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Research on the Motion Characteristics of Suction Valve Plate Based on Fluid Structure Coupling

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Abstract

The air valve is the core component of the cyclic operation of the compressor cylinder, and its structure and performance largely determine whether the reciprocating compressor can operate more efficiently and economically. On the basis of analyzing the basic structure and working principle of the air valve, this article mainly studies the motion characteristics of the suction valve plate. Based on fluid structure coupling mechanics and using ADINA software as a platform, numerical simulation analysis was conducted on the suction valve of a certain compressor model. Studying the stress of the valve plate and the variation of its upper and lower surface pressure with the opening and closing of the valve plate during the suction process of the compressor provides theoretical guidance for the rationality of the design of the air valve and related components, thereby improving the service life of the air valve and the working efficiency of the compressor.

Keywords: *reciprocating compressor; fluid structure coupling; tongue spring valve; motion characteristics*

1 Introduction

The air valve is the most critical component of a piston compressor, and its performance directly affects the energy efficiency of the compressor. A good design can reduce the flow resistance loss to as low as 3% to 7% of the compressor shaft power, and vice versa, it can reach as high as 15% to 20% of the shaft power[1]. The tongue spring valve is widely used in the design of air valves for small and medium-sized piston compressors due to its simple structure and small clearance volume. Wu Danqing[2] systematically introduced the basic mathematical model of tongue spring valve kinematics, studied key parameters such as flow coefficient and thrust coefficient of the valve plate that affect the efficiency of the gas valve, and conducted mathematical simulations of the motion law of the refrigeration compressor gas valve in reference[3]. These studies mostly focused on theoretical or fluid and structural research. This article is based on ADINA software for fluid structure coupling bidirectional simulation analysis, providing a reference basis for the further optimization design of the gas valve.

2 Structural Principle and Motion Law of Suction Valve

The suction valve is usually installed on a valve plate, and the typical structure mainly consists of two main components: the valve seat and the valve plate, as shown in Figure 1. The main function of the valve seat is to determine the opening and closing of the suction channel of the gas valve together with the valve plate, and it is the main pressure bearing component for the pressure difference inside and outside the cylinder of the reciprocating compressor; The valve disc is an opening and closing element, with one end fixed on the valve seat and the other end able to move up and down.

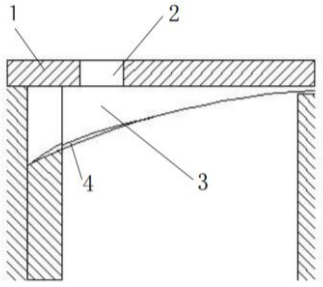

Figure 1 Inhalation valve group

1 valve seat 2 valve seat flow section 3 valve clearance flow section 4 valve disc

At present, most of the air valves used in reciprocating compressors are automatic valves. During the opening and closing process of the valve plate, the fluid pressure on both sides and the spring force on itself affect each other's dynamic changes, which are difficult to measure in experiments. Therefore, it is necessary to conduct transient simulation analysis of the compressor working process.

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3 Establishment and Solution of Finite Element Model

According to the operating principle of the compressor working mechanism, the reciprocating process of the working fluid flowing through the valve port into the cylinder from the gas chamber is regarded as the fluid region, and the valve components are regarded as the structural region. Fluid modeling and structural modeling are carried out in the ADINA-AUI module, and then relevant parameters and boundary conditions are set in the ADINA-CFD module and ADINA-Structures module respectively. Finally, the functions of ADINA-Structures and ADINA-CFD are integrated in the ADINA-FSI module to achieve coupling solution analysis between the fluid model and the structural model[4].As shown in Figure 2 and 3.

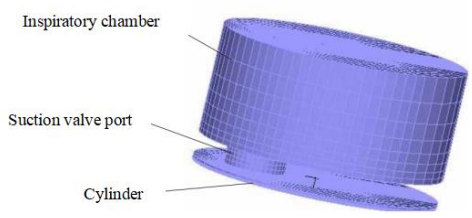


Figure 2 Fluid Model

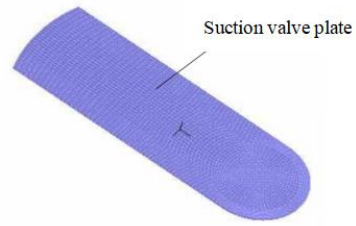


Figure 3 Structural Model

4 Pressure Characteristics of Valve Disc

4.1 Surface pressure of suction valve plate

The piston of a reciprocating compressor moves from the top dead center of the cylinder to the bottom dead center, completing the process of refrigerant gas expansion and suction. The suction valve undergoes a "close open close" cycle to complete a work cycle mission. The piston of a reciprocating compressor moves from the bottom dead center of the cylinder to the top dead center to complete the process of refrigerant gas compression and exhaust, and the exhaust valve undergoes the same opening and closing process. During the opening and closing process of the valve plate, the fluid pressure on both sides and the spring force on itself affect each other's dynamic changes, which are difficult to measure in experiments. Therefore, it is necessary to conduct transient simulation analysis on the working process of the compressor[5].

4.1.1 Analysis of surface pressure of suction valve plate

(1)Lift of suction valve plate.As shown in Figures 4 and 5, the lift curve and corresponding cylinder pressure curve of the suction valve plate with a speed of 1450r/min and a thickness of 0.635mm are presented.

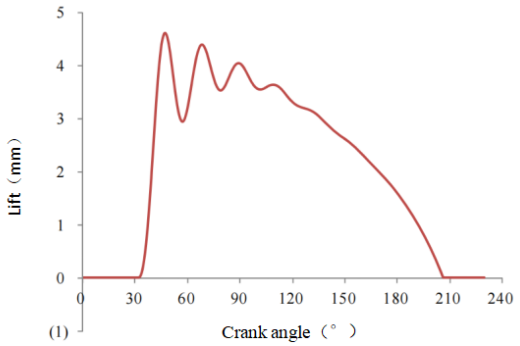


Figure 4 Valve lift curve

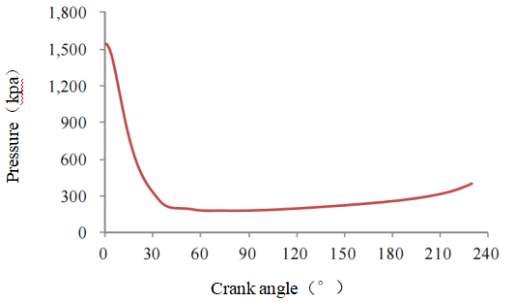
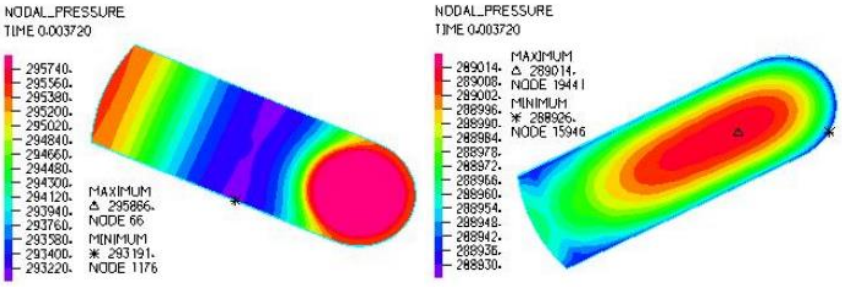


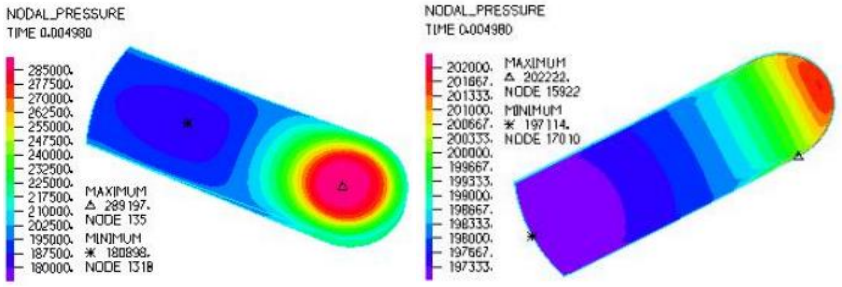
Figure 5 Cylinder pressure curve

The displacement (lift) of the valve plate in a reciprocating compressor is generated by the combined action of the pressure difference on both sides of the valve plate and its own spring force. The dynamic gas force generated by the pressure difference on both sides of the valve plate changes over time. The pushing effect of the dynamic gas on the valve plate when passing through the valve gap will cause rapid changes in the pressure and displacement it experiences. During the suction process of the compressor, as the lift of the suction valve increases, the deformation of the valve plate increases and the spring force increases. At the same time, the flow section of the valve gap increases, the decrease in cylinder pressure slows down, and the pressure difference on both sides of the valve plate decreases. When it reaches a certain degree, the valve plate will inevitably experience rebound; When the rebound lift of the valve plate decreases, the deformation decreases, the spring force decreases, and the valve clearance flow section decreases, the cylinder pressure drop increases, the pressure difference on both sides of the valve plate increases, and then the valve plate rises again. Therefore, when the suction valve plate reaches the maximum lift position, there will be a phenomenon of reduced amplitude fluctuation, and then the cylinder pressure changes relatively steadily, and the valve plate also lands smoothly.

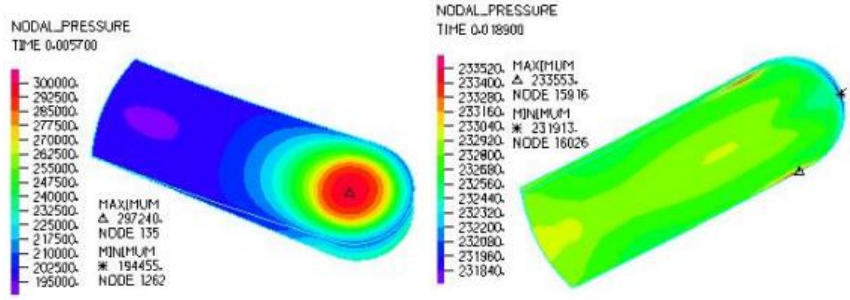
(2) Surface pressure characteristics of valve discs.The movement of the valve plate is mainly controlled by the pressure difference generated on both sides of the valve plate and its own spring force. When the combined force of dynamic gas forces on the upper and lower sides of the suction valve plate is upward, the valve plate is obstructed and in a relatively static state; When the combined force of dynamic gas forces on both sides of the valve plate is downward and greater than the valve plate's own elasticity, the valve plate moves downward. Conversely, when the combined force is downward and less than the valve plate's own elasticity, the valve plate rebounds upward. It is evident that the pressure difference on both sides of the valve plate plays an important role in the entire working process, so it is necessary to analyze the pressure distribution on both sides of the valve plate. As shown in Figure 6, the pressure cloud map of the upper and lower surfaces of the suction valve at the moment of just opening, half opening, full opening, half closing, and about to close (corresponding crank angles are shown in Table 1) is shown. The left column shows the pressure cloud map of the upper surface of the valve plate, and the right column shows the pressure cloud map of the lower surface.



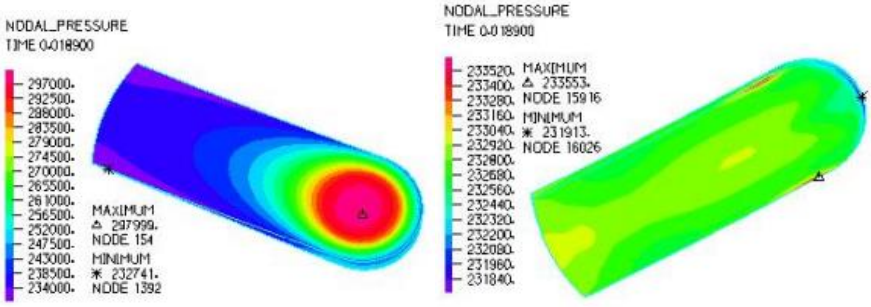
Just opened



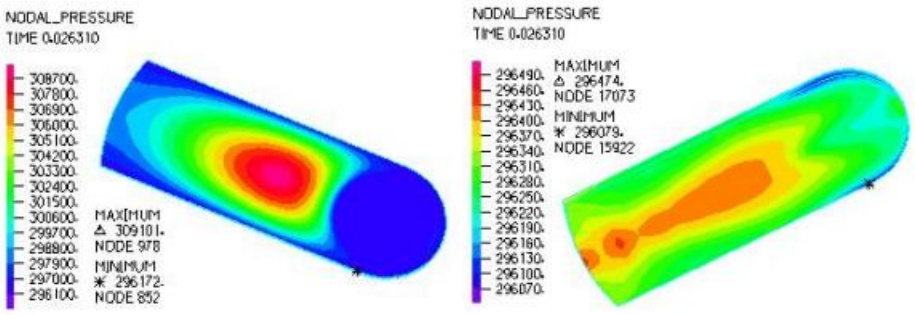
Half opened



Fully opened



Half closed



Close All

a) Upper surface of valve disc b) Lower surface of valve disc

Figure 6 Surface pressure cloud map of suction valve plate

From the above figure, it can be seen that when the suction valve is just opened, the valve clearance flow section is very small, and the gas flow resistance is large. A large high-pressure area appears at the top of the valve surface. At the same time, due to the structural form of the valve root, the gas flow is obstructed, resulting in a slightly higher gas pressure at the root than in the middle of the valve. The gas flow form of the tongue spring valve component causes a higher gas flow velocity and lower pressure in the outer ring on the lower surface of the valve; When the valve disc rises to half open, the lift of the valve disc increases, the effective flow cross-section increases, and the pressure on the upper surface is mainly concentrated in the head area of the valve disc corresponding to the valve port. The range of the high-pressure zone is reduced, and a high-pressure zone appears at the forefront of the lower surface; When the valve plate reaches the maximum lift position, the air flow rate reaches its maximum, and the high pressure area on the upper surface is more concentrated. Due to the influence of the tongue spring automatic valve structure on the flow pattern of the working fluid, the pressure on the lower surface of the valve plate decreases from the head to the root; When the valve disc falls back to half closed, the flow resistance increases again, the high-pressure zone on the upper surface increases, the pressure at the root of the lower surface decreases, and the overall pressure is relatively balanced. A medium and high-pressure zone appears on the side of the valve disc; When the valve disc is about to close, due to the upward movement of the piston after the crank angle exceeds 180° and the small lift, the pressure on the surface of the valve disc facing the valve port first decreases, and the pressure center shifts towards the middle of the valve disc. The valve clearance quickly decreases, causing the pressure on the lower surface of the valve disc near the root to slightly increase. In order to have a clearer understanding of the surface load changes during the movement of the valve plate, the maximum surface pressure and corresponding rotation angles of the valve plate are recorded in Table 1 and Figure 7(the relationship between the movement status of the suction valve plate and the corresponding rotation angle is set in this way, unless otherwise emphasized in the following text).

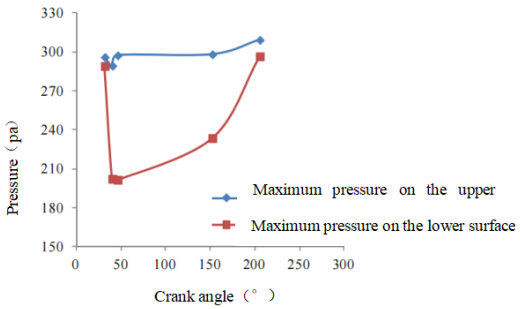


Figure 7 Maximum pressure on the surface of the suction valve plate

As shown in the above figure, as the valve plate rises and falls, the maximum pressure on the upper surface of the suction valve plate fluctuates slightly and remains basically constant. The maximum pressure on the lower surface decreases with the opening of the valve plate and increases with the falling back of the valve plate. Therefore, the pressure difference between the upper and lower surfaces increases with the opening of the valve plate and decreases with the falling back.

Table 1 Maximum pressure on the upper and lower surfaces during the movement of the suction valve plate

Sports state	Just opened	Half opened	Fully opened	Half closed	Close all
Corresponding angle( )	31.89	40.39	46.28	152.23	205.42
Upper surface pressure(pa)	295866	289197	297240	297999	309101
Lower surface pressure(pa)	289014	202222	201462	233553	296474

5 Conclusion

Using ADINA's fluid structure coupling technology, simulate the motion law and gas flow state of the valve plate, analyze the self stress and flow field changes on both sides during the valve plate motion process. The research results indicate that during the suction process, the opening time of the valve plate is relatively long during the cycle, and there is a large fluctuation in the initial stage of reaching the maximum lift. The high stress area of the valve plate is always concentrated at the root of the valve plate, and the upper surface pressure slightly increases and remains basically constant. The lower surface pressure decreases with the opening of the valve plate and increases with the falling of the valve plate. The pressure difference on both sides of the valve plate and its maximum stress also increase with the opening and decrease with the falling of the valve plate. When the valve plate moves to the highest lift position, the stress extreme value of the valve plate is maximum.

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