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Yuanyang Zhao
State key laboratory of compressor technology, Hefei General Machinery Research Institute, Hefei 210031, P. R. China, China, People's Republic of, yyzhao2@gmail.com

Jun Xiao
State key laboratory of compressor technology, Hefei General Machinery Research Institute, Hefei 210031, P. R. China, China, People's Republic of

Liansheng Li
State key laboratory of compressor technology, Hefei General Machinery Research Institute, Hefei 210031, P. R. China, China, People's Republic of

Qichao Yang
State key laboratory of compressor technology, Hefei General Machinery Research Institute, Hefei 210031, P. R. China, China, People's Republic of

Guangbin Liu
State key laboratory of compressor technology, Hefei General Machinery Research Institute, Hefei 210031, P. R. China, China, People's Republic of

Authors
Yuanyang Zhao, Jun Xiao, Liansheng Li, Qichao Yang, Guangbin Liu, Le Wang, and Bin Tang

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Yuanyang ZHAO *, Jun XIAO, Liansheng LI, Qichao YANG, Guangbin LIU, Le WANG, Bin TANG

Hefei General Machinery Research Institute, State key laboratory for compressor technology, Hefei, P.R. China
Contact Information (Phone +86-551-65335667, E-mail yyzhao2@gmail.com)
* Corresponding Author

ABSTRACT

A method of compressor performance analysis under multiple working conditions is present based on the Time-weighted average (TWA). The main operation parameters can be obtained based the estimate of the working conditions and times of compressors. Then the comprehensive analysis method can be used to get the overall performance of compressor. The performance of a basic centrifugal compressor was simulation by CFD method in this paper. The overall performance of the centrifugal compressor is calculated under different working conditions. The TWA analysis method can be used as a tool to evaluate the overall performance of compressor. And it can also be used during the design phase to improve the performance of compressor fundamentally.

1. INTRODUCTION

Compressors are key machines in the processes of petroleum, chemical, refrigeration industries, and so on. The compressor performance has much effect on the performance and reliability of the whole system. Compressors operate at off-design working conditions usually, which mean the performance of them would be lower than the designed ones. The working conditions of compressor change when the components of crude oil change in the petroleum processes (WANG Tong, GU Chuangang and YANG Bo 2002).
For the reason of multiple working conditions, there are many researchers were studied the compressor performance at multiple working conditions.
WANG Tong, GU Chuangang and YANG Bo (2002) studied the optimum design method for a centrifugal compressor. The structure parameters and the decision of best working condition of simulated were analyzed. The range of operating conditions and efficiency of compressor were researched.
Cristian C., Jean L., Vincent L. and Eric W. (2010) researched the characters of scroll compressor under the off-design working conditions.
Aprea C., Mastrullo R. and Renno C. (2009) research the decision of optimum working conditions. The optimum working speed of compressor was researched.
JH Kim, JH Choi, A. Husain. (2010) analyzed the multi-objective optimization of an impeller. The characters of compressor are simulated using the efficiency and pressure ratio as the optimization objecttive.
The research hotpot is focused on the multi-objective optimization design and performance prediction of compressor (Cristian C., Jean L., Vincent L. and Eric W. 2010; Aprea C., Mastrullo R. and Renno C. 2009; JH Kim, JH Choi and A Husain. 2010). There is little research on the analysis of the combination performance of compressor based on the real running time.
The method of time-weighted average (TWA) is used in this paper. The combination performance of compressor is analyzed based this method during its run cycle in this paper.

2. TIME-WEIGHTED AVERAGE MODEL

For the compressors which working conditions are changing usually, the most important thing is how to evaluate their performance.
There are many parameters which can be used to evaluate the compressor performance, such as power, efficiency, noises and vibrate value. Using the TWA method, the compressor parameters mentioned above can be calculated during an operating period. The equation can be present as following.

$$A = \frac{\sum_{i=1}^{n}(T_i A_i)}{\sum_{i=1}^{n} T_i} \tag{1}$$

where A is the performance parameter of compressor; T is the running time.
All structure type compressors can be researched using the method of TWA. The efficiency is one of the most important parameters. Hence the efficiency is choosing as the sample to analyze in the following research.
When compressors operate at different working conditions during one period, the efficiencies of compressors are different for all working conditions. TWA can be used to calculate the overall efficiency of compressor. The details of calculate is shown as following.

$$\eta = \frac{\sum_{i=1}^{n}(T_i \eta_i)}{\sum_{i=1}^{n} T_i} \tag{2}$$

where T is the running time; i is the order of working condition; n is the total number of working condition.

At the working condition i, the compressor efficiency η_i is the function of pressure p, temperature t, mass flow rate m, speed N, and pressure ratio ε.

$$\eta_i = \eta(p, t, \varepsilon, m, N)_i \tag{3}$$

3. PERFORMANCE ANASYS OF CENTRIFUGAL COMPRESSOR AT MULTIPLE WORKING CONDITIONS

3.1 Performance prediction model

There are many kinds of method which can be used to predict the performance of compressor. With the development of computational fluid mechanics (CFD), the numerical modeling based on CFD is an important method to get the performance of centrifugal compressor (Raef S. S., Hussein A. A. and Fayez F.G. A 2009). One centrifugal compressor is researched using CFD method in this paper. The performance of it is simulated under different working conditions.
This compressor has a vaneless diffuser and a closed backward swept impeller. The main structure of compressor is shown in Figure 1.

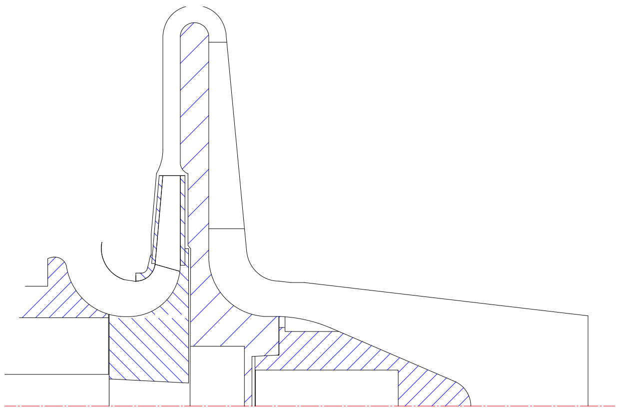

Figure1: Structure of compressor

The inlet diameter of impeller is 244.0 mm, the inlet angle is 27o. The outlet diameter of impeller is 450.0mm. The outlet diameter of impeller is 37.5o. The number of blade is 13. The vaneless diffuser is the type of parallel plate, and its outlet diameter is 718.0 mm. the inlet and outlet diameters of return channel is 708.0 and 346.0 mm respectively.
The mesh used in simulation model is shown in Figure 2.

Figure2: Mesh of simulation

The mesh is H type. The number of element is 617472. The standard k-ε model is used as the turbulence model.
The working fluid is air. The inlet pressure is 0.1 MPa. The inlet temperature is 17℃. The performance of compressor is simulated at speed 10100, 8400, 6700 and 4880 r/min respectively.

3.2 Compressor performance

The performance of compressor is simulated by CFD method under different working conditions. The flow field characteristics and performance curves are obtained in this paper.
Figure 3 shows the pressure contours of compressor at 50% height of blade when the rotation speed is 10100r/min and the pressure ratio is 1.35. From Figure 3 it can be seen that the pressure of air rise along the flow path of compressor.
From the simulation results, the relationship between mass flow rate and pressure ratio can be gotten. Figure 4 shows the curves of mass flow rate and pressure ratio.
Figure 5 shows the efficiency of compressor under different mass flow rates and rotation speeds. The relationships of mass flow rate, pressure ratio, and efficiency can be gotten from the results. Here, the efficiency is calculated from real power and ideal power of compressor. The real power is gotten from the CFD simulation results. When the rotation speed increases, the maximum pressure ratio of compressor is increasing. There is the maximum efficiency under each special speed.
The characters of centrifugal compressor mentioned before lead to their large differences of performances under different working conditions. Hence the TWA method is an important way to analyze the overall performance of compressors.

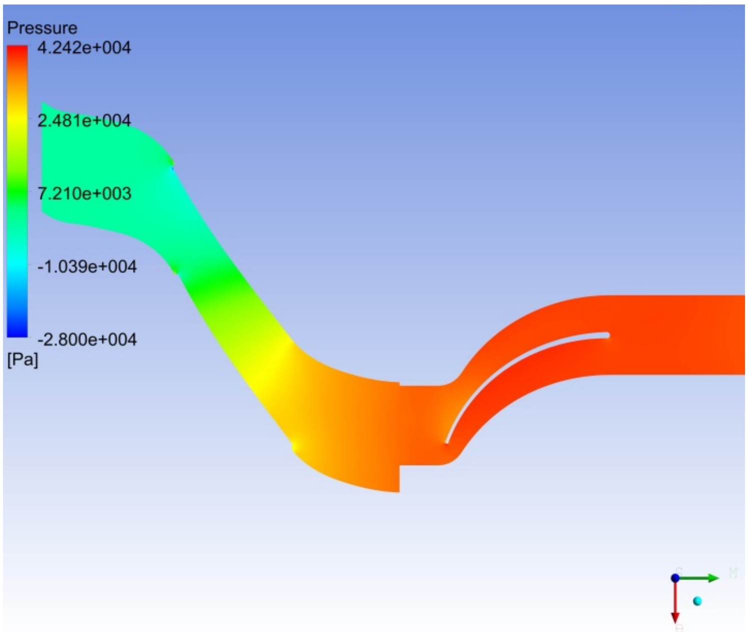

Figure3: Pressure contours of compressor

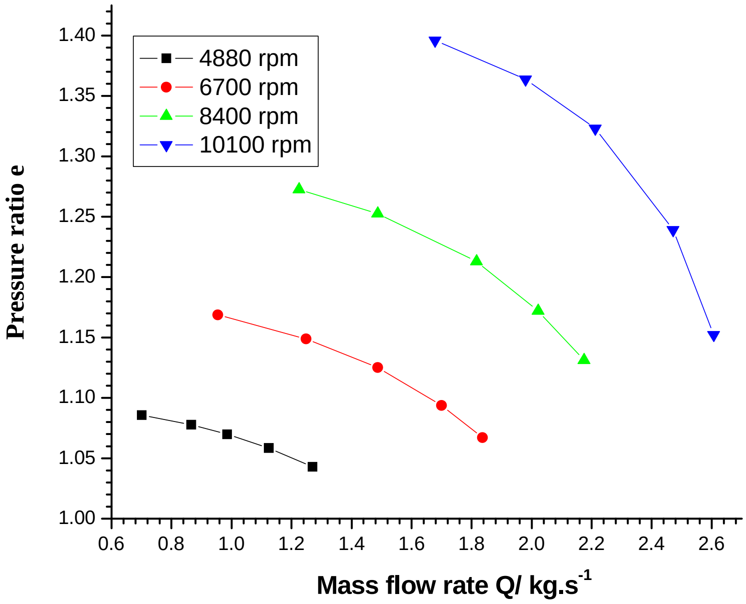

Figure4: Pressure-ratio curve at different speeds

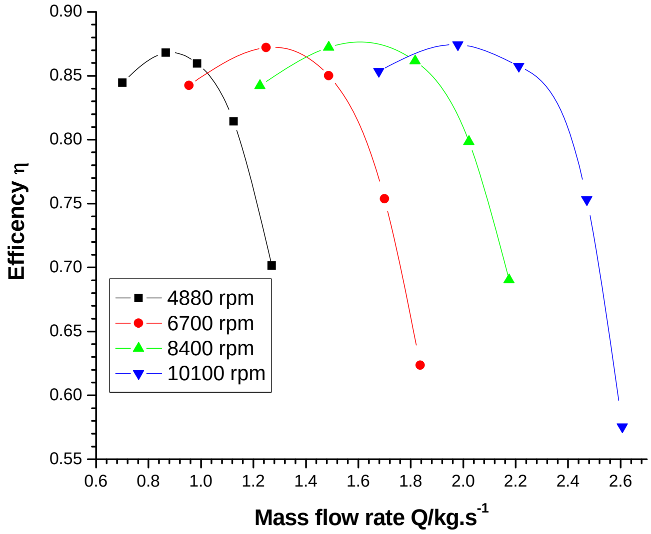

Figure5: Mass flow rate-efficiency curve at different speeds

3.3 Results analysis

Using the simulation results and TWA model, the overall performance of compressor during some period can be calculated.

To evaluate the overall performance of compressor under different working conditions, five working points is selected in this paper (for different speeds and pressure ratio). The speed, mass flow rate and discharge pressure are different for these five working points. We assume these five working points are the typical working condition of this centrifugal compressor. Actually, there are many centrifugal compressors working at wide working condition rage. For refrigeration compressor, the working condition is changed based on the refrigerating load frequently. For the compressor of chemical fertilizer industry, the working condition usually changed following the seasons.

The detail data is shown in Table 1.

Table1: Working conditions

Parameter	Condition i				
	1	2	3	4	5
Speed /rpm	4880	6700	8400	10100	10100
Flow rate /kg.s^{-1}	1.12	1.25	2.17	2.47	2.61
Pressure ratio	1.06	1.15	1.13	1.24	1.15
Efficiency	0.81	0.87	0.69	0.75	0.58

One working period of compressor is assumed as T. That means the length time of compressor is T. The compressor is operating at every working condition for different length of time. The detail data is shown in Table 2.

Table2: Compressor operate cases

Parameter	Condition i				
	1	2	3	4	5
Case 1	0.2T	0.2T	0.2T	0.2T	0.2T
Case 2	0.0T	0.10T	0.15T	0.25T	0.50T
Case 3	0.50T	0.25T	0.15T	0.10T	0.0T

Case 4	0.0T	0.25T	0.50T	0.25T	0.0T

Based on the equation (2), the overall efficiency of compressor can be simulated under four cases using TWA model. The results are shown in Figure 6. From the results it can be seen that the difference overall efficiency of compressor is large for different cases. The maximum overall efficiency is 0.801 for case 3. But the overall efficiency is only 0.668 for case 2.

From the results it can be seen that the overall efficiency based on TWA method can present the real situation of compressor.

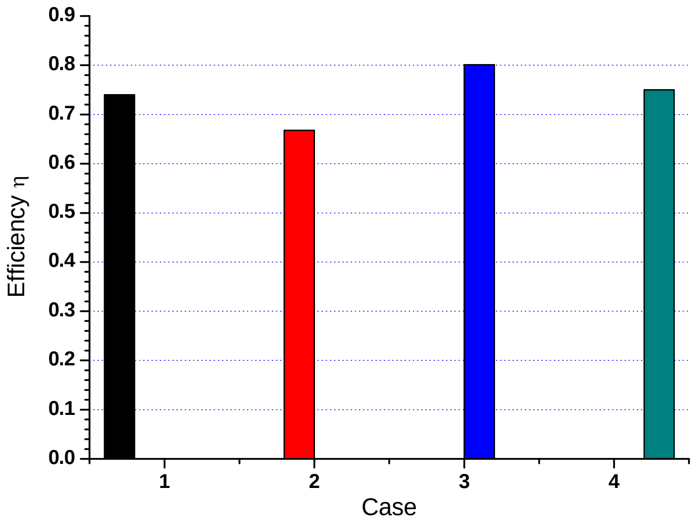

Figure6: Efficiency of compressor

4. CONCLUSIONS

It is difficult to evaluate the performance of compressor working under multiple conditions reasonably. To solve this problem, the time-weighted average (TWA) method is proposed to get the overall performance of compressor. A centrifugal compressor is researched in this paper. The results show that the working condition and length of working time have a large effect on the performance of compressor. The different value is 13.3% for four cases.

The method of multiple working conditions can present the real situation of compressor scientifically. This method can be used to evaluate the overall performance of compressor. And it also can be used to optimization design of compressor.

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