

Experimental Study on the Cooling Performance of a Hybrid Vehicle Air Conditioning Compressor

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Abstract

To investigate the specific cooling performance of a hybrid compressor, this thesis carries out a cooling performance test study on it. The object of the study is a hybrid compressor under development, and several different structural solutions are proposed, and the better hybrid compressor structural solution is selected through the performance test in the automotive air conditioning compressor cooling performance test bench. The analysis of the performance test data shows that the hybrid compressor with an internal check valve diameter of 0.45 mm, a flow rate of 10 L, and a main shaft diameter of 14.99 mm as the structural scheme has better cooling performance. In addition, the hybrid compressor is compared with the electric compressor and the pulley-driven compressor under several same working conditions to evaluate the specific cooling performance of the hybrid compressor. The results of the performance comparison show that the energy efficiency ratio of the hybrid compressor is high at low speeds with direct motor drive. In hybrid mode, its best performance occurs around 3000-5000rpm. And when the speed exceeds 6000rpm, a decrease in the energy efficiency ratio occurs. Especially at the critical speed of 3000rpm when the hybrid compressor is converted from the direct motor drive mode to the hybrid mode, there will be a greater compressor power consumption compared to the pulley-driven compressor, but overall, the difference in the energy consumption ratio is within the acceptable range.

Keywords

Hybrid Compressor; Cooling Performance Tests; Cooling Capacity; Compressor Power Consumption; Coefficient of Performance; Scroll Compressor; Comparative Analysis.

1. Introduction

Cars are one of the most important means of transport today. At present, cars can be divided into fuel vehicles and new energy vehicles[1,2]. Regardless of the type of car, the air-conditioning system is an indispensable and important part of it.

Traditionally, the air conditioning system in most cars is a non-independent air conditioning system, equipped with a mechanically driven compressor, which can only be driven directly by the engine's pulley, and cannot work independently by itself. Therefore, when a fuel vehicle is switched off, the air conditioning system cannot continue to work.

As far as the car air-conditioning system is concerned, the air-conditioning system of new energy electric vehicles, which is mainly driven by electric energy, is an independent air-conditioning system[3,4]. Unlike the pulley-driven compressor used in fuel vehicles, electric vehicles use an electric compressor as the driving device for the on-board air conditioning system. Since it is the electric motor that drives the electric compressor, and the energy source of the electric motor is the battery pack of the electric vehicle, the electric compressor can work

independently at any time[5]. However, the continuous operation of the electric compressor will consume the power of the battery pack, which will lead to a serious reduction in the range of the electric vehicle, thus restricting its performance and application range[5,6].

The hybrid vehicle air-conditioning compressor, which will subsequently be referred to as the hybrid compressor in this paper, is a new type of automotive air-conditioning compressor, which is mounted on a hybrid vehicle[7]. It is equipped with both pulleys and electric motors, which are the two driving components, and it uses a planetary gear mechanism as the transmission system. The structural characteristics of the planetary gear solves the problem of a single power source for the automotive air conditioning compressor. When the car is in park mode, the engine stops running, and the transmission mechanism relies on the motor to drive the hybrid compressor to complete the operation of the air conditioning system. When the car is in driving mode, the engine works normally, and according to the double-input and single-output characteristics of the planetary gear structure[8,9], the rotational speed of the motor and the rotational speed of the engine pulley determine the rotational speed of the hybrid compressor, thus ensuring the normal operation of the automotive air conditioning system.

This paper carries out experimental research on the cooling performance of the hybrid compressor, which helps to promote the scientific and technological progress of the automotive parts industry, specifically the automotive air-conditioning compressor development and manufacturing industry. The specific contribution is to clarify the temperature control boundaries that can be achieved by the automotive air conditioning system in the research and development stage of the hybrid automotive air conditioning system. And in the system design stage, it provides reference for the selection of other automotive air-conditioning system components to ensure that the whole vehicle air-conditioning system demonstrates better cooling performance.

2. Experimental

2.1. Experimental Subject

This thesis deals with a hybrid compressor that is under development and is designed to meet the technical requirements set out in the Chinese national standards GB/T 22068 and GB/T 21360. Table 1 provides the basic parameters of this hybrid compressor, mainly including: mechanical performance parameters, cooling parameters and electrical parameters.

Table 1. Basic Parameters for the Hybrid Compressor

No.	Technical parameters	Unit	Value
1	Compressor type	/	Scroll compressor
2	Refrigerant type	/	R134a/R1234yf
3	Speed of scroll disc	r/min	1250-5000
4	Motor speed	r/min	1800-5000
5	Compressor displacement	cc/r	27
6	Maximum cooling capacity	kW	5±0.2
7	Maximum cooling capacity when purely electric	kW	2±0.2
8	Rated power when purely electric	W	840
9	Rated voltage of compressor	V	24
10	Maximum compressor current	A	48

2.2. Experimental Purpose

The purpose of this experimental is to test the cooling performance of the hybrid compressor in several structural solutions, from which the better structural solution is selected. The cooling performance comparison with electric compressor and pulley-driven compressor is carried out

under several same working conditions to evaluate the cooling performance of the hybrid compressor.

There are three cooling performance parameters to describe the compressor: the first is the cooling capacity, the size of the cooling capacity directly reflects the cooling performance of the compressor; the second is the power consumption of the compressor, the size of the compressor power consumption under the same cooling capacity can also reflect the cooling performance of the compressor. Through these two cooling performance parameters, who can calculate the third and most important cooling performance parameters, that is, corresponding to the cooling capacity and compressor power consumption under the coefficient of performance.

In order to obtain the test data of the above cooling performance parameters, it is necessary to carry out the compressor cooling performance test on the test device, measure and record the test data including suction pressure, discharge pressure, discharge temperature, suction temperature, current, voltage and refrigerant mass flow rate, and carry out the calculation of the coefficient of cooling performance and carry out the analysis of the test data.

2.3. Experimental Equipment

Hybrid compressor cooling performance test research relies on the automotive air conditioning compressor performance test device[10], which is a test stand consisting of condenser, oil separator, liquid reservoir, sub cooler, quantity heater, oil cooler and regulating valve and other components. The device can not only test the performance of the compressor itself, but also test the applicability of compressor components, is an important equipment for testing and verifying the actual performance of automotive air conditioning compressors.

The test device is equipped with a computer installed on the test control software and test data acquisition software, which are written using LabVIEW software from NI. The test control software can be: compressor speed, suction pressure, exhaust pressure, supercooling and superheat and other parameters to set up, so as to be able to carry out different conditions of the test; test data acquisition software can be: exhaust temperature, suction temperature, current, voltage, power and valve temperature and other parameters to be displayed in real time, and can generate a data report and support the download. The schematic diagram of the automotive air conditioning compressor performance test device is shown below.

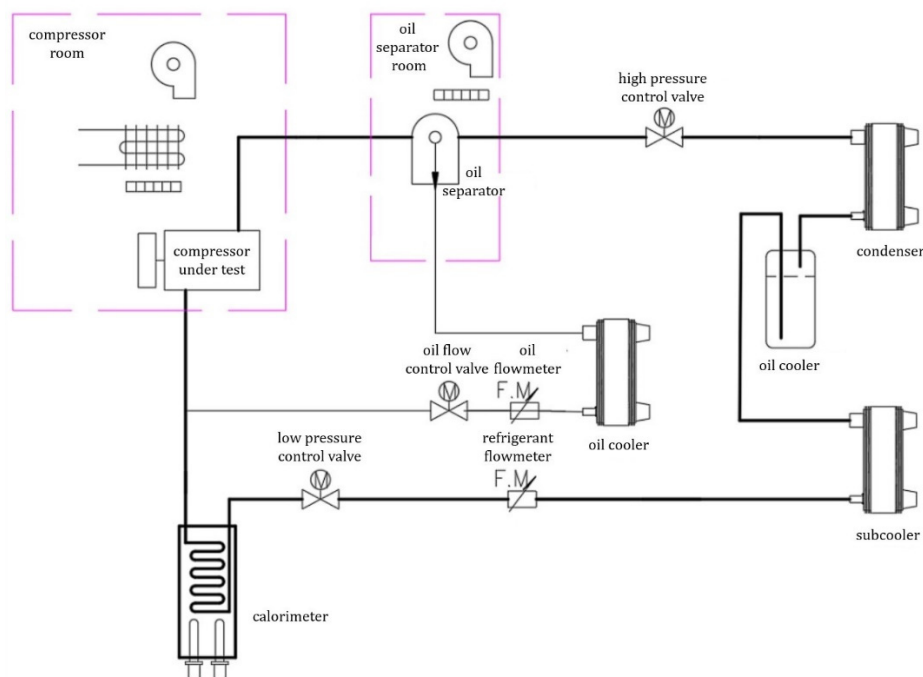


Figure 1. Automotive Air-conditioning Compressor Performance Test Device

2.4. Experimentation

Mainly as follows:

1. Do the standard running test. Test the cooling performance of the standard compressor against the test conditions in the national test standard, and verify whether the operation status and test error of the automotive air conditioning compressor performance test device are stable.
2. For the same hybrid compressor, under the same test conditions, apply several different structural solutions, the specific differences between the structural solutions are the main shaft diameter and check valve structure parameters. Carry out the cooling performance test under standard test conditions, obtain the performance test data of the hybrid compressor with different structural solutions, and calculate the cooling performance parameters. Select the better structural scheme architecture, as the structure of the compressor form.
3. Conduct cooling performance tests under several test conditions with electric compressors and pulley-driven compressors of the same structural form but with different drive modes, compare the cooling performance parameters and evaluate the cooling performance of the hybrid compressor.

3. Results and Analysis

The test data will be analyzed according to the following classification.

One is to classify the hybrid compressor according to different structural solutions and make a comparative analysis, in order to select the better structural solution architecture, and use the hybrid compressor using this structural solution as the structure of the subsequent research, the main difference between different structural solutions is: the length of the main shaft diameter, the size of the backpressure, the check valve structural parameters, and so on.

The other is to distinguish the test data according to the type of compressor, or the compressor drive mode, and make a comparative analysis, including hybrid compressors and electric compressors, hybrid compressors and pulley-driven compressors.

In this section, the above two classifications will be used to analyze the data from the compressor performance test data, using the control variable method, through a combination of quantitative and qualitative analysis, in order to better understand the performance of the hybrid compressor.

3.1. Influence of Different Structural Solutions on the Performance of Hybrid Compressors

All compressors mentioned in this thesis are scroll compressors. Several important structural parameters affecting cooling performance in scroll compressors are: main shaft diameter, back pressure, check valve structural parameters, etc.

According to the test procedure described in Section 2.4, the test conditions of the five structural scenarios mentioned in this section are the same: compressor speed 1300 r/min, suction pressure 0.4 MPa, discharge pressure 0.9 MPa.

The five structural options are: option 1 is measured in the case of the main shaft diameter of 14.97mm. Option 2, on the other hand, was obtained with a low back pressure when the main shaft diameter was increased to 14.99 mm. Option 3 was tested using a new internal check valve combination with a check valve diameter of 0.45 mm and a flow rate of 10 L, while the main diameter was 14.99 mm. Option 4 was based on Option 3, where the structure of the check valve and the length of the main diameter were altered to compare the differences between the two options, and in this case the check valve had a diameter of 0.45 mm, a flow rate of 5 L, and the main diameter was 14.99 mm. Option 5 is based on option 4, the structure of the check valve is changed again to reduce the flow rate, the diameter of the check valve is 0.45mm, the flow rate

is 3L, and the shaft diameter of the main is 14.98mm. The test sequence is divided according to the structural parameters of the five structural options are listed in Table 2.

Table 2. Basic Parameters for the Hybrid Compressor

Option	Main shaft diameter/mm	Check valve diameter/mm	Check valve flow rate/L
1	14.97	\	\
2	14.99	\	\
3	14.99	0.45	10
4	14.98	0.45	5
5	14.98	0.45	3

In the test data recording form, the more interesting cooling performance parameters are the cooling capacity, the power consumption of the hybrid compressor and the coefficient of performance. Using these three columns of data, the performance of hybrid compressors with different structural solutions is plotted in a comparative graph, which is shown in Figure 2.

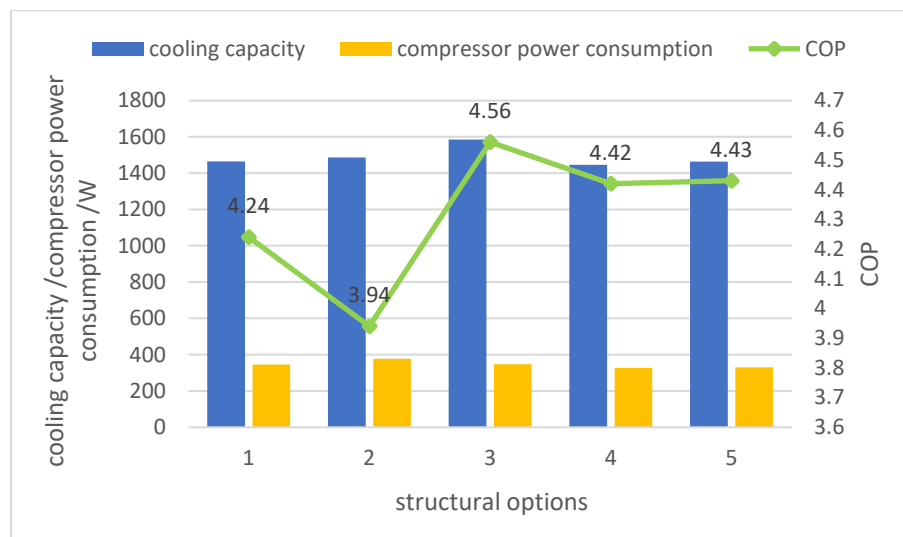


Figure 2. Performance Comparison Chart for Hybrid Compressors

Combining the changes in the structural parameters of the five structural options with the performance of these five structural options during the actual performance test, a clear performance comparison is produced in Figure 2. From the figure, it can be found that the second structural option has changed the main shaft diameter of the hybrid compressor compared to the first structural option, but it has led to a decrease of 0.3 in the COP of the hybrid compressor, which has not achieved the purpose of improving the performance of the hybrid compressor. On the contrary, the third structural option significantly increased the cooling capacity and the COP of the hybrid compressor, which is the most effective one among these structural options. The fourth structural option proves that as the check valve flow rate and the main shaft diameter decrease, the cooling capacity of the hybrid compressor decreases by 139 W and the COP decreases by 0.14 compared to the third structural option, and this structural option leads to a reduction in performance. The fifth structural option proves that the cooling capacity and the COP of the hybrid compressor recovered as the flow rate of the check valve was reduced, resulting in an increase in the performance of the hybrid compressor, but with 122W less cooling capacity and 0.13 smaller COP compared to the third structural option. Of these five structural options, the third structural option was chosen as the structural form for the subsequent study because the hybrid compressor in the This structural option shows the

best performance in the actual performance test, which meets the requirements of R&D design and usage.

3.2. Comparative Analysis of Hybrid and Electric Compressors

In this section, the cooling performance test data of hybrid compressors and electric compressors will be compared and analyzed. Under the condition that the test parameters such as compressor speed, suction pressure and discharge pressure are the same, the performance test is carried out on two compressors with different driving modes but the same structure type, and the changes in cooling performance indicators such as cooling capacity, compressor power consumption, and COP are compared between the hybrid compressor and the electric compressor. After the test conditions stabilized, the actual performance test data were recorded and are shown in Table 3.

Table 3. Test Data Record Sheet

Compressor Type and Speed	Suction Pressure /MPa	Exhaust Pressure /MPa	Cooling Capacity /W	Power Consumption /W	COP
electric 1300rpm	0.4	0.9	1099	259	4.24
electric 2000rpm	0.35	1.1	1361	451	3.02
hybrid 1000rpm	0.4	0.9	1199	245	4.89
hybrid 1300rpm	0.4	0.9	1468	377	3.94
hybrid 2000rpm	0.35	1.1	1939	645	3.01

According to the data in Table 3, it can be found that in the comparison test sequence of compressor speed of 1300r/min, suction pressure of 0.4MPa, discharge pressure of 0.9MPa, the hybrid compressor compared to the electric compressor, its cooling capacity increased by 369W, the compressor power consumption increased by 118W, the increase in cooling capacity is less than the compressor power consumption. While in the compressor speed of 2000r/min, suction pressure of 0.35MPa, discharge pressure of 1.1MPa in the comparative test sequence, hybrid compressor compared to the electric compressor, the cooling capacity increased by 578W, the power consumption increased by 194W, the increase in cooling capacity and the increase in compressor power consumption is more similar to the increase in the COP is only 0.1 of the float. Therefore, the COP only floats by 0.1. Two groups of compressor type and speed test sequence of the actual performance test data comparison chart, shown in Figure 3.

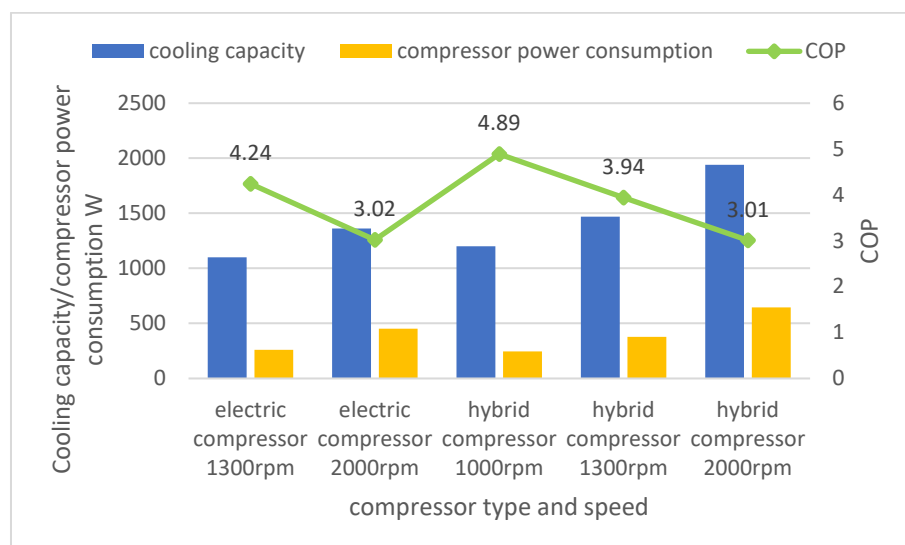


Figure 3. Actual Performance Test Comparison Chart

Comprehensive comparison of the data of the two compressors under the same test conditions, it can be concluded that when the hybrid compressor is driven only by the motor, the cooling efficiency is slightly lower than that of the electric compressor, but the difference is not very large, so the hybrid compressor can still meet the requirements of the use of electric drive. When the speed of the hybrid compressor is increased from 1000r/min to 1300r/min, the cooling capacity is increased by 269W, however, the COP value is decreased by 0.95. This shows that when the hybrid compressor is only driven by the electric motor, the hybrid compressor's performance is better at low speeds, which is able to effectively improve the cooling efficiency.

3.3. Comparative Analysis of Hybrid and Pulley-Driven Compressors

Under the same test conditions, the test sequences are divided according to the speed, and the cooling performance test experiments are carried out on the pulley-driven compressor and the hybrid compressor. In order to ensure the accuracy of the test results, one group of test conditions are the same test sequence as a reference, and the other groups of test sequences and its comparison.

Analyze the hybrid compressor and the actual performance of the pulley-driven compressor test data, found that the cooling capacity and compressor power consumption will increase with the increase in compressor speed, showing a clear positive correlation. However, this is not the case for the COP. In order to be able to clearly show the belt wheel drive compressor and hybrid compressor at different speeds in the COP changes, the two changes in the same graph for clear comparison, see Figure 4.

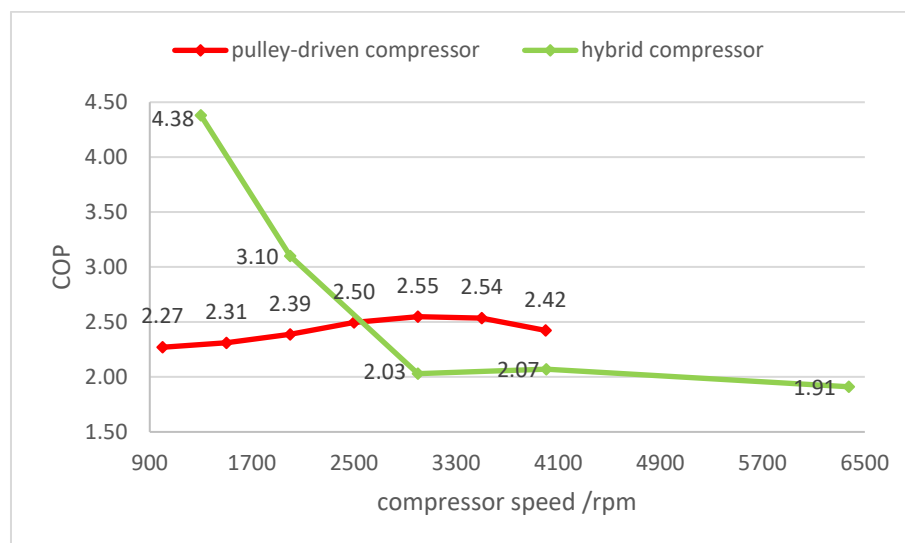


Figure 4. Comparison of COP at Different Compressor Speeds

The COP of a pulley-driven compressor increases gradually with speed at low speeds. However, after exceeding a certain speed, the performance of the compressor shows a decreasing trend. The minimum value of the COP is 2.27 and the maximum value is 2.55 during the increase in compressor speed from 1000 rpm to 4000 rpm, with the maximum value occurring in the test sequence at a speed of 3000 rpm.

For the hybrid compressor, the change rule of its cooling capacity and compressor power consumption is consistent with that of the pulley-driven compressor. As the scroll speed increases from 1300 rpm to 6375 rpm, the cooling capacity increases from 1480 W to 4659 W, and the power consumption increases from 338 W to 2440 W. At a scroll speed of 6375 rpm, the COP is the smallest at 1.91, and the COP is the largest at a scroll speed of 1300 rpm at 4.38. This means that the energy efficiency ratio of the hybrid compressor is higher when the hybrid

compressor is driven only by the electric motor at low speed. When the hybrid compressor is driven by a mixture of electric motor and pulley, its best performance occurs around 3000-5000 rpm. When the speed exceeds 6000 rpm, the energy efficiency ratio decreases, which indicates that the performance of the hybrid compressor in hybrid mode decreases as the speed increases.

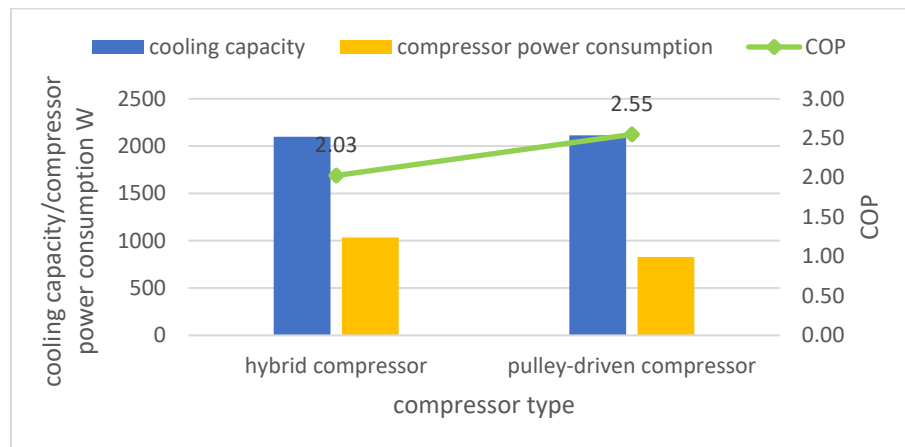


Figure 5. Comparative Analysis of Compressor Speed 3000rpm

Comparative analysis of the cooling performance parameters was carried out by selecting the test sequence test data with a rotational speed of 3000 rpm, a suction pressure of 0.3 MPa, a discharge pressure of 1.5 MPa, a degree of superheat of 10°C, and a degree of subcooling of 5°C, which are shown in Figure 5. It was found that the cooling performance ratio of the hybrid compressor was reduced. Specifically, the cooling capacity is reduced by 15 W, while the compressor power consumption is increased by 206 W, resulting in a reduction of the COP by 0.518. Considering that this speed is the critical speed for the hybrid compressor to start the hybrid mode, there will be a greater power consumption of the compressor compared to the pulley-driven compressor, but overall, the difference is not significant and is within the acceptable range of acceptability.

4. Conclusion

The structural option with internal check valve diameter of 0.45mm, flow rate of 10L and main shaft diameter of 14.99mm has the best cooling efficiency of up to 4.56 under the test conditions of compressor speed of 1300r/min, suction pressure of 0.4 MPa and discharge pressure of 0.9 MPa.

Comparative analysis of the hybrid compressor and electric compressor results show that the hybrid compressor in the low speed, that is, only the electric motor drive, the cooling performance is better, can effectively improve the cooling efficiency.

The results of the comparative analysis of the hybrid compressor and the pulley-driven compressor show that the energy efficiency ratio of the hybrid compressor is higher at low speeds, i.e., when it is driven only by the electric motor. When the hybrid compressor is in the mixed motor and pulley-driven state, its best performance occurs at a speed of about 3000-5000 rpm. And when the speed exceeds 6000 rpm, a decrease in the energy efficiency ratio occurs, which indicates that the performance of the hybrid compressor in hybrid mode decreases as the speed increases. In particular, at the critical speed of 3000 rpm when the hybrid compressor is converted from electric to hybrid mode, a greater compressor power consumption occurs compared to the pulley-driven compressor, but overall, the difference in the energy consumption ratio is not significant and is within acceptable limits.

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