Trends in high performance compressors for petrochemical and natural gas industry in China

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Abstract. Compressors are the key equipment in the petrochemical and natural gas industry system. The performance and reliability of them are very important for the process system. The application status of petrochemical & natural gas compressors in China is presented in this paper. The present status of design and operating technologies of compressors in China are mentioned in this paper. The turbo, reciprocating and twin screw compressors are discussed. The market demands for different structure compressors in process gas industries are analysed. This paper also introduces the research and developments for high performance compressors in China. The recent research results on efficiency improvement methods, stability improvement, online monitor and fault diagnosis will also be presented in details.

1. INTRODUCTION
Compressors are the key equipment of process systems in many industries. They are called the heart of process industry and have been used in many fields such as the petrochemical, metallurgy, energy, aerospace, refrigeration and so on. The main role of compressor is to transfer mechanical energy to the pressure or kinetic energy of gas.

The performance and reliability are very important for the compressors using in petrochemical and natural gas industry. For the compressors using in petrochemical and natural gas industry, the capacity and power is usually very large. Hence, the operate power and efficiency is very important for consumer. On the other hand, when the process system is operating, the compressors cannot shut down during several months, therefore the reliability of main parts of compressor is very important. The main parts are impeller of centrifugal compressor, crankshaft of piston compressor, rotors of screw compressor, and so on.

In the past decades, the compressor technologies in China are rapidly developed in structure design, large scale production, and the performances improvement with the technical progresses of the material, measuring, simulation, fault diagnosis control, and so on. Now, China is one of the largest counties for the compressor production and application. Figure 1 shows the sales of process gas compressor in China during the past years.

This paper summarizes the application trends and the technology researches for process gas compressor (Turbo compressor, screw compressor and reciprocating compressor), especially for compressor in the petrochemical and natural gas industry.
2. TURBO COMPRESSOR

Turbo compressors are used as the core unit in many process gas systems. As the size of process system increases, the capacity and power of turbo compressor is increasing. The compressors for $1 \times 10^5$ Nm$^3$/h air separation system are produced by Chinese companies in 2014. The capacity of the main compressor in this system is $5 \times 10^5$ Nm$^3$/h. For this kind of compressor unit, the technologies of aerodynamic design, structure design, rotor dynamic analysis, control system and online monitoring system are the key points for the perfect products.

2.1. Basic technology

Flow analysis

The most basic theory of turbo compressor is the internal flow theory. The unsteady flow in compressors results in some phenomenon, such as low efficiency, choke and surge, and so on. To research the flow mechanism of compressor, the simulation and experimental methods can be used. Nowadays, the CFD software is widely used during the design of turbo compressor to verify the design from model stage. Also, the CFD method can be used to predict the compressor performance under off-design and ultimate conditions.

At the same time, the PIV test method was also be used widely in China to research the internal flow. The flow in impeller and diffuser was tested and researched by PIV instrument.

Rotor dynamic analysis

As the scale increase of compressor unit and the rise of parameters, more and more turbo compressors in China are designed as the multi-shaft type. That means the speeds of every stage of compressor are different, every shaft has their critical speeds. The operation of compressor unit should keep away from all these critical speeds. Many Chinese researchers have investigated the rotor dynamic of multi-shaft type compressor carefully. Some new phenomenon of these systems was found.

2.2. Surge suppression technology

When the turbo compressors are operating at the low mass flow rate, the phenomenon of surge and/or rotating stall would occur. And this usually results in the serious accident when turbo compressor is operating at these working conditions long time.
Hence, the surge suppression of turbo compressor is very important. The main mechanism of surge suppression is to maintain the steady flow in compressor. The main flow separation in compressor can be restrained using the surge suppression methods.

There are many kinds of surge suppression methods. The traditional methods are exhaust bypass, inlet guide vane (IGV) method. The casing treatment and flexible blades are researched as the surge suppression methods in recent years in China.

For flexible blade method [2], the flexible material part is fixed on the local of blade. The location of flexible material part is at the flow separation position in impeller. When the compressor is operating, the shape of flexible material part is changed by the gas flow. This kind of shape change can be called self-excited vibration. This vibration of the flexible material part can change the flow pattern in impeller. The flow separation can be restrained by this vibration. Hence, this method can be used as the anti-surge technology.

The casing treatment can also be used as the anti-surge technology. The caves on diffuser and shroud can improve the unsteady flow in compressor. The researches at this direction have been done in recent years in China.

Another casing treatment was proposed based on the active control method [3], which was called Active Control Casing Treatment (ACCT). Figure 2 shows the schematic diagram of ACCT. There are bleeding ports on the shroud near the blade tip. The injecting port is on the inlet pipe of compressor. There is the control device in the middle of the flow pass between injecting and bleeding ports. The control device can be control valve or small compressor. The flow parameters of the flow pass can be controlled by the control device.

![Figure 2. Schematic diagram of ACCT](image)

ACCT can change the flow pattern of impeller. Figure 3 shows the pressure distribution of impeller. Figure 3a shows the gas pressure in impeller when the ACCT is not used. Figure 3b shows the pressure when the ACCT is used. The area of low total pressure near the beginning end of split blade is decrease when using ACCT structure. The vortex in impeller is changed by the ACCT system. That means the flow loss is increasing and the flow is improved. The flow separation is restrained by the ACCT system.

Figure 4 shows the result of surge suppression by ACCT. From the results it can be seen that the pressure ratio increases as the increase of bleeding mass flow rate when the compressor operate at low mass flow rate condition. The ability of stability enhancement is increasing when the bleeding mass flow rate is increasing. When the bleeding mass flow rate is 0.64 kg/s, the ability of stability enhancement is 35%.
2.3. Reliability research

For the turbo compressor used in the petrochemical and natural gas industry, the main parts of compressor are affected by pressure, temperature, and chemical gas [4]. The reliability of compressor may be decreasing under these working conditions.

Figure 5 shows the fault mode of centrifugal compressor in China [5]. Almost 61% failure is owe to the problem of blade and seal.

Figure 6 shows an example of the centrifugal compressor failure. The failed impeller of recycle hydrogen centrifugal compressor is the closed type used for hydrorefining. The failure can be mainly attributed to sulfide stress cracking [4]. This is a typical chemical action which leads to the compressor failure.

To obtain the effect of pressure, temperature, and different chemical gases on the reliability of compressor impeller, the failure of impeller for different material ((such as AISI630/17-4PH and FV520B/14-5PH) was investigated in China.

The other way to maintain the reliability of turbo compressor is the technology of online monitoring and fault diagnosis. Nowadays, the online monitoring and fault diagnosis system is built in most of the turbo compressor used in petrochemical and natural gas industry. And many these kinds of system have the function of remote monitoring through internet. Therefore, the manufacture and customer can both get the situation of compressor unit in time. Some safety measure and action can be used before the occurrence of serious accident.
3. RECIPROCATING COMPRESSOR

The reciprocating compressor is widely used in the petrochemical and natural gas industry. The higher gas pressure can be gotten through this type compressor. The biggest reciprocating compressor 4M150 was manufactured and used in the 1200 million tons/y oil refinery plant in China.

The high operating efficiency and reliability are the main development direction on reciprocating compressor. There are many reciprocating compressor is operating at the off-design working conditions. The real operating capacity of gas process system is usually less than the design capacity of compressor. Hence, the bypass system is usually used. The efficiency of whole system is very low. The capacity adjustment technology is very useful for this situation.

There are many failures of reciprocating compressor every year in China. Figure 7 shows the fault mode of reciprocating compressor in China [5]. Because there are many easily damaged parts for reciprocating compressor, the failure reasons are different.
3.1. Capacity adjustment technology
The method of Partial Stroke Press-off Inlet Valve (PSPIV) is the most energy conservation method to adjust compressor capacity [6]. The compressor working process is changed when the PSPIV system is used. In Figure 8, the area of the closed curve ABCDA expresses the compression power of reciprocating compressor with full load, and the area of the closed curve ABCEFA expresses that with part load. It shows that about half of power has been saved when the compressor operates with part capacity, which is described by area of the closed curve CDFEC. Figure 9 shows the schematic diagram of PSPIV system. The device of PSPIV was developed and applied in the petrochemical plant in China. The energy saving effect is very huge when this device was used. Figure 10 shows that the real power is decreasing with the real capacity approximate linearly.

![Figure 9. Schematic diagram of PSPIV](image)

![Figure 10. Compressor performance](image)

3.2. Fault diagnosis technology
Based on the technologies of sensor, data acquisition, signal analysis, expert diagnosis, and internet, the advanced intelligence fault diagnosis system was developed and used in the process industry in China. There is a relationship between compressor fault and vibration signal. Hence, the vibration signal is the key parameter of diagnosis system. According to the parameters of vibration, the possible fault position and model of compressor can be predicted. The enlargement of fault can be prevented by the instant repair or working condition adjustment.

Using this system on the reciprocating compressor unit, the thermodynamic and dynamic failures can be gotten before the serious accidents occur. The typical faults are the leakage of valve caused by the break of valve plate, the break of piston rod caused by the wear of piston ring, the crosshead and crank shaft fault by the wear of bearing.

4. SCREW COMPRESSOR
As a type of displacement compressor with high reliability, screw compressors are widely used in the process gas system, such as coal chemical, coal chemical, and natural gas industries. And many screw compressors were used to recovery the coalbed gas, flare gas, and oil associated gas in China. The technical level of screw compressor for process gas was improved greatly. The profile theory, structure design, rotor manufacture, and gas seal are all researched in China. The biggest screw compressor was manufactured in China. The main parameters are as following:

- Rotor diameter: φ 816 mm
- Capacity: 650m³/min
- Power: 4500kW
- Gas: CO₂

The sales of process gas screw compressor increased very fast during the past years (shown in Figure 11) [1].
Many experimental researches have been done on process gas screw compressor. Figure 12 shows a test system. The seal of shaft is dry gas seal, which can increase the reliability and service life of compressor. And the water injection on the performance of screw compressor was tested on this test rig.

![Figure 12. Test system of process gas screw compressor](image)

Figure 11. Sales of screw compressor

Figure 12. Test system of process gas screw compressor

Figure 13 shows some test results of screw compressor with water injection. When the amount of injected water increases from 0.12 t/h to 3 t/h, the discharge temperature decreases rapidly. The discharge temperature is determined by the amount of water injection. When the speed is 3000 r/min, the discharge temperature of compressor is 79°C when the amount of injected water is 0.12 t/h. While the amount of injected water is rising to 6 t/h, the discharge temperature is decreasing to 24.3°C and approaches to the suction temperature. With the increasing of injected water, the capacity of compressor is rising quickly at the beginning. When the amount of injected water is increase to a certain value (about 1 t/h), the capacity of compressor tends to be stable.

![Figure 13. Effect of water injection on compressor performance](image)

5. CONCLUSIONS
The application status of petrochemical & natural gas compressors in China is introduced. The turbo, reciprocating and twin screw compressors are discussed. This paper introduces some research and developments for high performance compressors in China. The recent research results on performance improvement, surge suppression, reliability improvement, online monitor and fault diagnosis is also presented in details.
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