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Experimental Research on Surge and Stability Enhancement of Centrifugal Compressor

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ABSTRACT

Centrifugal compressors are wildly used in many process industries. The stability is one of the most important characters of centrifugal compressor. When the compressor operates in the condition of small volume flow rate, the working conditions of rotating stall and surge will occur, which leads to the unstable condition for centrifugal compressor.
The signals of compressor are tested and analyzed when surge condition occurs in this paper. In addition, a new method to improve the compressor stability is proposed. It is called the active control casing treatment (ACCT) system. The flow in the compressor impeller is changed by the ACCT system and the stability of compressor is improved. The experimental researches have been done in this paper. The test results of ACCT system are also discussed in this paper.

1. INTRODUCTION

Centrifugal compressors are widely used in many industry fields, such as petrochemical, coal chemical, and refrigeration industries. Surge is one of the most important characters of centrifugal compressors. When the centrifugal compressors operate at the margin of the surge line, the compressors will be unstable. In the real industry systems, the anti-surge control systems are always used to make sure that compressors operate at the stable working conditions. There are some kinds of methods to enlarge the stable working condition range of the centrifugal compressors, such as inlet guide vane (M Coppinger& E Swain, 2000). In addition, some casing treatment methods have been researched. Fisher (1988) first researched a recirculation casing treatment in a turbocharger compressor. The surge margin of compressor was extended without much decrease of efficiency. L. Ding (2013) investigated the holed casing treatment (self-recirculation) in an industrial centrifugal compressor. The surge margin of the compressor is increased by about 10%Q_{design} with negligible decrease in efficiency.
This paper present a stability enhancement method based on casing treatment, which is called Active Control Casing Treatment (ACCT). All parts of this system are introduced in details in this paper. A test system is set up to verify the function and performance of the ACCT system. Moreover, the compressor performance is tested when using the ACCT system. At the same time, the character signals of surge are tested in this paper.

2. TEST SYSTEM

Figure 1 shows the schematic diagram of test system. The driving system includes motor, frequency converter, torque meter, gearbox, and bearing box and oil station. At the inlet and outlet pipes, there are temperature, pressure and vibration sensors. During the test process, the rotating speed of compressor is controlled by the frequency converter. The ratio of compressor speed and motor speed is 10. The real-time speed and power is tested by torque meter. The discharge pressure is controlled by the adjusting valve in the outlet pipes. The flow rate of compressor is tested by the flowmeter. The transient pressure and vibration of compressor are recorded by the data acquisition and control system.

Figure 2 shows the main schematics of ACCT system. In principle, the unsteady flow in impeller leads to the rotating stall and surge of centrifugal compressor. The unsteady flow is usually located at the throat of the impeller. For the surge working condition, the flow separation occurs at the throat because the decrease of the mass flow rate. In the moment of surge, some high-speed gas is injected into the impeller by ACCT system to change and depress the unsteady flow. The ACCT subsystem includes the control valve, small compressor and test sensors. The transient pressure, temperature and volume flow rate at the ACCT subsystem are also recorded by the data acquisition and control system.

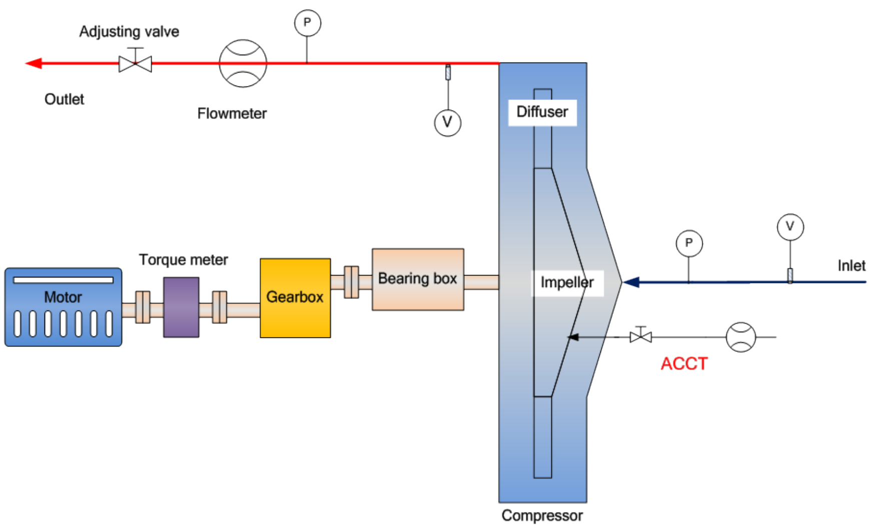

Figure 1: Schematic diagram of test system

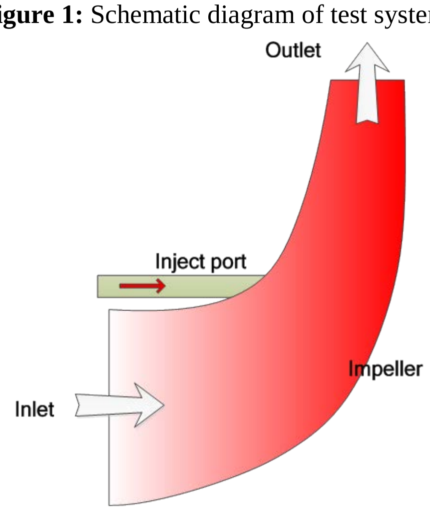

Figure 2: Schematics of ACCT

Figure 3 shows the photograph of the test system. In this picture, all the details of the test system can be seen, such as gas inject pipe (red pipes), compressor and driven system, and many sensors installed in the test rig to monitor the working conditions of the whole system.

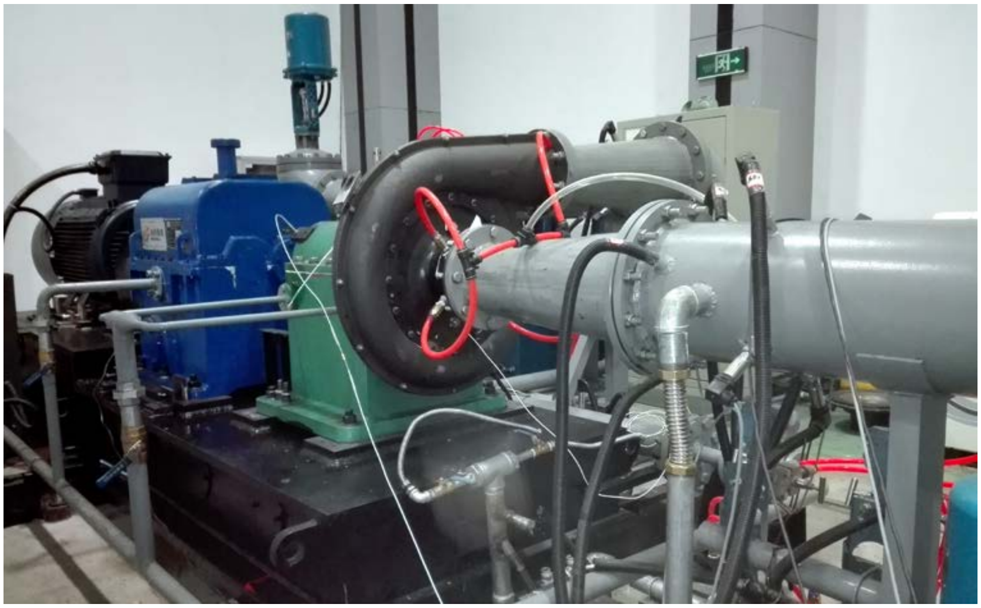

Figure 3: Photograph of the test system

3. SURGE TEST

To capture the surge working condition accurately, the surge of the compressor was test firstly. When the compressor is operating at a speed, the adjusted valve in the discharge pipe is closed by degrees. The pressures of inlet and outlet pipe and the vibration of inlet pipe are test during this process.

Figure 4-6 shows the fast Fourier transform (FFT) results of vibration signals of inlet pipe. The signals were gotten in the normal and surge working conditions. The results also compared in the figures.

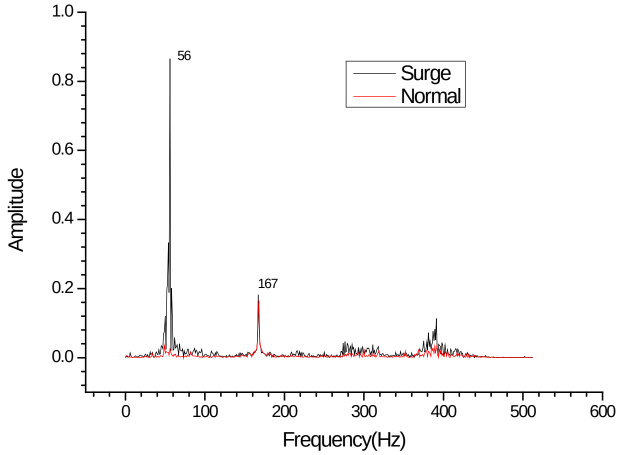

Figure 4: Vibration test of inlet pipe at 10000rpm (166.7Hz)

From the figures it can be seen that the maximum amplitude is at the working frequency of the centrifugal compressor when the compressor operates in the normal working conditions, such as 166.7Hz (10000rpm), 200Hz (12000rpm), and 233.3Hz (14000 rpm). When the compressor operates in the surge working conditions, the amplitudes at working frequency are almost same as that in the normal working conditions. However, the maximum amplitude in the surge working conditions is at the lower frequency and it is about four times of that at working frequency. For different working speed, the maximum amplitude is at 56 Hz. This may relates to the character of the pipe system.

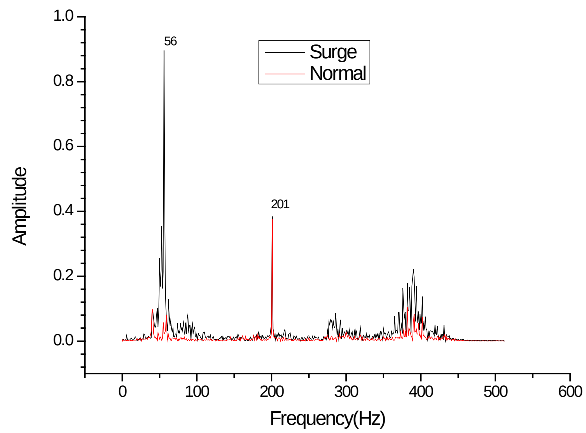

Figure 5: Vibration test of inlet pipe at 12000rpm (200Hz)

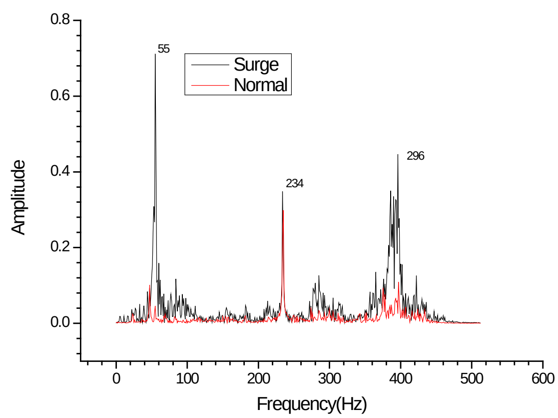

Figure 6: Vibration test of inlet pipe at 14000rpm (233.3Hz)

Figure 7-8 show the suction and discharge pressure and the FFT analysis when the compressor operates in the surge working conditions. It can be seen that when the compressor is operating at the surge condition, the pulse of pressure is increasing. Moreover, the pulse of the discharge pressure is bigger than that of suction pressure. The suction pressure is even smaller than the atmospheric pressure at some moments. From the FFT analysis, it can be seen that the frequency of the pressure pulse is 6Hz, which is about 0.03 of the rotating speed frequency.

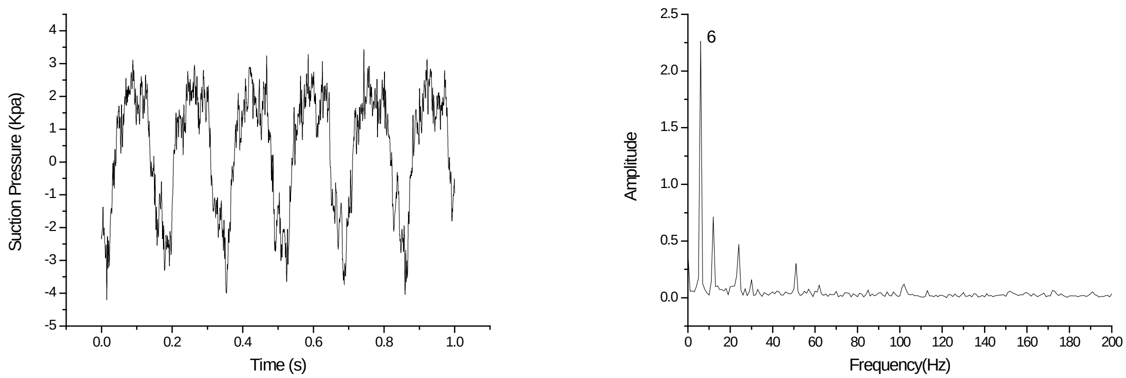

Figure 7: Suction pressure of the compressor in surge condition

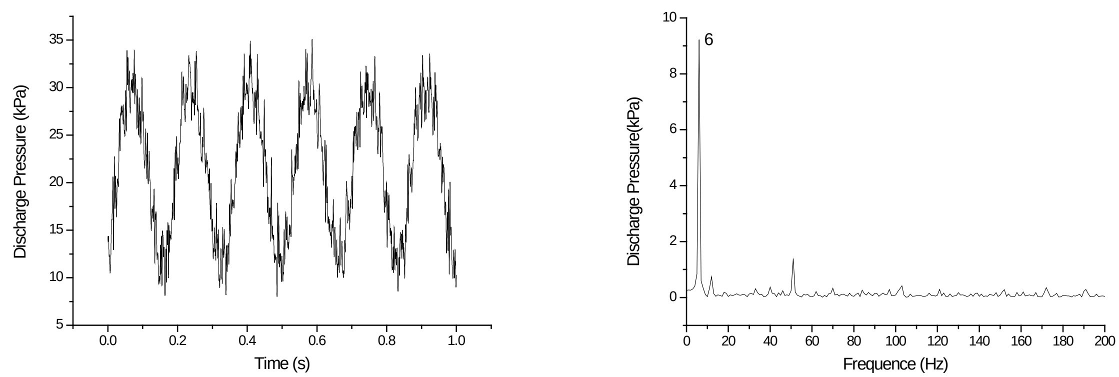

Figure 8: Discharge pressure of the compressor in surge condition

4. STABILITY ENHANCEMENT

Figure 9 shows the performance test results of the centrifugal compressor. The centrifugal compressor was tested under three rotating speeds. The flow rate of the injecting gas by ACCT system is 2.5 m^3/min. During the test process, the rotating speed is changed at one fixed value (about 10000, 12000, 13000 rpm) using the frequency converter. Then the control valve is closed gradually by the data acquisition and control system. The relationship between the discharge pressure and volume flow rate can be gotten. When the ACCT system operates, the test process is repeated. The difference of these two curves is the effect of ACCT on the performance of test centrifugal compressor.

The compressor performance is almost not being changed by using the ACCT system in the normal working conditions. That means when the flow rate of compressor is bigger than the smallest flow rate, the differences of performance of compressor are very little for ACCT condition and traditional condition. The effect of ACCT on the compressor in the normal working condition can be ignoring.

However, the smallest flow rate at the surge condition obviously decreases when the ACCT system is used. The black solid line is the test surge line when the compressor is the original (traditional) structure. The red dot line is the surge line when ACCT system is used. That means the surge line of the test centrifugal compressor is moved from the right of the compressor performance map to the left. The stability of the compressor under the small flow rate is enhanced.

The test results show the improvement of surge by ACCT is increasing when the compressor speed decrease. When the flow rate of injecting gas is fixed, the decrease of compressor speed means the proportion of injecting gas on the compressed gas by the centrifugal compressor is increasing. That is the main reason for the difference of affection of ACCT on the different compressor speeds.

When the compressor is operating around the condition of surge, the flow in the impeller is unstable. There are many low speed eddies at the throat of compressor impeller. The phenomena causes the unstable operate of compressor. When the ACCT used, the high-speed gas is injected into the throat of impeller, the energy is added to the low speed eddies. The location and scale of eddies in impeller are changed by the ACCT system. The flow in compressor is improved. Hence, the operational stability of compressor is improved too. The surge of centrifugal compressor is moved from right to left when using the ACCT system.

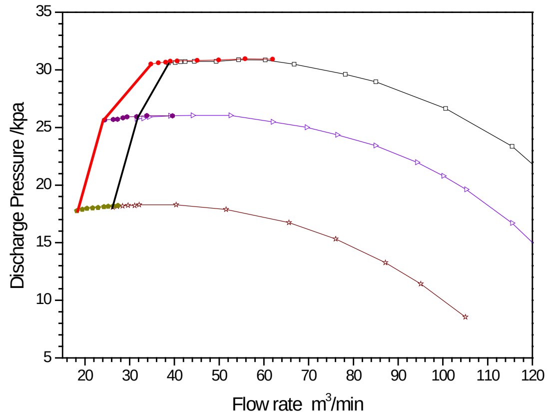

Figure 9: Test results of compressor

5. CONCLUSIONS

The surge of the centrifugal compressor is researched by experiment. The suction and discharge pressures are tested when the compressor operates in the surge working conditions. The signals of pressure are analyzed by FFT method. The pulse frequency of the pressures is very small (6Hz), and it is about 0.03 of the rotating speed frequency. At the same time, the vibration of the inlet pipes is also researched as the character of the surge of compressor. The vibration test results show that it can be as a signal to estimate the surge working condition. When the surge occurs, the vibration amplitude at the low frequency is bigger, and it is about four times of that at the working frequency. However, the maximum amplitude is not change by the rotating speeds. The effect of the ACCT system is tested on the experimental rig. The results show that the surge line can be moved from right side to the left side in the compressor performance map. That means the ACCT system can enhance the range of stable working conditions. In addition, the ACCT is a potential method to use as the anti-surge technology.

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