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Experimental Investigations On The Performance Improvement Of Oil-gas Separator In Electric Driven Scroll Compressor For Eco-friendly Vehicles

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Experimental investigations on the performance improvement of oil-gas separator in electric driven scroll compressor for eco-friendly vehicles

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ABSTRACT

Experimental research on the oil-gas separator was conducted to improve the performance of electric driven scroll compressor used in eco-friendly HEV/EVs. The compressor used in the test was "back pressure" method type by oil and an oil separator was made in the discharge chamber to manage the adequate back pressure. The pressure drop could be occurred when the refrigerant passing to oil separator. It makes input power increase and COP decrease. Various parameters of the oil separator— the length of vortex finders; installation angle; and the inlet, outlet diameters— related to the pressure drop were considered. The installation angle and the outlet diameters had no significant effect on the pressure drop; however, the pressure drop decreases as to the length variation of the vortex finder and the inlet diameter. As to the vortex finder length decreased and the inlet diameter increased, the input power of the compressor is decreased about 4.12% and the COP is increased about 2.66%.

1. INTRODUCTION

Since the scroll compressor was introduced in 1983, the demand and application range of scroll compressor has been increased due to the high efficiency and low noise level compared to the other types of compressors. Currently, in response to global environmental problems, the research and development has been focused on hybrid and electric vehicle along with advanced air conditioning systems. Unlike the conventional gasoline engine, the electric driven scroll compressor should be used for the air conditioning system in the HEV or EV. (Nam et al. 2012)

There are some factors to be determined the performance of the compressor. The oil management is one of them. It is necessary for the compressor to circulate the oil of the appropriate amount to lubricate the friction parts. The oil in the compressor prevents the wear of each part and the leakage of the refrigerant. Particularly, in the case of the back pressure type scroll compressor, the oil management is important factor depend on performance and reliability as to control the hermetic sealing about the axial leakage gap with the back pressure force of the orbiting scroll bottom.

However, when the gas of the compressor is discharged to the system after the refrigerant gas is compacted, oil is flowed out to the system along with the discharge gas. The oil from the compressor flows into the evaporator of the system, then the heat transfer coefficient of the heat exchanger is decreased and the overall performance of the refrigeration system is decreased. We installed the oil separator in the compressor in order to reduce the effect of such oil. The oil separator is installed in the compressor discharge port and the separated oil is circulated into the compressor through the back pressure chamber. The oil to circulate the compressor is the lubrication in the compressor and seal the leakage gaps of the scroll. However, the oil separator for this purpose causes a pressure drop and performance degradation because of the flow path resistance in the discharge chamber. Accordingly, this study measured the pressure drop about the each case in which a change of inlet diameter, the mounting angle, the vortex finder length, and the outlet diameter of the oil separator. And it was confirmed the improved performance.

2. EXPERIMENTAL FACILITY AND METHODS

2.1 Electric driven scroll compressor

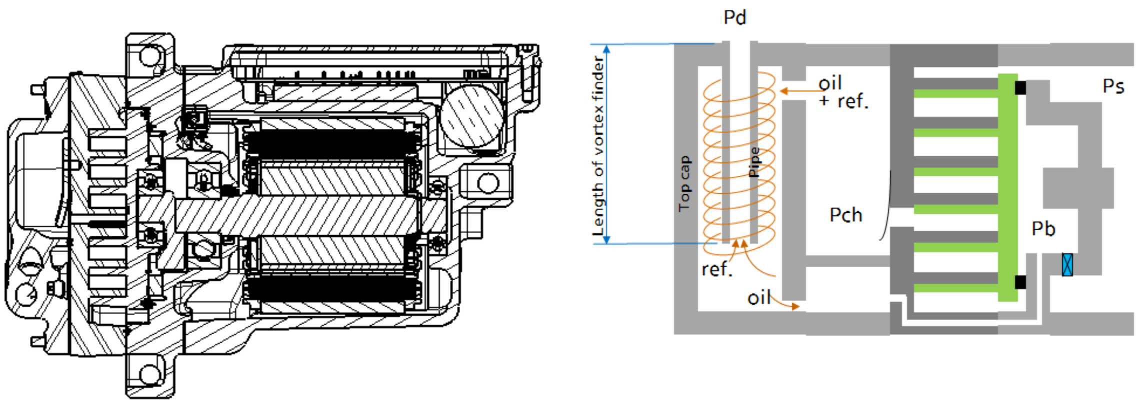

Figure 1. Section view of electrically driven scroll compressor and schematic diagram of oil separator

Figure 1 shows the electrically driven scroll compressor and oil separator in discharge chamber that is used in this research. The compressor is composed of the compression part, the motor and the inverter. The scroll compressor has an axial and radial leakage gap. It is one of hot issues and many approaches are being to try to minimize this gap. The compressor in this research applied the oil back pressure to minimize the axial gap. Using the oil separator, the gas and oil exerted from the compression part is separated. Then the high-pressure oil is sent to the orbiting scroll lower part, and the orbiting scroll adheres closely to the fixed scroll. This method could be minimized the axial gap. In addition, it lubricates the bearings in the back pressure chamber and improves the compressor durability. The R134a and POE were used for the refrigerant and oil respectively.

2.2 Experimental System

Figure 2 displays the schematic diagram of the bench system of the vehicle air conditioning system for the teat. As described above, the electrically driven scroll compressor is used, which includes an AC/DC converter to operate the compressor. The suction, discharge and back pressures were measured with pressure transducers and the accuracy of the pressure measurement was ± 0.08 kgf/cm^2 full scale. The temperatures were measured with k, t type thermocouples and the accuracy was ±0.75°C. The condenser and evaporator of the actual vehicle were also used and an expansion valve (TXV) was used. In addition, a sensor to measure the refrigerant temperature was installed on the front side of the expansion valve. The temperature measurement module was mounted at the evaporator's front and back to measure the refrigerant temperature. And it was configured to can install the OCR meter between the mass flow meter and expansion valve. To measure the OCR, a sound velocity transducer(maker : SensoTech) was used. It measures the temperature and the velocity of sound in the liquid. It has the full range of 150 to 3000m/s and the accuracy of ±0.1m/s. Measurements can be performed in the temperature range of -20°C to 120°C and at pressures up to 16000kPa. For the measurement of sound velocity in refrigerant and refrigerating oil mixtures.

The digital signals from thermocouples, pressure transducers, and mass flow meters were collected and processed by a data acquisition.

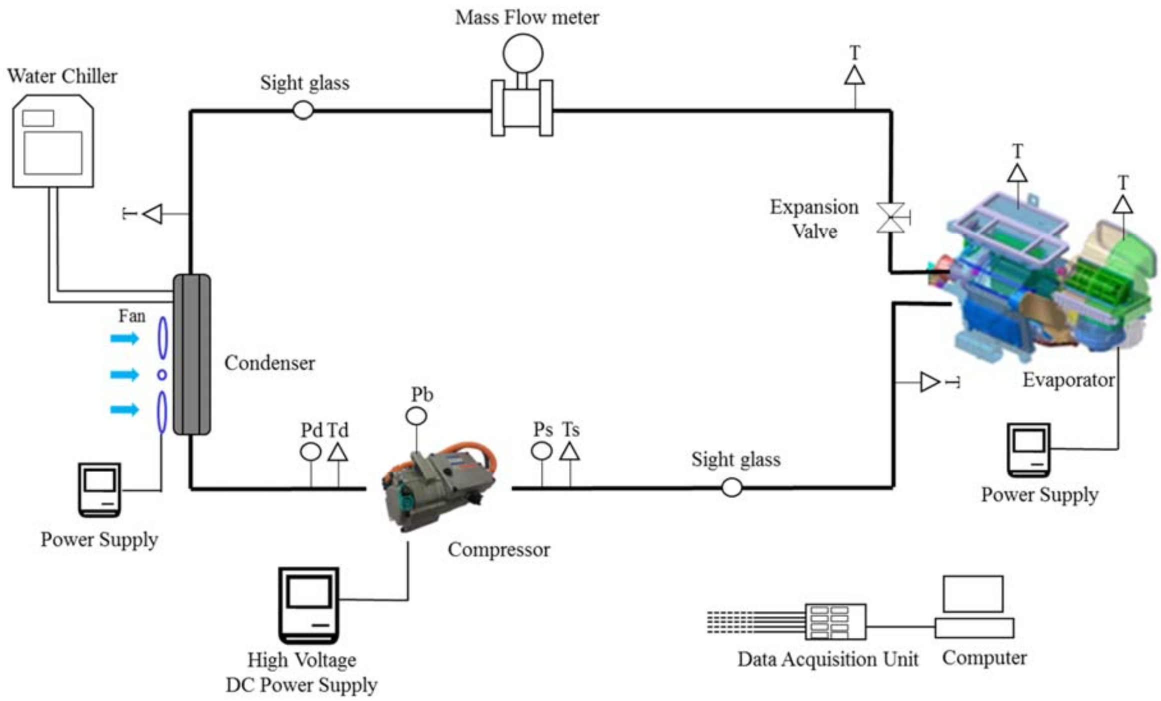

Figure 2. Schematic diagram of the bench system

2.3 Experimental procedure

2.3.1 System refrigerant charge test

At first, a test was carried out to determine the optimal amount of the refrigerant charge on the test equipment. For this, the temperature-cross-over method was used proposed by Wandell al.(1997) in ACRC TR-128. This method adds 10% to the refrigerant amount and then measures the refrigerant temperature of the evaporator inlet and outlet where they intersect. For the test condition, the fan speed of the condenser and evaporator was set to keep the performance test within a temperature range of 40~43°C and humidity within 17~21%. In addition, the EEV opening degree was fixed at that time. The refrigerant temperatures on the front and back of the evaporator were measured at 25g intervals, starting with 600g of refrigerant with fixed boundary conditions.

As shown in figure 3, the refrigerant temperatures of the evaporator front and back intersect at the refrigerant amount of 775g. In addition, the refrigerant was confirmed to be at liquid status in the sight glass in the condenser backend.

Therefore, the refrigerant charge resulted in 852.5g, a 10% increase over the amount of 775g. Finally, the amount of refrigerant was determined to be 860g for the optimum experiment.

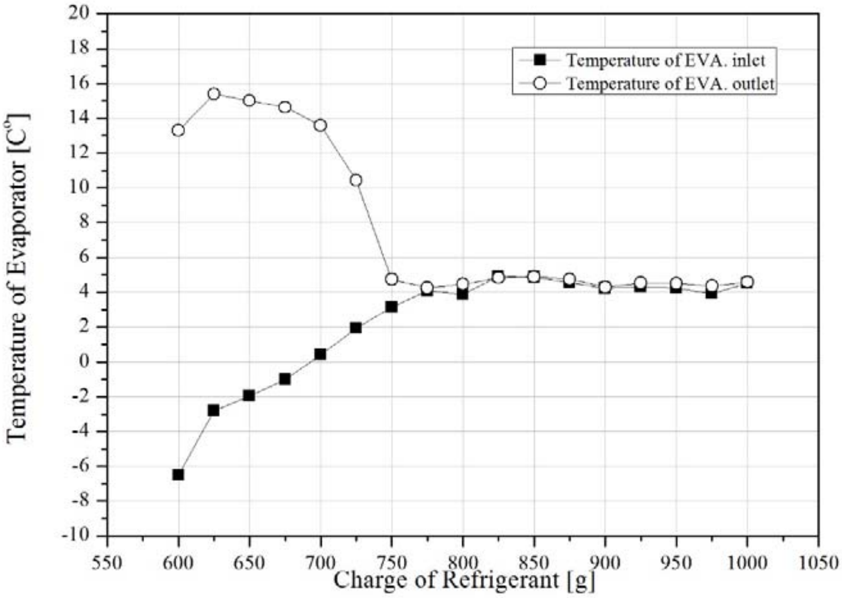

Figure 3. Temperature of evaporator

2.3.2 Experimental conditions

A test was conducted about the pressure drop by vortex finder length in the oil separator. The length of vortex finder is a factor which depends on the pressure drop. The length at the initial design is 50mm. To determine the change in length, tests was conducted to the variation of lengths, 35mm, 40mm, 45mm, 50mm, 55mm, 60mm, and 65mm.

Figure 4. Vortex Finder

The compressed refrigerant and oil discharged through the oil separator. Therefore, the pressure drop was measured by the pressure before and after oil separator through the length of vortex finder. The pressure transducers was added in the discharge chamber. The test condition is shown in below table 1. The suction and discharge pressure fixed 2.04kgf/cm^2 and 14.28kgf/cm^2. It is performance test condition at the refrigerant compressor for real vehicles. And compressor rotation speed was increased from3000 rpm to 8600rpm.

Table. 1 vortex finder length test conditions.

Suction Port Pressure	2.04kgf/cm^2
Discharge Port Pressure	14.28kgf/cm^2
Rotation speed	3000 ~ 8600 rpm
Ambient temperature	20 ~ 24℃
Ambient humidity	14 ~ 26 %

Second test is parameter study on the vortex finder angle and length, inlet and outlet diameter. The inlet diameter is 6mm and 8mm. The outlet diameter is 3mm and 5.5mm. The vortex finder angle is 60 and 90 degree. The vortex finder length is 25mm and 50mm. Table 2 shown the each case through the various parameters. Test condition was shown table 3. The suction and discharge pressure is same to the condition of performance test. And compressor rotation speed is 8000rpm.

Table.2 Test case through each parameter

Test case	**Base**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**
VF length [mm]	50	50	50	50	50	50	25	25	25	25	25	25
VF angle [mm]	60	90	60	90	60	90	60	90	60	90	60	90
I.D [mm]	6	6	8	8	8	8	6	6	8	8	8	8
O.D [mm]	3	3	3	3	5.5	5.5	3	3	3	3	5.5	5.5

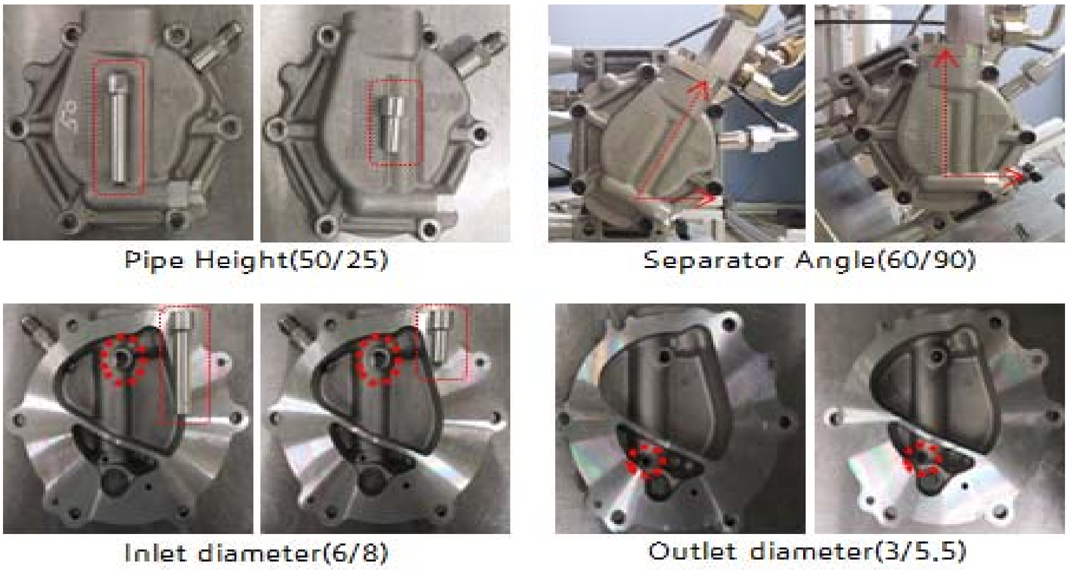

Figure 5. Vortex finder angle, inlet and outlet diameter test parameters

Table. 3 Vortex finder angle, inlet and outlet diameter test conditions.

Suction Pressure	2.04 kgf/cm^2 (const.)
Discharge Pressure	14.28 kgf/cm^2 (const.)
Rotation speed	8600 rpm
Ambient temperature	19 ~ 24 ℃
Ambient humidity	15 ~ 25 %

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Vortex finder length test

Figure 6 shows a pressure drop in the vortex finder length. The pressure drop increases to the faster rotational speed of the compressor. And the longer length of the vortex finder also makes pressure drop increased caused the flow resistance. When the length of the Vortex finder 65mm, the pressure drop was measured by 0.275kgf/cm^2 at 3000rpm, the pressure drop was measured by 1.035kgf / cm^2 at 8600rpm. And when its length is 35mm, the pressure drop is measured by 0.218kgf/cm^2 at 3000rpm, and was measured by 0.788kgf/cm^2 at the 8600rpm. In the low-speed, the pressure drop was measured by 0.057kgf/cm^2 and in the high-speed, it was measured by 0.247kgf/cm^2.

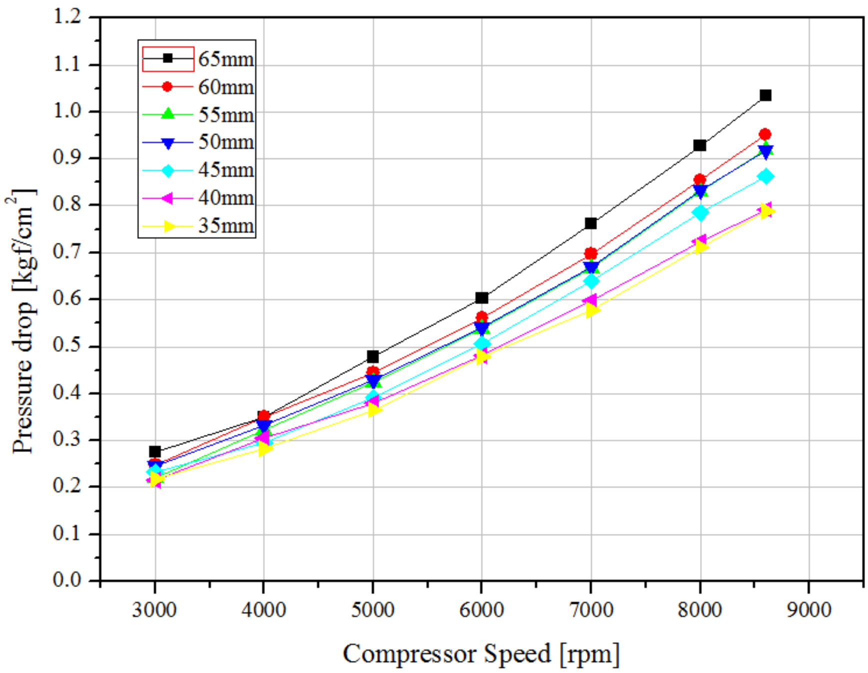

Figure 6. Pressure drop according to the length of vortex finder

3.2 Vortex finder angle, inlet, outlet diameter test

Depending on the length of the Vortex finder angle, inlet / outlet diameter, and the vortex finder, the compared evaluation was carried out. Table.4 shows the result of the pressure drop to each case. First, according to the result of the vortex finder length, it is equal to the previous test results. The pressure drop due to the angle of installation of the Vortex finder was below which means not meaningful. However, the size of the inlet diameter that is the inlet of the refrigerant and oil mixture in the oil separator is measured to affect the pressure drop. Depending on the size of the inlet diameter, increases of pressure drop was reduced up to 26%. The size of the separated oil outlet diameter in the oil separator was determined to have no effect on the pressure drop.

Table. 4 Test Results

Test case	Base	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
VF length [mm]	50	50	50	50	50	50	25	25	25	25	25	25
VF angle [°]	60	90	60	90	60	90	60	90	60	90	60	90
I.D [mm]	6	6	8	8	8	8	6	6	8	8	8	8
O.D [mm]	3	3	3	3	5.5	5.5	3	3	3	3	5.5	5.5
Pressure drop [kgf/cm^2]	0.9	0.9	0.67	0.66	0.67	0.67	0.75	0.75	0.59	0.59	0.58	0.59
Power [kW]	2.67	2.67	2.59	2.6	2.59	2.58	2.63	2.61	2.58	2.58	2.57	2.56
COP	1.88	1.87	1.91	1.9	1.91	1.92	1.88	1.89	1.91	1.92	1.94	1.93

The power of the test case was decreased with decreases in the pressure drop. The power was measured by 2.67kW in the base case, but it was measured by 2.56kW in case 11. It was reduced about 4.12%. And the coefficient of performance were up 2.66% at 1.88 to 1.93.

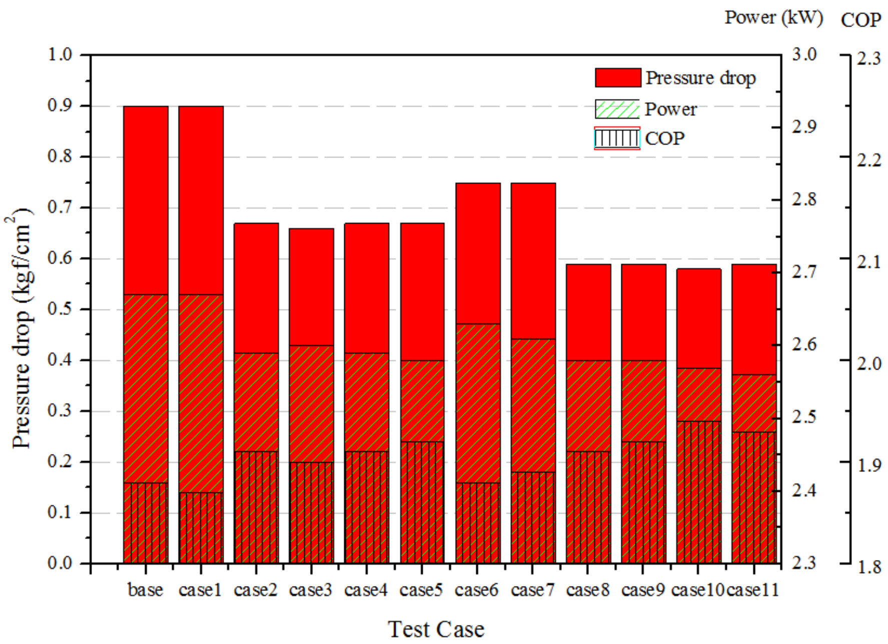

Figure 7. Test results

3.3 OCR and NVH test about base case and improved case

Parameter study results shown that the improvement of 10, 11 case appear larger than the base case. So it measured to the change of OCR in the base case against improved case. Measurement results, the OCR of improved case is measured with the equivalent as compared with the OCR of base case. The OCR of base case was measured in 3.5%, the OCR of improved case was measured in 3.4%. Also, the back pressure was measured in 5.195kgf/cm2 at the base case and 5.18kgf/cm2 at the improved case. This indicates that the separated oil flows equally to go the back pressure chamber. Therefore, it shows that the oil separation efficiency is not difference between the two cases.

And the sound level and pulsation was measured between the two cases through the NVH test. There are measured according to specifications of the car maker. Table. 5 shown the results of NVH test. Measurement results, the sound level of improved case is measured with the equivalent as compared with the base case. Suction pulsation was measured with the equivalent about two cases, but discharge pulsation was measured in improvement case larger than base case. But the discharge pulsation of improved case is applicable because of the satisfaction with the standards by the car maker.

Table. 5 NVH test results

Division			Base case	Improved case	Deviation	Note
Noise	3000rpm	RMS dB(A)	54.8	54.8		
		Peak dB(A)	43.5	45.1		
Pulsation	3000rpm	Suction Pulsation, mbar	16	18		
		Discharge Pulsation, mbar	152	178	8.7% ↑	
	4000rpm	Suction Pulsation, mbar	19	18		
		Discharge Pulsation, mbar	206	237	10.3% ↑	

4. CONCLUSIONS

The study was tested by changing the design parameters of the compressor discharge oil separator room for the performance upgrading of the electric driven compressor. First, to measure the pressure drop along the length of the Vortex finder. And the test has been carried out about the design parameters of various oil separator depend on the number of case. Finally, through the OCR and NVH tests, it was possible to verify that it was applied. The test results are as follows.

- The test results according to the length of the vortex finder, the longer length of the vortex finder is increased pressure drop. And the faster rotational speed of the compressor increases the pressure drop.

- The test results of the various case, the pressure drop by the installed angle of vortex finder and the size of the separated oil outlet diameter in the oil separator was determined to have no effect.
- The test results of the various case, the length of vortex finder and the size of the inlet diameter that is the inlet of the refrigerant and oil mixture in the oil separator was measured to affect the pressure drop. The pressure drop was decreased by max. 23.9% and the power was decreased by 4.12%. So COP was increased by 2.66%.
- Test results about the OCR of base case and improved case was measured with the equivalent. It shows that the oil separation efficiency is not difference between the two cases.
- The sound level and pulsation was measured between the two cases through the NVH test. Base case. , the sound level of improved case is measured with the equivalent as compared with the base case. Suction pulsation was measured with the equivalent about two cases, but discharge pulsation was measured in improvement case larger than base case. But the discharge pulsation of improved case is applicable because of the satisfaction with the standards by the car maker.

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