1996

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DEVELOPMENT OF HORIZONTAL SCROLL COMPRESSOR IN AIR-CONDITIONERS FOR COMMERCIAL USE

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ABSTRACT

Mitsubishi Heavy Industries, Ltd. has developed a new horizontal scroll compressor for commercial use. It satisfies the recent demand for a small installation area, lower energy consumption and lower noise. This paper presents how they were achieved as follows.

1)Under steady conditions, it was confirmed that necessary oil was supplied to the bearings by the analysis. At starting, the check valve can make the pressure difference and reduce the delay time of oil supply.

2)To avoid slugging, the return pipe was designed to be located below the limitation of the height level where the scroll walls were damaged.

3)The flank contact force was optimized by the analysis and the measurement of the behavior of the driving bush.

4)Impact force has been reduced by applying the new profile.

INTRODUCTION

Mitsubishi Heavy Industries,Ltd. developed a new "Saison air-conditioner" for commercial use in the spring of 1995. The outdoor unit of the air-conditioner has a slender profile. It satisfies the recent demand for a small installation area and lower energy consumption. This was realized by the development of a new horizontal scroll compressor, which was the first horizontal one for commercial use. Though horizontal compressors had not been commercialized due to their low reliability, the improvement of reliability by using our lubrication technology has made it possible. Both high efficiency and low noise have also been achieved.

This paper presents the technology which realizes high reliability, high efficiency and low noise level, in the development of the horizontal scroll compressor(Figure 1).

IMPROVEMENT OF RELIABILITY FOR HORIZONTAL COMPRESSOR

The horizontal compressor has smaller oil capacity than the vertical one. Therefore, the horizontal one needs an oil tank to accumulate oil. It makes oil supply path of the horizontal one much more complicated than that of the vertical one.

Because the air-conditioner for commercial use needs much refrigerant, much liquid refrigerant may be accumulated in the compressor. As a result, it causes the compressor slug and the scroll walls are damaged.

In order to avoid them, the decrease of accumulated refrigerant in the compressor is necessary.

1. Analysis of oil supply system

Oil is supplied from the bottom of the housing by centrifugal pump utilizing shaft rotation in a vertical compressor. However, the centrifugal pump cannot be applied to the horizontal compressor because oil is accumulated in the oil tank installed separately from the compressor housing. Therefore, a new displacement type pump has been developed and the oil supply network system was analyzed by using the equivalent circuit.

1.1 Under steady conditions of compressor

The displacement type oil pump was applied. It is a rotary type pump with the unrolling piston which consists of blade and rotor. The characteristics of the pump is analyzed by considering the leakage of both pressure difference and Couette flow. Figure 2 shows the analysis and the experiments. The results of the analysis agreed with the those of the experiments. The amount of oil supply for bearings was obtained from the results.

Next, the oil supply network system was analyzed by using the equivalent circuit. The oil supply path of the horizontal compressor is as follows.

Oil flows from the oil tank to the center of a crank shaft. The oil is distributed to a main bearing and a sub bearing, then, a driving bearing through the shaft. After that, the oil is supplied to a thrust bearing. Finally, the surplus oil flows to the oil pan through the oil return pipe.

The oil supply was obtained from the pressure loss of each element. The numerical analysis was carried out by using Newton-Raphson method. Figure 3 shows the analysis and the experiments. From these results, it is confirmed that the necesary oil can be supplied to each element.

1.2 At start of compressor

At start, the delay of the oil supply in the horizontal compressor is larger than that of the vertical one because the suction pipe for oil supply of the horizontal compressor is longer than that of a vertical one. Moreover, when the compressor starts, the pressure in the compressor decreases and it is expected that the efficiency of the oil pump decreases. This has been improved by the following methods.

At steady running, the pressure in the housing keeps equal to that in the oil tank. The oil accumulated in the housing falls into the oil tank. When the compressor starts, however, the pressure in the housing is lower than that in the oil tank. A check valve was set between the housing and the oil tank and the oil was pushed up by the pressure difference from the oil tank to the oil pump in a short period.

Figure 4 shows the improvement of the delay time of oil supply by the check valve. Without the check valve, the maximum of the delay time is about one minute. This delay is caused by the forming of refrigerant in the oil. Bearing seizure due to the delay of oil supply can be expected. With the check valve, oil can be supplied immediately after the compressor starts. Thus, the bearing seizure can be avoided and the reliability has been improved.

2. Avoidance of slugging

The height of liquid is high while the compressor stops because liquid refrigerant migrates into oil. As a result, when the compressor starts, liquid refrigerant flows into the compression chamber and the scroll walls are damaged due to liquid slugging. The relationship among the height of liquid, the cylinder pressure and the fatigue strength of the scroll walls was researched.

Figure 5 shows the distribution of the probability of the cylinder pressure when the height of liquid is 50% (the ratio of diameter of compressor housing). The cylinder pressure exceeds the allowance pressure, which causes the allowance stress of the scroll walls.

From the experiments, it was confirmed that the cylinder pressure was within the allowance pressure when the height of liquid was lower than 40%. The return pipe was designed to be located below this height, and the damage of the scroll walls were avoided.

HIGH EFFICIENCY AND LOW NOISE TECHNOLOGY

1. Optimization of flank contact load

In this chapter, the dynamical behavior of the scroll compressor's variable orbiting radius mechanism is presented[2]. As shown in Figure 6, a driving bush is installed between the shaft pin and the orbiting scroll. The orbiting radius of the orbiting scroll can changes by the slide of the driving bush. With this mechanism, even if there are machining or assembly errors, the orbiting scroll walls can contact the fixed scroll wall constantly.

The flank contact load F_L can be obtained from the balance of the centrifugal force of the orbiting scroll F_i, the gas compression force F_P, and the force of the friction on the sliding surface. It can be expressed with equations(1).

$$F_L = F_i + F_p \frac{\cos(\theta_p - \alpha + \delta)}{\cos(\alpha - \delta)}$$

$$\delta = \tan^{-1}\mu \; ; \; F_i \propto \omega^2$$

(α : coefficient of friction on slide surface)

In other words, when the sliding angle α is set larger, the flank contact load F_L increases. The vibration of the scroll walls is excited more intensively and the noise level becomes higher. On the other hand, when the sliding angle α is set too small, the flank contact load decrease and is not large enough to keep the contact of the scroll walls. This causes the leakage of the compressed gas and the deterioration of the performance. Therefore, to establish a high efficiency and low noise scroll compressor, the minimum sliding angle that does not cause the deterioration of the performance must be set. In order to obtain the optimum sliding angle from the dynamic behavior expressed in Eqs.(1), the coefficient of friction must be obtained. The coefficient of friction was obtained from the measurement and the analysis as follows. Figure 6 shows the behavior of the driving bush. This was obtained from the measurement of the displacement of the disc installed on the driving bush from two perpendicular directions. When the rotating speed is high enough, the scroll walls contact each other. But when the rotating speed decreases, the driving bush could not slide and the scroll walls failed to contact. Then, the coefficient of friction μ was obtained from the above equation of flank contact load by substituting $F_L=0$ and the critical centrifugal force at which the scroll walls separate.

By using the coefficient of friction obtained, the optimum sliding angle when the flank contact force F_L became zero was obtained.

By optimizing the sliding angle α, the performance could be maintained even if assembly errors, etc. existed and both high efficiency and low noise could be achieved.

2. Reduction of impact noise by smoothing of scroll wall contact

In addition to the noise reduction by the optimization of the sliding angle mentioned above, the impact noise at the scroll wall was reduced.

From the time records of the acceleration at the housing shown in Figure 7, it was confirmed that the impact was caused at the starting point of suction in the scroll profile, where the both scroll walls began to contact. In particular, it was found that the torsional assembly error of the scroll increased the impact force at the points and caused the higher noise level. In order to reduce this impact, the tapered profile scroll was applied. With this profile, the flank contact force at the starting point of suction was smoothed because the contact length in the axial direction increase smoothly. The effect of this profile is shown in Figure 7. By taking the assembly error mentioned above into consideration, the taper angle was determined.

As a result, the impact at the starting point of suction could be eliminated, and the noise could be reduced by approximately 6 dB (A).

CONCLUSIONS

It was commonly believed that the horizontal compressor had the disadvantages in the respect of reliability compared to the vertical compressor. However, with the reliability technology described in this paper, the reliability equivalent to the vertical compressor could be achieved. The horizontal scroll compressor developed for the "New Saison Air-conditioner" has realized the highest quality in efficiency and noise.

REFERENCES

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2)T.Hirano et al., Mitsubishi Heavy Industries, Ltd. Technical Review Vol.30 No.5(1993) P.398 (in Japanese)

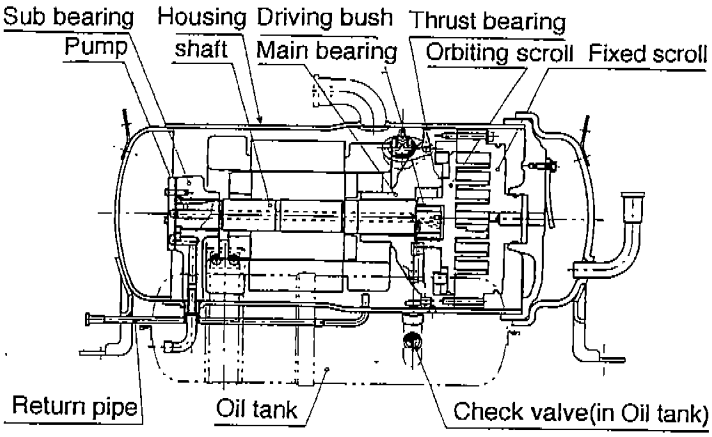

Fig.1 Structure of horizontal scroll compressor

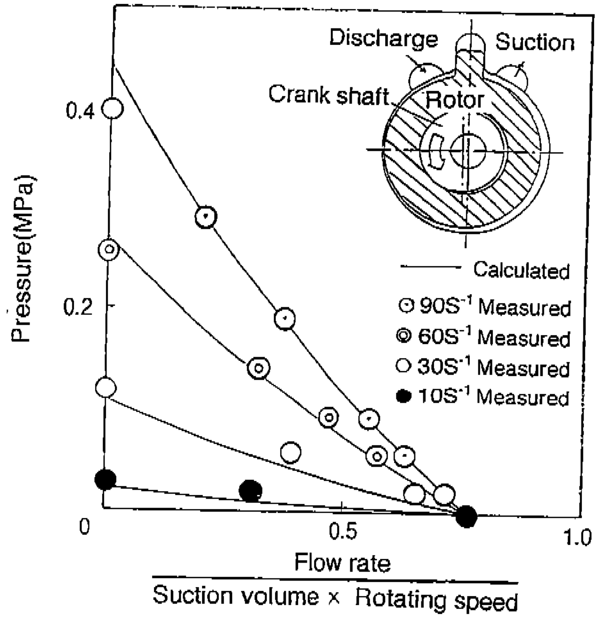

Fig.2 Structure and characteristics of displacement type oil supply pump

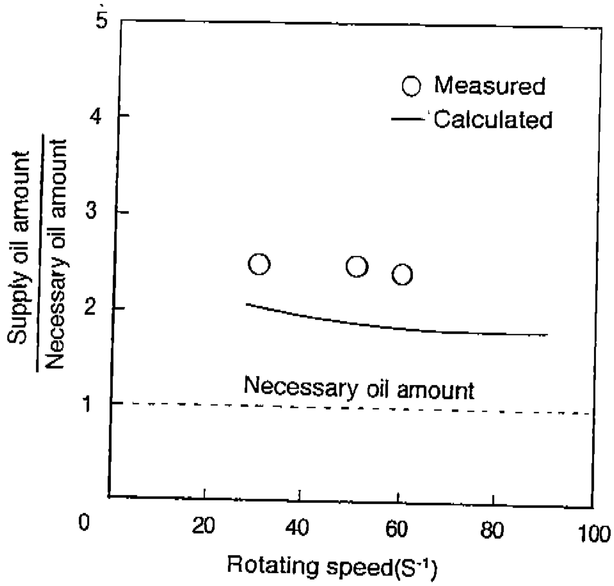

Fig.3 Oil supply amount of main journal bearing

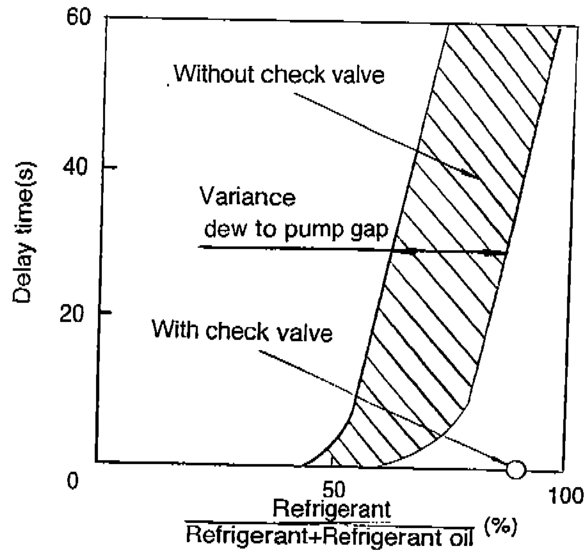

Fig.4 Delay time of oil supply at compressor starting

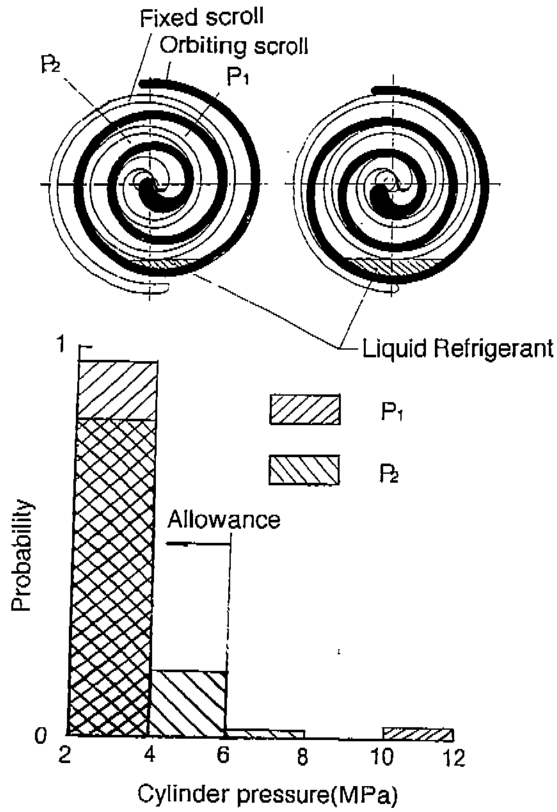

Fig.5 Distribution of probability of cylinder pressure

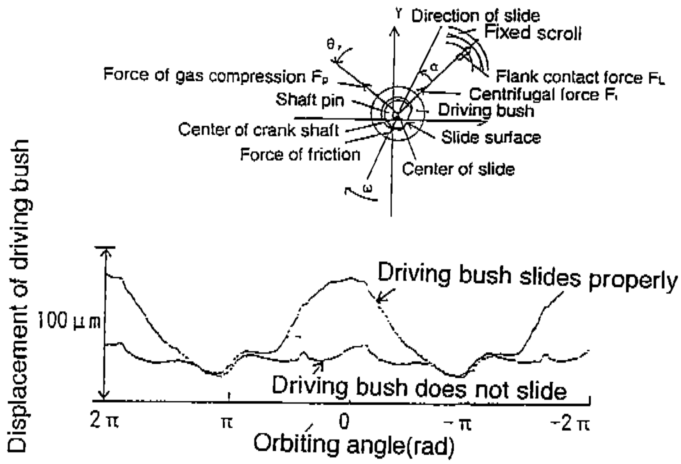

Fig.6 Behavior of driving bush
in sliding type variable crank radius mechanism

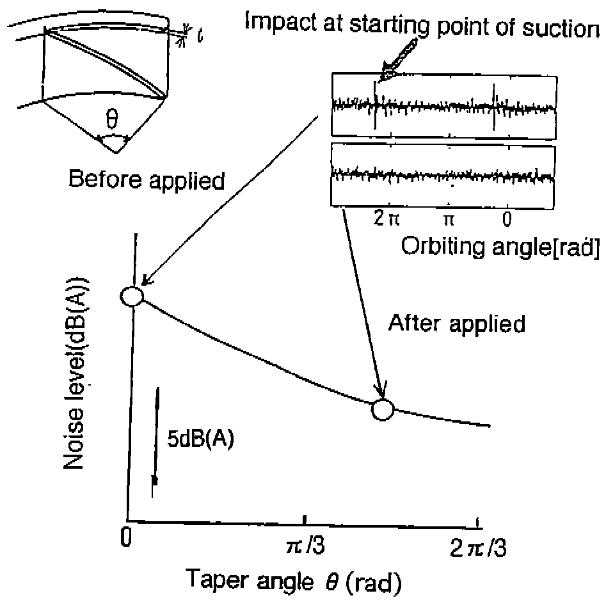

Fig.7 Reduction of impact noise
by smoothing contact force between walls

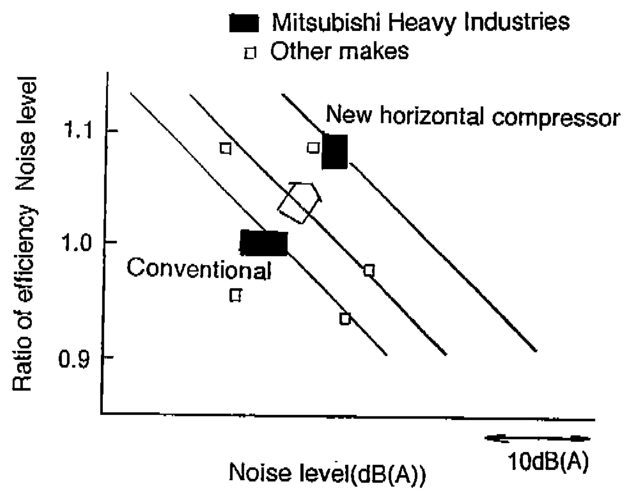

Fig.8 Realization of high efficiency and low noise
in new scroll compressor