to about 0.3 in the prototype sensor. It is required to minimize the influence by change in resistance of coil wire to reduce temperature drift. Electrical equipment is a bridge circuit to minimize temperature drift. There are a coil for measurement and for temperature compensation on the circuit. The prototype sensor was designed to minimize the measuring error caused by unevenness of temperature of the sensors for the temperature compensation and for measurement. There are a coil for measurement and for temperature compensation on the same bobbin as shown in Fig. 1.

The measuring circuit is shown in Fig. 3, which is composed of bridge circuit, oscillator, phase detector, filter and amplifier.

The bridge circuit comprising coils for temperature compensation and measurement is provided to cancel the influence by temperature, but it is very hard to provide a coil with such characteristics as meeting the requirements thoroughly. Thus further temperature compensation was conducted using the phase detection circuit for a little amount remained not to be compensated by the sensors for temperature compensation and measurement.

GAPS AT EACH PORTION OF COMPRESSOR

The rolling piston type compressor for heat pumps is shown in Fig. 4. A compression part is composed of cylinder, rotor, blade, upper bearing and lower bearing, in which different micron-size gaps are formed. Such micron-size gaps are shown in Table 1.

These gaps are formed in the compression part, and other gaps are also found between a shaft and upper or lower bearings. The influence of these gaps on performance and reliability of the compressor is significant. For example, if the gap B is larger, compressed gas will flow into the suction side through the gap. If it is smaller to the contrary, it causes lower reliability due to abnormal wear as well as lower COP due to increase in loss power.

EXPERIMENTAL METHOD

Several gap sensors were mounted in rotary compressor with 17cc in displacement to measure the gaps A and B shown in Table 1. The position where gap sensors were mounted is shown in Fig. 5. The gap A is that between the blade and the blade guide groove. Two sensors were mounted at the cylinder to measure the gap from the both sides of the blade guide groove. The total value given by the sensor 1 and the sensor 2 corresponds to the gap between the blade and the blade guide groove.

The gap B is that between the rotor and the cylinder, and two sensors were mounted at the cylinder. As the sensor was mounted at the cylinder, the gap B formed during rotation of a turn was not given but only the gap of rotational angle at the position of the sensor mounted was measured.

The blade movement was also measured on the base of rotational angle. The temperature control was performed to the signal processing part comprising the bridge circuit and the phase detector etc. on the same tempera ture at the calibration and higher accuracy was given.

An example of the check results of gap characteristic and temperature characteristic for the sensor 1 is shown in Fig. 6 and Fig. 7.

The output change of 3mV per 1 μm in gap is shown, and very low value of 5μm approx. in temperature drift is given between the room temperature and 120℃. When the behavior was measured, temperature compensation was conducted by the temperature measured by a thermocouple integrated with the sensor. Other factors of error are unevenness of electrical characteristics of the blade and the rotor faces. Since the position of the blade where the measurement was made by the gap sensor changes during rotation of a turn, any unevenness of the electrical characteristics at such place cause measuring error. Fig. 8 shows the output change of the sensor when the blade is caused to rotate a turn. As the value in Fig. 8 is the total of those by the sensor 1 and the sensor 2, the value should be constant unless any unevenness of the electrical characteristics. The total output value of the sensor 1 and the sensor 2 shown in Fig. 8 is bigger about by 2 μm around the portion at 180 degrees in rotational angle. It seems the cause is due to unevenness of the electrical characteristics of the measured blade face. The gap measured between the blade and blade guide groove was corrected by the value in Fig. 8

The surface of the rotor shall be measured similarly by the sensor when the gap between the rotor and the cylinder is measured. The change in output occurred when the rotor is caused to rotate a turn is about 2 μm.

Since the rotor is turning under the operation, the correction is unavailable and about 2 μm of measuring error may be inevitable as maximum.

THE DYNAMIC BEHAVIOR OF GAP UNDER THE COMPRESSOR OPERATION

Fig. 9 shows the dynamic behavior of gaps at each portion under the operation. A1 is the data measured by the sensor 1, A2 is the data measured by the sensor 2, and A1+A2 is the total value of A1 and A2 showing the gap between the blade and the blade guide groove. B1 is the data measured by the sensor 3, and B2 is the data measured by the sensor 4.

The values of B1 and B2 show the gap between the rotor and the cylinder at a certain angle.

Gap between blade and blade guide groove

(1) The gap between the blade and the guide groove is about half in value of that assumed by single components, and the gap fluctuation during rotation of a turn is clarified. The reason why the gap is about half of the assumed value is supposed to be deformation caused by assembling,

cylinder pressure and heat.

(2) The cause for the change in gap during rotation of a turn seems to be deformation of the blade guide groove by cylinder pressure. The maximum gap is occured at the rotational angle of 340 degrees approx., and the gap becomes smaller between 340 to 10 degrees. And then the gap is gradually increasing. It appears the deformation is encouraged by the pressure within the blade guide groove.

(3) Maximum value of the gap between the blade and the blade guide groove with the difference of pressure between discharge and suction pressure is shown in Fig. 10. As the difference of pressure increases, the mamixmum value of gap becomes larger.

Behavior of gap between rotor and cylinder

(1) The gap between the rotor and the cylinder under the operation is about half of that established when the compressor is assembled. Gap B2 is larger than gap B1.

(2) The gap between the rotor and the cylinder depends on the difference of pressure as shown in Fig.10 like the gap between the blade and the blade guide groove, and is supposed to be subject to the deformation by the cylinder pressure.

(3) Since the size of clearanace B2 is a little larger than that of clearance B1 when the compressor is operated in the state of air open, the cause for which is larger clearance B2 than that of B1 is due to the deformation by assembling not because of the deformation by pressure and heat under the operation.

SUMMARY

The gap sensor which is compact, heat proof and lower temperature drift has been developed to understand several gaps in the order of microns under the compressor operation. The gaps between the blade and the blade guide groove as well as that between the rotor and the cylinder were measured with the gap sensor developed. Respective gaps were found to be smaller than those pre-estimated, and it was understood that one of factors was deformation by the cylinder pressure.

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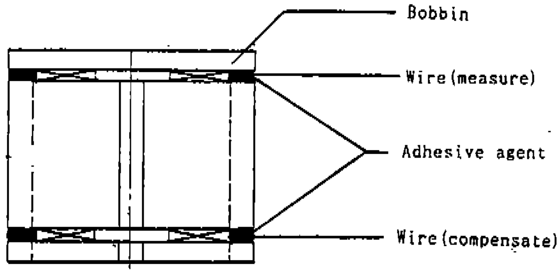

Fig. 1 Sensor structure

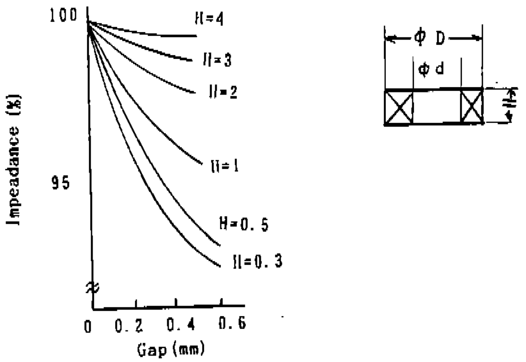

Fig. 2 Characteristic of gap sensor

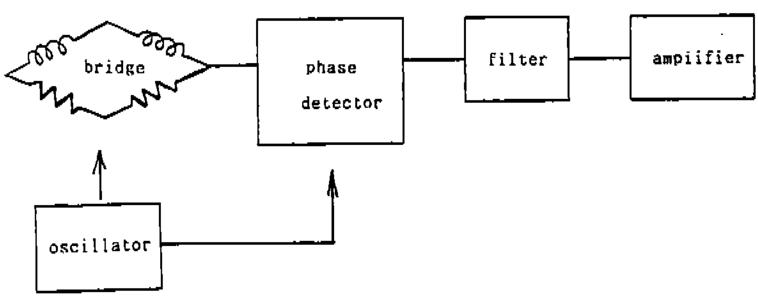

Fig. 3 Circuit diagram

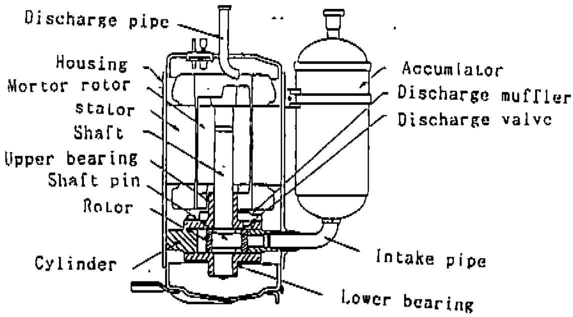

Fig. 4 Compressor structure

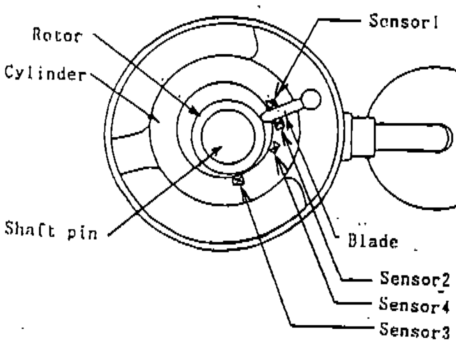

Fig. 5 Installation of sensors

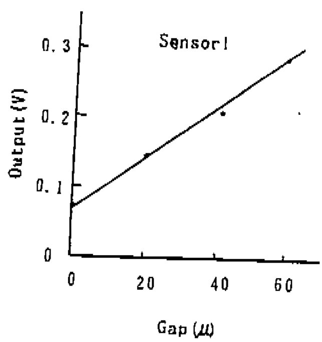

Fig. 6 Characteristics of sensor1

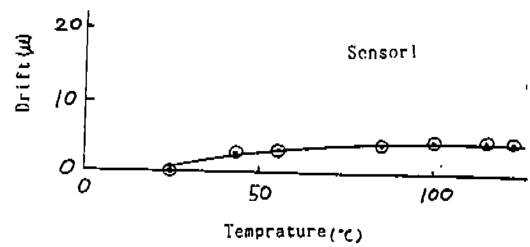

Fig. 7 Characteristics of temprature drift

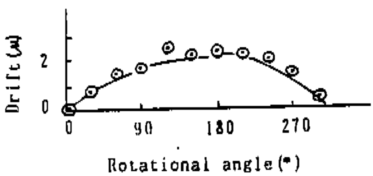

Fig. 8 Characteristics of drift

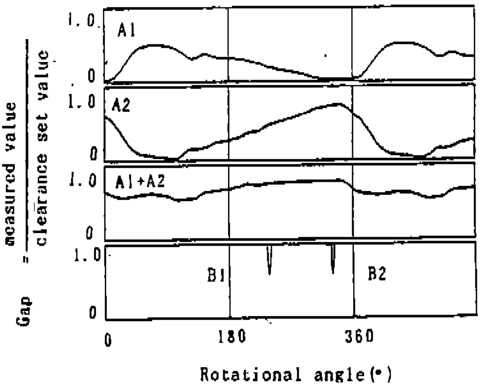

Fig. 9 Behavior of gap

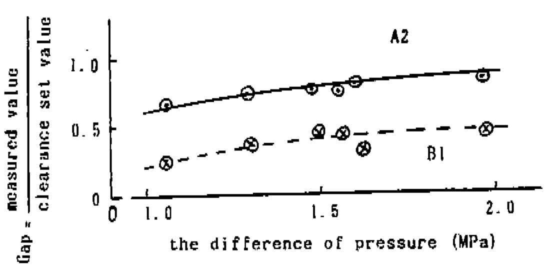

Fig. 10 Characteristic of the difference of pressure

Table 1. Micron-size gaps in compressor

Gap A	Gap between blade and blade channel within cylinder
" B	Gap between rotor and cylinder
" C	Gap between upper bearing and rotor
" D	Gap between lower bearing and rotor
" E	Gap between upper bearing and blade
" F	Gap between lower bearing and blade
" G	Gap between rotor and shaft