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Optimization of Oil Separator for Variable Swash Plate Compressor in the Vehicle Air Conditioning System

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ABSTRACT

Studies for improving performance of the vehicle air conditioner have been becoming an important research theme to reduce fuel consumption of a vehicle because the air conditioner is applied most vehicles by the convenient device maintaining the temperature inside the vehicle and directly uses the vehicle power. In addition, since the compressor which is main part of the air-conditioner is connected to engine and operated by the engine, the compressor durability performance affects the reliability of the vehicle, so a compressor durability is also a key research subject. In this paper, the research of the oil separator in the compressor has been carried out to improve the system efficiency and to guarantee the compressor durability. The compressor circulates not only refrigerant but also oil in the system, and the Oil Circulation Ratio (O.C.R) is an important factor affecting system performance and compressor lifetime. Through this research, the basic principle of oil separation was analyzed mathematically, and optimized oil separator in the compressor has been suggested. Then its function is verified in the actual car air conditioning system.

1. RESEARCH BACKGROUND

The vehicle air-conditioning system which has been applied a vehicle since 1970s has now become an essential convenience device. Such as Figure 1, the vehicle air conditioner is consisted of condenser, compressor, and heating ventilation air conditioning (HVAC) in front of vehicle, and also there are the thermal expansion valve and evaporator in the HVAC. Generally, refrigerant R134a is used in the vehicle air conditioner until now, but alternative refrigerant R1234yf began to be used in the USA and Europe.

![Vehicle air conditioner system](image)

Figure 1: Vehicle air conditioner system
Since the air conditioner is directly using the vehicle power, a research about efficiency improvement of air conditioner is important to increase the gas mileage of vehicles. Figure 2 shows the effect of the air-conditioner on the fuel efficiency of the vehicle. The average rate of decreasing efficiency by the air conditioner is 9% per year, and maximum 23% in the summer.

Among the air conditioner parts, the compressor uses the power of 53% per annum, and 70% in the summer, which has the greatest influence on the fuel efficiency of the vehicle. Therefore, to reduce power consumption by the compressor, a fixed swash plate type compressor which is On-Off controlled has been replaced by an external controlled variable swash plate type compressor whose stroke volume is controlled proportionally by an external signal, and the compressor power consumption has been reduced about 20%. Both the fixed swash plate compressor and external controlled variable compressor are showed in the Figure 3. In this paper, the research of the oil separator in the external controlled variable compressor has been carried to improve the air-conditioner system performance. Generally, when the performance of the compressor oil separator is getting increased, the oil amount inside compressor is increased, so that the durability performance by the lubrication is improved, and since the oil that interferes with heat exchange at the condenser and evaporator is reduced, performance of air conditioner system is improved. However, it is found that in case of high performance oil separator, the surface temperature of compressor is too high under the high speed condition, and finally it causes the compressor failed. Therefore, the purpose of this study is to find the method to improve both the durability of the compressor and the system performance by applying the high efficiency oil separator and also to prevent the increasing surface temperature of compressor at the high speed condition.

Figure 2: Fuel consumption influence by the air conditioner system and parts

Figure 3: Compressors for vehicle air conditioner system
2. EXPERIMENT SETUP

The schematic of air-conditioner system test rig, Field Simulation Pattern (F.S.P), used in this research is shown in the Figure 4. This test rig has a vehicle interior room chamber that can control the temperature and humidity and an engine room chamber which can control the temperature. And, the motor for driving the compressor and a fan to control wind velocity of condenser side are installed in the engine room chamber. The air-conditioner parts used in the test rig are actual parts, the condenser and the compressor are installed in the engine room chamber, and the HVAC that consists of an evaporator, an expansion valve and a blower is installed in the vehicle interior room chamber. The wind velocity of condenser side is controlled by the fan installed in the test rig and the volume flow of evaporator is controlled by the blower in the HVAC. To know both the refrigerant and oil state, the pressure and temperature sensors are installed at the compressor inlet, outlet and condenser outlet, and also the mass flow meter and oil circulation meter are installed in the condenser outlet. And, the temperature and humidity is measured in the air side of evaporator, and the temperature is measured in the condenser air side inlet and outlet. Since actual parts of the air-conditioner are used this test rig, the air conditioner system state including oil circulation ratio can be measured in the actual air-conditioner condition, and it is possible to analysis effect on actual air-conditioner parts.

3. OIL FLOW IN THE COMPRESSOR

3.1 External Controlled Variable Swash Plate Compressor

The external controlled variable compressor can control the stroke volume by changing the swash plate angle. The swash plate angle is changed by the control room pressure which is controlled by the external control valve located between the control room and discharge muffler. Not only high pressure control refrigerant through the control valve but also leakage refrigerant from the cylinder through the clearance between the cylinder and piston flows into the control room, and the refrigerant in the control room flows into the suction muffler through the bypass hole located between control room and suction muffler. The control refrigerant in the suction muffler flows into the cylinder together with the suction gas and is discharged after being compressed in the cylinder. The refrigerant flow in the external control variable compressor is shown in the Figure 5, and the oil also flows with the refrigerant. Since this compressor is mounted on the engine and operated by the engine through the belt, the rotation speed of the compressor is proportional to the engine rotation speed and generally faster than the engine speed about 1.1 to 1.3 times. The normal rotation speed of the engine is the range 700 to 3,500 rpm and the maximum instantaneous rotation speed is about 8,500rpm, therefore the compressor performance has to be optimized between 800 to 4550rpm, and the compressor durability has to guarantee until 11,000rpm.

Figure 4: Vehicle air conditioner Field Simulation Pattern
3.2 Compressor Oil Separator and Surface Temperature

There are sample A and B for the test in the Figure 6. Based on the understanding of the oil distribution inside the control room through the previous studies, the test sample A has bypass path whose inlet is located in the oil rich area which is cylinder block face in the control room, and the other sample B has the bypass path started from the oil-less area which is near the rotation shaft. In the test result, the O.C.R of sample B is remarkably lower than sample A since the bypass path started from the oil-less area. This means that there is a lot of oil in the compressor and there is a little oil in the system. In this case, it is expected that the compressor durability and system performance will be improved. However, as a result of compressor surface temperature measurement, the surface temperature of sample B is too high when compressor is running at the high speed condition such as 7,000 rpm. It is understood that the reason for the temperature increasing of sample B is the friction between oil in the control room and rotating swash plate. When the temperature of compressor is too high, the viscosity of the oil inside the compressor becomes low, which causes a serious problem of the compressor durability. Experience in durability test indicates that when the temperature of compressor surface exceeds 150 °C, the compressor is damaged. Therefore, although model B has high oil separator performance, it can’t be used by the high compressor surface temperature.

Figure 5: External controlled variable compressor

Figure 6: Test sample A, B and test results
4. OIL SEPARATOR OPTIMIZATION DESIGN

4.1 Oil separator design idea

In the test results of chapter 3.2, since the sample B has low O.C.R at all operating speeds, it can improve system efficiency and compressor durability, but there is a problem of low viscosity due to increase surface temperature at the high speed rotation condition. On the other hand, the sample A is not increased the compressor surface temperature at the high speed condition, but the efficiency of the system and the compressor durability at the low speed conditions is getting low. In order to solve this problem of sample A and B, it has to be designed that the O.C.R is low such as sample B to improve the system efficiency and compressor durability at the normal operating condition (from 800 to 5,000 rpm), and the O.C.R is high such as sample A to prevent increase of the compressor surface temperature at the high speed condition (over 5,000rpm). The bypass path of sample A is located on the cylinder block face, and the path of sample B is on the rotating shaft. In this case, the flow resistance of the bypass hole in sample A is constant regardless of the operating speed of the compressor while the flow resistance of sample B is proportional to the square of the rotation speed of shaft. The idea of the oil separator in this research is that the compressor has two bypass holes of sample A and B and its characteristics are shown in Figure 7A. As shown in Figure 7A, when there are both bypassing paths shaft hole(oil-less area) and cylinder block face(oil rich area), if the shaft hole is larger than the cylinder hole, most of the bypass gas is discharged through the shaft hole at the low speed condition, and as the operating speed increase of the compressor, the bypass gas through the cylinder wall is relatively increased by the shaft hole flow resistance. Figure 7B shows the calculation results of a 5mm shaft hole and 1mm cylinder block hole. In condition of 800 rpm, over 90% of the bypass gas is discharged through the shaft hole, so that the O.C.R can be kept low. As the amount of bypass gas through the hole on the cylinder increased in proportion to the operating speed, at 8,000rpm or more, more than 60% of the bypass gas is discharged through the cylinder hole, so that the O.C.R is increased, and increasing compressor surface temperature can be prevented at high speed condition. Therefore, the oil separator for a variable compressor presented in this paper is suitable for design purpose because O.C.R is low at the normal operating speed and high at the high speed condition. Based on the theoretical calculation results presented above, the actual diameter of the cylinder hole and shaft hole is going to be confirmed by experimental study.

4.2 Experiment result

A. Oil Circulation Ratio and Compressor Surface Temperature

Figure 8 shows changes of OCR and surface temperature with the variation of cylinder hole for a shaft hole diameter of 5mm. First, when the shaft hole diameter is 5mm and the cylinder hole diameter is 1mm such as in theoretical analysis, the OCR is 2~5.5%, and this OCR is higher than the sample B but lower than the sample A. On the other hand, since the surface temperature of the compressor does not exceed 120℃ even under the high speed operation condition of 7,000 rpm or more, it can be confirmed that it is equal to the sample A. For the optimization of the oil separator, the test was carried out by the increasing the diameter of the cylinder hole from 0.5mm. As the results, by the increasing diameter of cylinder hole, the OCR becomes higher, and the surface temperature at high speed is lowered, but when diameter greater than 1.0mm the result values of OCR and temperature are the same.
When the diameter of the cylinder hole is 0.5mm, the OCR is as low as that of the sample B, but the surface temperature is 140℃ and approaches the limit temperature at the high speed operating condition. In the case of the cylinder hole 0.7mm, the OCR tends to be slightly higher than 0.5mm, but the compressor surface temperature at the high speed condition is 130℃, although it is 10℃ higher than the minimum temperature 120℃ of sample A, it is sufficiently lower than the limit temperature of 150℃. Therefore, the optimization design of the oil separator discussed in the section 4.1 confirms that the diameter of the cylinder hole is 0.7mm with the shaft hole diameter 5.0mm.

B. System Performance

Figure 9 shows the cooling capacity and the air temperature at the outlet of the evaporator about the vehicle air conditioner performance test conditions. In the test condition, the condenser room temperature is 35℃, discharge pressure is 18kgf/cm²G (the discharge pressure is controlled the condenser wind velocity), evaporator temperature and the relative humidity are each 35℃ and 50% and the evaporator blower voltage is 12V. This test condition corresponds to a high load condition of the vehicle air-conditioner. In this test results, the cooling capacity of the model B and the oil separator presented in this research is higher than model A about 1.7% (900 rpm), 6.5% (1800rpm) and 4.8% (2500rpm) and evaporator outlet air temperature of both oil separator and model B are 1~2℃ lower than the sample A. Compressor surface temperature with the oil separator of this study does not exceed the limit temperature for durability guarantee at the high speed condition such as the result in figure 8. And, in the normal operation condition, the cooling performance of the compressor with oil separator is almost same model B, and the evaporator outlet air temperature is lower than the model A about 1 to 2℃.
5. CONCLUSIONS

In this paper, the following results were obtained through the study on the oil separator of the external variable compressor to improve the system performance of the vehicle air conditioner system and the durability of the compressor.

(1). When the oil is enough left in the compressor due to the excellent performance of the compressor oil separator, it can be expected that the improve of the system performance and compressor durability at the normal operating condition, but as the surface temperature of the compressor is increased due to the friction between the excessive oil in the control room and the swash plate operated at high speed, the viscosity of the oil is getting lower and compressor is damaged.

(2). In order to improve the compressor durability and system efficiency by reducing the OCR at the normal operating speed and prevent the increasing temperature by increasing the OCR at the high speed condition, the oil separator design whose bypass path of control gas has both the shaft hole (oil-less path) and the cylinder hole (oil rich path) has been proposed

(3). For the proposed oil separator design, through the test for the various cylinder hole diameter at the shaft hole 5mm, the cylinder hole is fixed 0.7mm. The OCR of cylinder hole diameter 0.7mm was 2.0% and remarkably improved compared to sample A 8%, and it is confirmed that the surface temperature of the compressor at the high speed condition is 130℃ and very stable.

(4). As a result of the system performance test of the proposed oil separator and the comparative sample A and B, the system performance of the oil separator is equal to the sample B, and both the cooling performance is increased about 1.7–6.5% and the air outlet temperature of evaporator is lower about 1 to 2℃ compared with the sample A

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>P</td>
<td>Pressure</td>
<td>(kgf/cm² G)</td>
</tr>
<tr>
<td>ρ</td>
<td>Density</td>
<td>(kg/m³)</td>
</tr>
<tr>
<td>r</td>
<td>Radius</td>
<td>(m)</td>
</tr>
<tr>
<td>ω</td>
<td>Angular velocity</td>
<td>(rad/sec)</td>
</tr>
</tbody>
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Subscript

s suction muffler  
c control room  
d discharge muffler

REFERENCES


