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DEVELOPMENT OF A VARIABLE CAPACITY ROTARY COMPRESSOR PART Ⅰ: DESIGN CONCEPTS AND EXPERIMENTAL EVALUATION RESULTS

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ABSTRACT

In order to reduce the indirect global warming contribution, efforts to improve the efficiency of air conditioning systems are being continued. The development of capacity control technology is essential for the improvement of efficiency; this should be accompanied by the development of a variable capacity compressor. A novel rotary compressor that controls capacity mechanically without any electronic frequency modulation has been designed. Its major difference from the typical variable capacity compressors that have two cylinders is the variable displacements alternatively operate at each stage according to the external load condition. In this paper, we will introduce the techniques for improving the efficiency under both the full and part loading condition with guaranteeing the reliability of core parts. In addition, this paper presents brief explanations of the new mechanism and preliminary test results from a full-scale prototype.

1. INTRODUCTION

Demand of energy-saving goods is on the rise because the social need for the global-warming prevention and environmental control are being stronger each year. Most of annual running period of air-conditioning systems is in low loading mode. However, a conventional air-conditioner having a single capacity consumes much larger electric power, compared to a variable capacity air-conditioner. The consumption power of a single capacity air-conditioner doesn't change according to the variation of the temperature around the indoor unit.

Such a characteristic is clearly demonstrated in Fig. 1. In fig.1, A's represent either a room temperature or input power of a variable capacity air-conditioner, which is mounted with the newly developed rotary compressor modulated in 2 stages. On the other hand, B's represent either the room temperature or input power of an air-conditioner using a conventional single rotary compressor, which has the same capacity as the full capacity of type B. The number of On-off cycles of type A is much smaller than that of type B. Therefore, type A makes more continuous match to external load than type B and makes more optimal air-conditioning. Furthermore, type A is more advantageous in reliability of a unit device than type B. It is well known that in electric and mechanical aspects intermittent running is far severer than continuous running. If the room temperature amounts to a setting temperature, the running mode of type B will be switched from full loading to part loading. Not change of the external condition, the room temperature is maintained by using only part loading mode. And change of the external condition, the running mode is switched from part loading to full loading. If the outdoor temperature is very high, it will be continuously running in full loading mode without switching.

Recently, capacity modulation technology is taking notice of the industry because it makes the improvement of efficiency, like Seasonal Energy Efficiency Ratio, of an air-conditioner. To enhance the efficiency, it is essential to develop a capacity modulation compressor. In this paper, we will introduce a new variable capacity rotary compressor, named *ES* compressor, which provides two-step capacity modulation mechanically without using any electronic frequency modulation. In the new rotary compressor, capacity modulation is achieved by the alternation of rotation direction of shaft in both the clockwise and counterclockwise direction. In the systematic aspects of the new compressor, the control of rotation direction has to do with key mechanisms such as control of eccentricity and distribution of refrigerants. When properly designed, it could be used to increase the efficiency of air-conditioning systems to a considerable extent.

It has been mentioned that the variable capacity compressor is essential to the improvement of efficiency of an air-conditioner. Therefore, many compressor makers are trying to develop several types of capacity-controlling compressors, one of which is *ES* compressor. This paper mainly focuses on the introduction of the capacity control mechanism of the newly developed compressor and its experimental results.

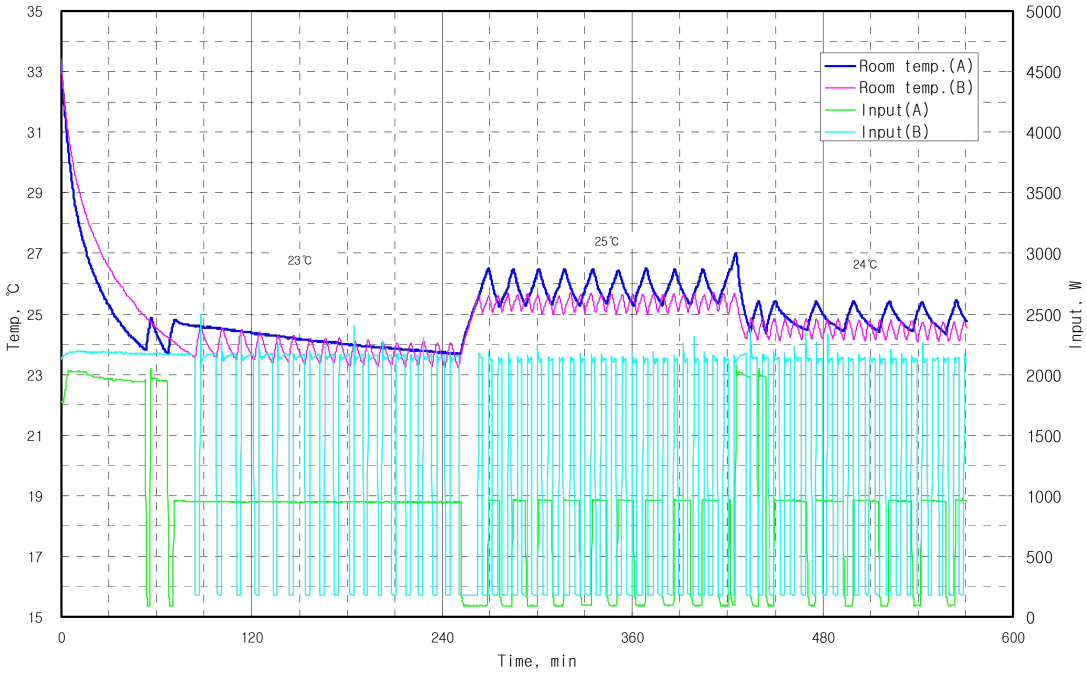


Figure 1: Room temperature and input power of a 2-step capacity modulated air-conditioner and a single capacity air-conditioner

2. DESIGN CONCEPTS AND EXPERIMENTAL EVALUATION

2.1 Capacity Modulation Mechanism

In this chapter, we intend to brief the capacity modulation mechanism of the new compressor. The new rotary compressor has two cylinders like a conventional twin rotary compressor, however it's unique in that the displacement of part load is different form that of full load, the volume rate of the smaller cylinder based on the larger cylinder ranging from about 40% to 60%. The displacement of part load is able to be designed to match an application engineer's request.

Whether the shaft is rotated in the clockwise or counterclockwise, either of two cylinders operates with the other idling. The compressor provides full load capacity when the shaft is rotated in the clockwise direction and part load capacity when the shaft is rotated in the counterclockwise direction. To do this, it is absolutely necessary that the new compressor should have the following core items; a reversible motor that can provide full speed in both the rotating directions of shaft, a shaft that incorporates with an eccentric rotatable throw block, named cambush.

As shown in Figs. 2,3, each of the eccentric parts such as shaft and cambush has two eccentric cams. The eccentric cams of the shaft have the same eccentricity in the same direction and are respectively provided on an outer surface of the rotating shaft to be placed in each of the compression chambers, whereas those of the cambush have the different eccentricity in the opposite direction and are rotatably fitted over the eccentric cams of the shaft, respectively. Further, the two rollers are also rotatably fitted over each of the eccentric cams of the cambush, respectively. The two eccentric units are respectively installed in each of the two cylinders, are eccentric from a rotating shaft to execute a compression operation while a remaining one of the rollers is released from eccentricity of the rotating shaft to prevent the compression operation from being executed, according to a rotating direction of the shaft. As shown in Fig.3, an operating cylinder has small clearance whereas an idling cylinder has large clearance. The clutch pin moving along the switching slot of cambush makes one of two cams of cambush be eccentric from the rotating shaft, when the shaft is rotated. Due to its structural characteristics having an idling cylinder and controlling eccentricity by the rotation direction of the shaft, several problems against the reliability of the system may occur. A unique latching mechanism that insures reliability has been developed with the aid of innovative tool, TRIZ. This subject is treated in part Ⅱ; " Design of Reliable Clutching Mechanism".

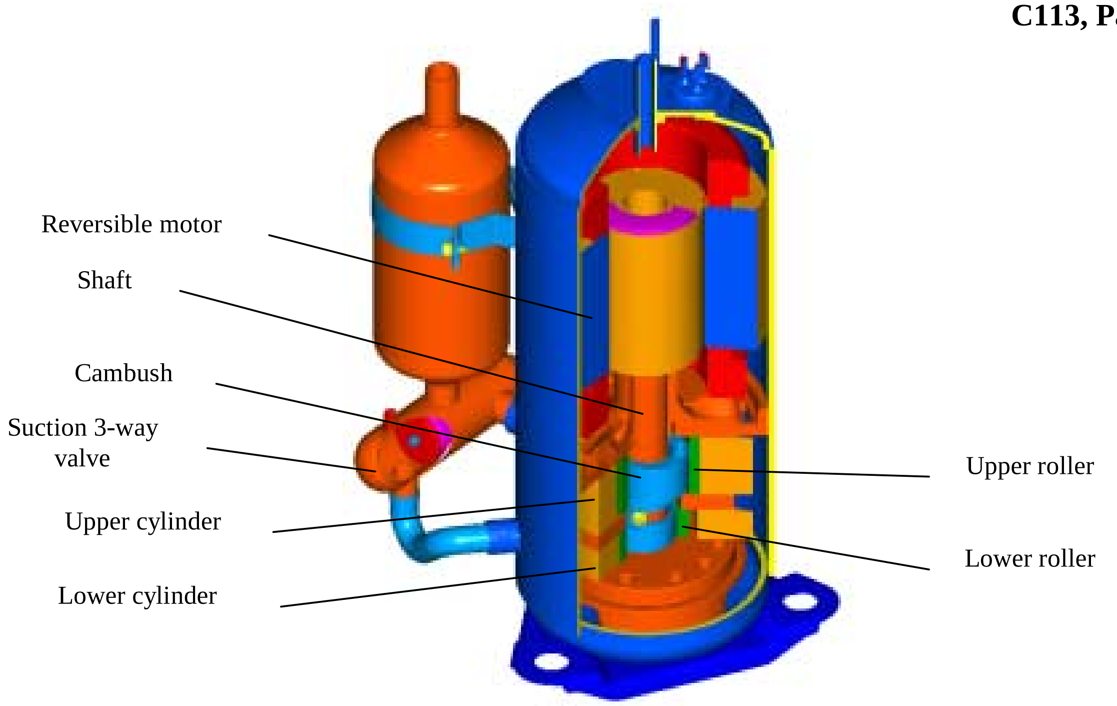
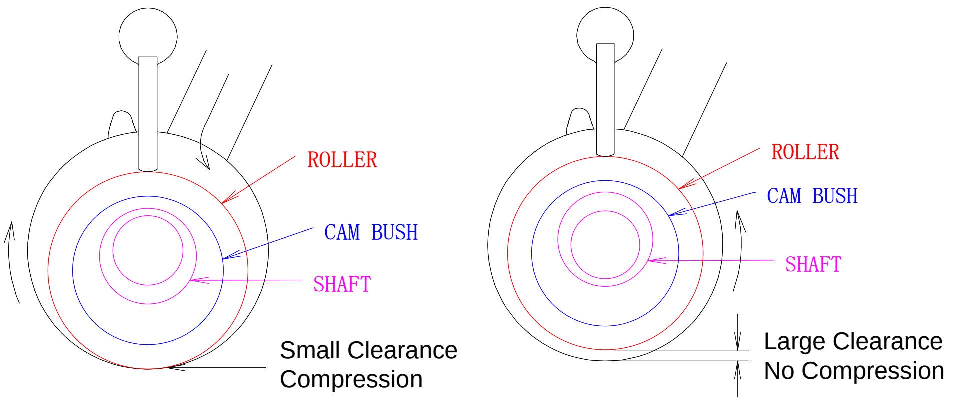


Figure 2: Structure of the newly developed compressor



(a) An operating cylinder (b) An idling cylinder

Figure 3: Control of Eccentricity

2.2 Supply of refrigerant

In the new rotary compressor, flow direction of suction refrigerant should be controlled because of the alternative operation of a cylinder according to its running mode. Otherwise, the hot gas from an idling cylinder has undesirable influences on the performance and reliability of the compressor. So, in running, leakage form the idling cylinder should not occur and besides, flow direction of suction refrigerant should be also switched in response with the alternation of the running mode. It can be accomplished by attachment of a special device such as 3-way solenoid valve. However, the new compressor controls flow direction of refrigerant by mechanical operation, which is more advantageous in terms of cost than solenoid valve. 3-way valve of the new compressor is shown in Fig. 4. There are 3 tubes connected to 3-way valve shell, which distributes refrigerant to the operating cylinder. One of the

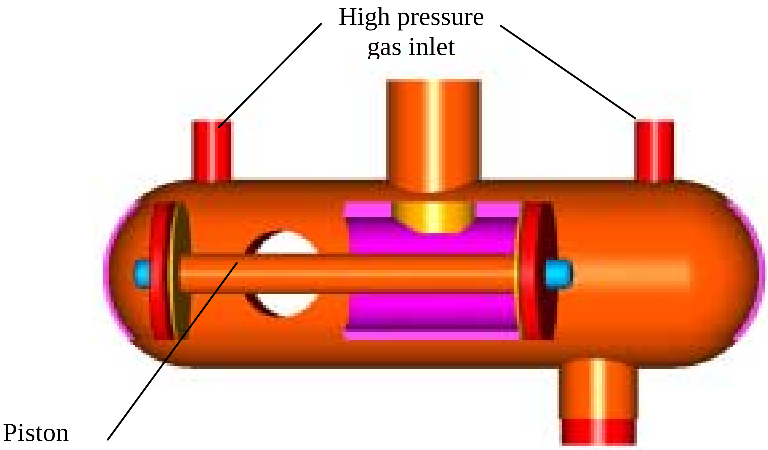


Figure 4: Structure of suction 3-way valve

tubes is connected to the accumulator, the rest of them are each connected to two cylinders and an operating cylinder are supplied with refrigerants by the movement of piston in suction 3-way valve. To switch flow of refrigerant, it uses a differential pressure between the operating cylinder and the idling cylinder. Before running, the equivalent pressure of all the spaces is approximately 10 bars. When the compressor starts, the suction pressure of the operating cylinder becomes much lower than the suction pressure of the idling cylinder and then the piston in suction 3-way valve moves to the operating cylinder to open suction path connected to the operating cylinder while the suction path connected to the idling cylinder is blocked by the piston.

2.3 Prevention of oil leakage into an idling cylinder

In the initial running time, the pressure of the idling cylinder is relatively lower than the pressure of other spaces in the closed shell of the compressor, except for the suction pressure of an operating cylinder, because the pressure in the idling cylinder rises more slowly than the other pressure in the compressor shell, which almost keeps up with the discharge pressure because the compressor shell is occupied with the high pressure gas directly discharged out of an operating cylinder. So, in the early running time, there is pressure difference among the spaces, oil in the closed shell leaks into the idling cylinder. The leaked oil in the idling cylinder works as a much larger fluidal resistance, compared to refrigerant gas. In aspects of efficiency, that is one of main causes of performance reduction. Therefore, to prevent oil leakage into the idling cylinder, the initial pressure difference between the idling cylinder and inner space of the compressor shell should be minimized. So, the new compressor has a special device to reduce a viscous fluidal resistance by oil leaked into the idling cylinder. It is the gas-injection device that supplies the high-pressure gas discharged out of the compression cylinder for the idling cylinder. By using the gas-injection device, the initial pressure balance between inner spaces of the compressor except for the operating cylinder has been almost simultaneously accomplished and so the oil leakage into an idling cylinder could be prevented.

2.4 Experimental Results

To improve the efficiency of the new compressor, design of a reversible motor has been optimized by minimizing the loss in the efficiency of part loading mode with considering reasonable starting torque and as mentioned above the gas-injection device supplies an idling cylinder with a high-pressure gas discharged out of an operating cylinder. From the experimental results under ASHRAE-T condition, it has been demonstrated that EER, Energy Efficiency Ratio, of the new compressor with the gas-injection device was higher about 3~4% than that of the compressor without the device. This result is similarly applied to both loading conditions. The efficiency of the air-conditioner mounted with the new compressor was also tested in both modes. As a result, the energy consumption of the air-conditioner was reduced to about 40%, compared to a unit mounted with a conventional single rotary compressor. As for noise, the noise level of full loading condition is the same level as that of a single rotary compressor while the noise level of part loading condition is lower about 2 dB than that of full load condition because the amount of refrigerant of part load condition is relatively small, compared to that of full load condition.

3. CONCLUSIONS

From the experimental results of the performance and reliability test of the new rotary compressor, the following conclusions could be reached.

- The new variable capacity rotary compressor mechanically controlled has been developed and from the rigorous test in the laboratory and field it has been proved that the compressor is as much reliable as a conventional rotary compressor.
- The consumption of annual electric power in an air-conditioner has been reduced to about 40%, compared to a conventional single rotary compressor with comparable capacity.
- The new rotary compressor enhances the installation flexibility by minimizing weight and size, compared to a variable capacity compressor of other types.
- The noise level of full loading condition is the same level as that of a single rotary compressor with comparable capacity while the noise level of part loading condition is lower about 2 dB than that of full load condition.

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