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FUNDAMENTAL STUDY OF HIGH-EFFICIENCY ROLLING-PISTON-TYPE COMPRESSORS FOR REFRIGERATORS

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ABSTRACT

In order to further improve the efficiency of rolling-piston-type compressors for refrigerator use, the authors have measured the performance of current compressors and estimated each loss quantitatively. Because of high compression ratios and less refrigerant flow, the losses caused by superheating the refrigerant suction gas are considerably high. The mechanical and motor loss also account for a considerable part of losses. Based on this estimation, we re-designed the fundamental structure of the compressor, and reduced these losses. A prototype compressor has been designed, constructed and tested. This paper describes the loss analysis, the design of prototype compressor and its test result.

INTRODUCTION

Rolling-piston-type compressors are typical ones with many characteristics such as ①no suction valves ②a smooth compression process ③good rotating balance ④a small size and low manufacturing cost. In 1970 MITSUBISHI Electric Corp. developed rolling-piston-type compressors for domestic air-conditioning use, and developed compressors for refrigerator use with laid configuration in 1980. Since then many improvements have been carried out on efficiency and function.⁽¹⁾ Two factors have limited further improvements in the efficiency. They are (a) large losses caused by superheating the refrigerant gas under high compression ratios and (b) significant mechanical losses.

The authors have re-examined the basic design of this compressor and tried to further improve the efficiency. For this purpose we have brushed up on loss analysis, heat and fluid analysis and motor design technique. We estimated and appreciated each loss, searched after the means of loss reduction and re-designed the fundamental structure of the compressor. Consequently we have found a way to improve the efficiency by 10% on the prototype compressor.

ANALYSIS OF PERFORMANCE

Current Compressors

As the object of the efficiency improvement study, we chose the rolling-piston-type compressors with laid configuration for refrigerator use (we refer to it as the "current compressor" from here on). Major specifications of the current compressor are listed in Table 1.

Table 1 Major Specifications of the Compressor

Compression Mechanism	1-cylinder, Rolling Piston Type
Stroke Volume	4.2 cm ³
Motor	single-phase 100V, 130 W class
Dimension	outer diameter: 92 mm, length: 195 mm
Weight	5.2 Kg

Fig.1 shows a sectional view of the current compressor. The pressure in the compressor shell is kept at discharge side, and lubricating oil is stored in the lower part. A differential-pressure oil supplying mechanism is adopted. The pressure difference between the inside of the shell and the inside of the cylinder supplies sealing parts and bearings with lubricating oil. The compressing mechanism is a rolling-piston-type with one cylinder. Refrigerant gas is sucked directly into the cylinder, discharged into the shell, separated from oil, and then finally exhausted from the shell.

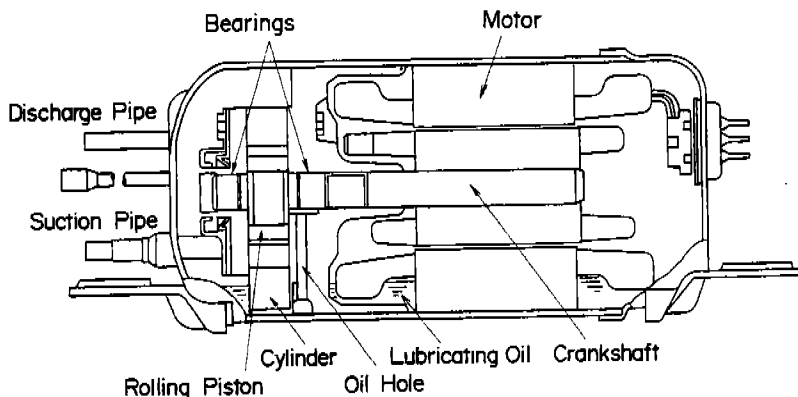


Fig.1 Sectional View of a Current Compressor

Analysis

In order to improve the efficiency of a compressor by reducing losses, it is important to estimate each loss, such as motor loss, mechanical loss and indicated losses shown in Fig.2. First, we tested the performance of current compressors, by

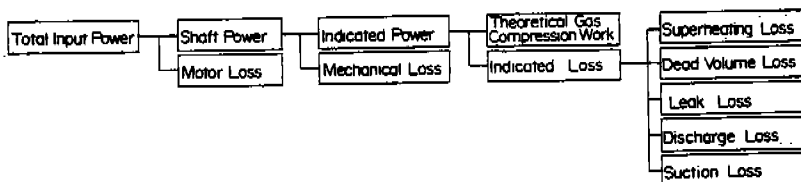


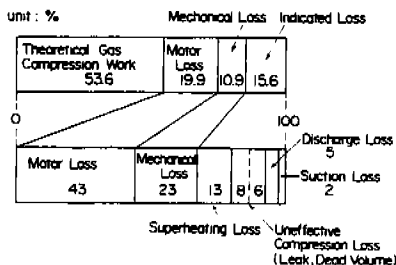
Fig.2 Distribution of Work and Losses

measuring input power and refrigerating capacity so that they might be the base of efficiency improvement. The motor loss was separated from other types of losses by conducting a performance test on only the motor. The indicated power were calculated on a computer using pressure measured in the compression chamber, and converted into gas compression work and indicated losses. The performance test conditions of the compressor are listed in Table 2.

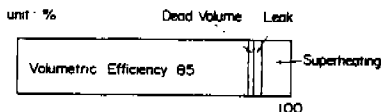
Table 2 Performance Test Condition of the Compressor

Operating Frequency f : 60Hz	
Condensing Temperature T_c : 54.4°C	Evaporating Temperature T_e : -23.3°C
Discharge Pressure P_d : 1.35MPa-abs	Suction Pressure P_s : 0.13MPa-abs
Subcooling ΔT : 22.2K	Suction Temperature T_s : 32.2°C
Ambient Temperature T_a : 32.2°C	

For an example of the performance test result, Fig.3 shows details of power, losses and a volumetric efficiency drop. According to Fig.3(a), about 54% of total input power is theoretical gas compression work, 20% is the motor loss, and 11% is the mechanical loss. About 16% of the power is the indicated loss caused in the suction process, in the compression process and in the discharge process. The loss caused by superheating the suction gas accounts for a considerable part of the indicated losses, representing 13% of total losses and is equivalent to almost 57% of the mechanical loss. As mentioned above, an overshooting loss caused in the discharge process and a suction pressure loss account for only a small part of the loss. Superheating loss and mechanical loss account for a large part, because of less refrigerant flow in the refrigerator compressor in comparison with compressors for air-conditioning use.



(a) Analysis of Power (upper) and Loss (lower)



(b) Causes of Volumetric Efficiency Drop

Fig. 3 Performance Analysis of Current Compressors

Fig.3(b) shows the factors of volumetric efficiency drop and their ratio as a result of analyzing volumetric efficiency of current compressors. It is remarkable that the volumetric efficiency is also greatly influenced by superheating as is the loss. As the heat generated by the motor loss transfers to the compressor body and superheats suction gas, the motor loss increases the superheat loss. Thus it is one of the most important tasks to reduce the motor loss in regard to the refrigerator compressors in which superheating loss accounts for large part of losses. Based on above-mentioned result of analysis, reducing mechanical loss of the compressing part, superheating loss and motor loss is considered important in order that the efficiency of refrigerator compressors may be improved.

REDUCTION OF LOSS

Motor Loss

To reduce the motor loss in the tentative compressor for the efficiency improvement study (we refer to it as the "prototype compressor" from here on), we examined and carried out the following:

- (1) The supporting of both ends of the rotor with bearings to reduce the whirl and lessen the air-gap,

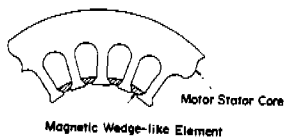


Fig. 4 Construction of Motor Stator with Magnetic Wedge

- (2) Making the rotor from a high density aluminum alloy,
- (3) Inserting magnetic wedge-like elements (see Fig.4) into the open side of the coil slots on the stator to make magnetic flux uniform.

By carrying out these procedures, we can decrease the copper loss and the iron loss of the motor as shown in Fig.5, and the motor loss under the rated power condition at 60Hz is reduced to 90% in the current compressor.

Indicated Loss

We examined the way to reduce superheating loss, which accounts for a large part of indicated losses. If the suction gas is superheated in the suction process, the temperature at the instant of starting compression rises, and compression work increases. Thus superheating loss is caused, and the volumetric efficiency also falls, because the density of the suction gas becomes low. The superheating of suction gas spoils the performance of a compressor because of the power increase and the refrigerating capacity decrease.

Suction gas is heated by the discharge part and the motor through the walls of the suction pipe and the cylinder. In order to reduce the loss, it is important to thermally insulate the suction pipe and adopt an effective structure radiating the heat of the cylinder and the motor. We then formulated a heat analysis technique which predicted the temperature of each part of the compressor, and chose a more effective thermal insulation structure and radiation design.

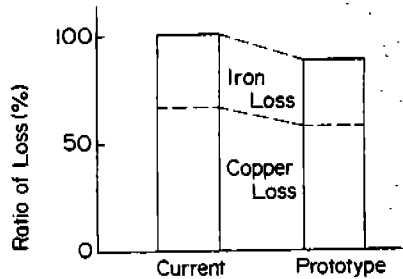


Fig. 5 Reduction of Motor Loss (estimated at 60Hz, on rated power)

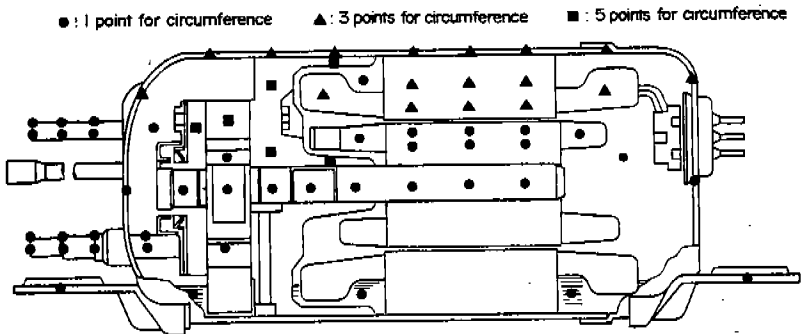


Fig. 6 Node Arrangement of Thermal Network

Fig.6 shows, as an example, the model of thermal network for analyzing temperature in the compressor. Temperature distribution is not always symmetrical in the compressors with laid configuration, because of the lubricating oil stored in the lower part, the suction part and the discharge part. A thermal network constructed in only one longitudinal section does not give a sufficiently accurate result. So we arranged 3 or 5 nodes in circumference, and we supposed that the temperature of the rotating parts, such as crankshaft, were uniform in a cross section. We made a thermal network model of the oil-circulating and heat-transferring route(see Fig.7), as heat transfer caused by lubricating oil can not be ignored.

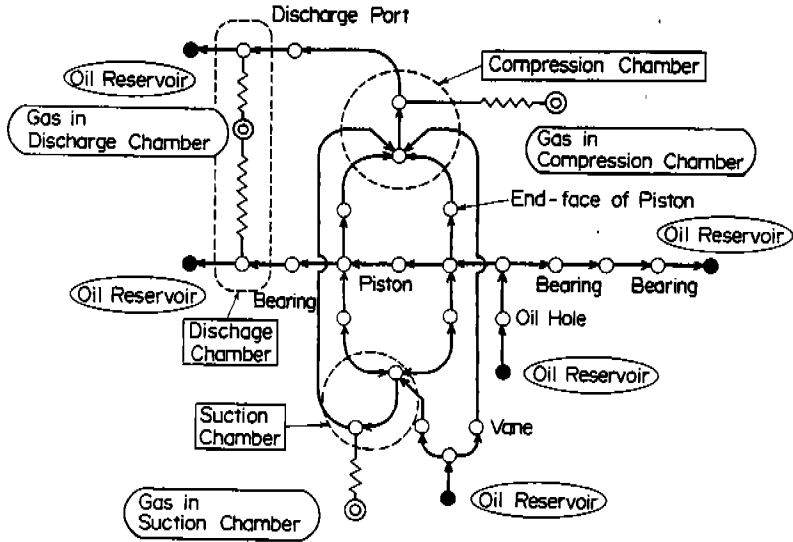


Fig. 7 Model of the Route Supplying Lubricating Oil

The oil-circulating route starts from the oil reservoir and comes back to the oil reservoir through bearings and the inside of the cylinder. It is now taken into consideration that lubricating oil either gives and takes heat with compressing parts or with each sliding part. Heat generations by gas compression, by motor loss and by mechanical loss were calculated and assigned to each node. We consulted the reference⁽²⁾ for the value of thermal resistance.

Results of thermal analysis and measurement in the current compressor were compared in order to verify that the analyzing technique and the model were reasonable. Conditions were almost the same as those in Table 2. Two cases where the temperatures of the suction pipe were 32.2°C and 10.3°C were analyzed, measured and compared as shown in Fig. 8. Calculated temperatures at five points in the compressor do not differ more than 3K from the measured one.

Using this analyzing technique, we examined the structure to insulate effectively the heat transfer to gas in the compressor, and clarified that the following procedures were effective.

- (1) Putting in an insulating material inside the suction pipe,
- (2) Installing an insulating cover preventing the heat of hot discharge gas transferring to the compression part,
- (3) Designing the structure that radiates a great deal outside of the compressor.

Fig. 9 shows the predicted temperatures of several points in the prototype compressor adopting this improved design. They

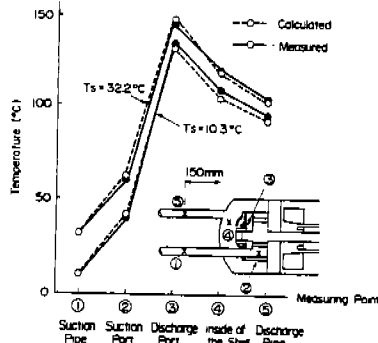


Fig. 8 Thermal Analysis of the Current Compressor

are obviously lower than those in the current compressor.

Mechanical Loss

Generally speaking, the mechanical loss of well designed rolling-piston-type compressors is low in comparison to the other type rotary compressor. Mechanical loss, however, accounts for no small percentage of losses in smaller class compressors such as those for refrigerator use. Most of the mechanical loss in rolling-piston-type compressors is consisted of ①friction loss on the main bearing, ②friction loss on the inside of the rolling piston, ③friction between the side of the vane and the slot, ④friction between the tip of the vane and the outside of the rolling piston, etc. To reduce the mechanical loss, we tried the following improvement items in the prototype compressor.

- (1) Supporting both ends of the rotor to reduce the friction loss in the bearings, on the other, the adjusting of dimensions(diameter, length) of the main bearing and the inside of the rolling piston, being based on the bearing performance analysis. This is taking into consideration the fact that the crankshaft and compression parts will deform.
 - (2) Reducing roughness on the sliding surface to 80% of the current one to decrease friction forces at the tip and the side of the vane.
- These improvements were expected to do well in reducing mechanical loss to 86% or so for the current one.

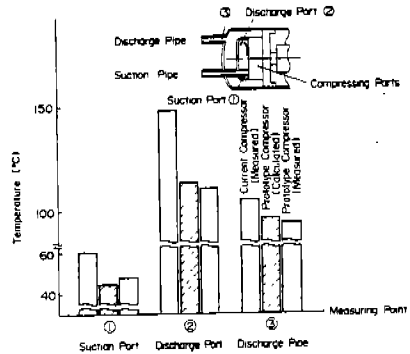


Fig. 9 Results of Temperature Drop (Calculation and Measurement)

TEST OF PROTOTYPE COMPRESSOR

Appreciating Performance and Temperature

Fig.10 shows a sectional view of the prototype compressor in which the above-mentioned procedures were adopted. The basic construction was the same as that of the current compressors, but the configuration of bearings, thermal insulating in the compressor shell and the radiating structure were altered.

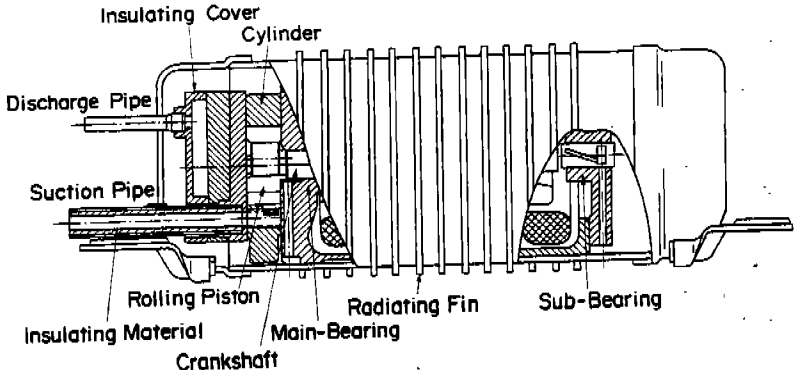


Fig. 10 Sectional View of the Prototype Compressor

We measured the performance of the prototype compressor with a secondary refrigerant calorimeter under the conditions listed in Table 2. Table 3 shows the performance test result of the prototype compressor in comparison to the current compressors. The volumetric efficiency was 88%, higher than that of current compressors.

Table 3 Performance of the Prototype Compressor
(compared with the Current Compressor)

	Current Compressor	Prototype Compressor
Ratio of Input Power	1.0	0.95
Ratio of Refrigerating Capacity	1.0	1.04
Ratio of C.O.P	1.0	1.10

Temperatures measured in representative points are shown in Fig.9 with those of current compressors. According to this result, structure changing appears to be remarkably effective for temperature drop in the prototype compressor. Comparing predicted temperatures and measured ones, a temperature drop of 15K was expected at the suction port① of the prototype compressor where a 12K drop was measured. The difference was 3K. As for the discharge port② and discharge pipe③, the difference between the measured temperature and the calculated one was 2K, showing that these temperatures are closely matched.

The effect of insulating material in the suction pipe of the prototype compressor was verified by means of two measurements with the insulating material and without it. Fig.11 shows the result. Without the insulating material, the temperature is 3.5K higher than that of the case with it. The remarkable effect of insulating the suction pipe is made clear.

We consider the cause of the 4% improvement in volumetric efficiency. Generally speaking, the temperature drop of suction gas causes its density to raise, and the mass flow of the refrigerant increases. As shown in Fig.9, the gas temperature in the suction port① of the prototype compressor is about 12K lower than that of the current one. This fact corresponds to a 4% density rise, and the figure is the same for the measured refrigerating capacity increase. The changing of insulation and a radiating structure appears to contribute to high volumetric efficiency.

Analyzing Power Loss

Based on the results of the performance test, temperature measurement inside the compressor, and the performance test on only the motor and loss analysis of current compressors, we carried out a loss analysis of the prototype compressor. Fig. 12 shows the percentage of each loss in comparison with that of the current compressors.

A performance test of the motor was done under the conditions of those in the air, at 25°C, at the operating frequency of 60Hz and with constant load of torque. Due to the improvement of the motor, the motor loss forms 18.1% of total input power, which is 1.8% smaller than that of current compressors. The decrease of loss corresponds to the expected one. The motor loss is analyzed further in detail.

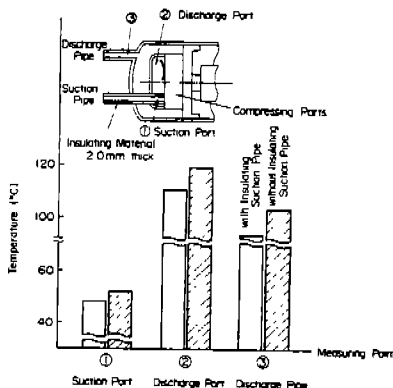


Fig. 11 Effect of Insulating Suction Pipe on Prototype Compressor

by testing each compressor with only one improvement procedure. The result clarifies that each procedure contributes to loss reduction.

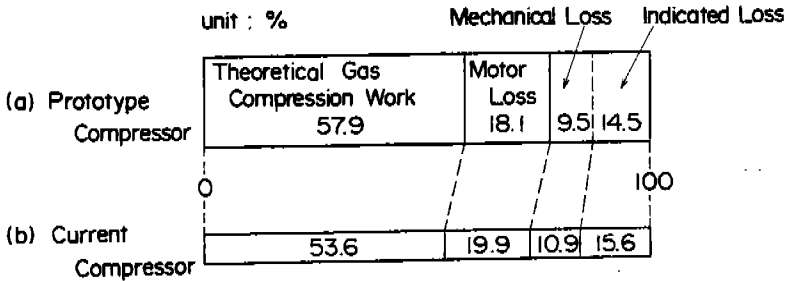


Fig. 12 Comparison of Loss Analyses

Equipping a compressor with interior pressure sensors, the dead volume will be great and will disturb the precise measurement of refrigerating capacity. As the prototype compressor is equipped with no pressure sensors, we can not separate indicated loss from others by the pressure measurement result. The sum of the indicated loss and the mechanical loss, however, can be estimated by the expression:
 $(\text{indicated loss}) + (\text{mechanical loss}) = (\text{total input power}) - (\text{theoretical gas compression work}) - (\text{motor loss})$

As shown in Fig.12, the sum of the indicated loss and the mechanical loss is about 2.5% smaller than that of current compressors.

The indicated loss was separated from the mechanical loss based on the following assumption. The mechanical loss on the main bearing and that on the inside of the rolling piston and so forth were estimated by means of the fluid lubrication theory of bearings with their specifications and measured temperature. The indicated loss is estimated basing on the reduction of input power caused by the temperature drop at the suction port in the compressor. Thus we can estimate the ratios of the mechanical loss and the indicated loss. The mechanical loss accounts for 9.5% of total input power and the indicated loss 14.5%. They are respectively reduced in comparison with current compressors.

CONCLUSIONS

We have carried out the study of further efficiency improvement on the 130W class rolling-piston-type compressor for refrigerator use. Based on the thorough loss analysis of current compressors, we have put into effect the following procedures for improvement.

- (1) Reforming the structure for radiation and insulation in the compressor based on an advanced technique of heat and fluid analysis to reduce indicated loss, particularly superheating loss.
- (2) Supporting both ends of the rotor and adjusting the dimension of the bearings and roughness on the sliding surface to reduce the mechanical loss.
- (3) Adopting high density material for the rotor, making magnetic flux uniform and lessening the air-gap to reduce the motor loss.

We constructed, tested and appreciated the prototype compressor. The efficiency was about 10% higher than that of current compressors. Though this study is concerned with only a rolling-piston-type compressor for refrigerator use, the same method for efficiency improvement will be appropriated for other types of compressors or for air-conditioning use.

REFERENCES

- (1) SAKAINO, K. et al., "Some approaches towards a high efficiency rotary compressor", Proc. Int. Compressor Engineering Conf. at Purdue, 1984
- (2) J S M E Data Book : Heat Transfer, 1975