1990

A Research of Scroll Compressor Working Process Computer Simulation and Testing

Z. Jie
Xi'an Jiaotong University

W. Disheng
Xi'an Jiaotong University

A RESEARCH OF SCROLL COMPRESSOR WORKING PROCESS COMPUTER SIMULATION AND TESTING

Zhu Jie, Assistant of Xi'an Jiaotong University, China

Wang Disheng, Professor of Xi'an Jiaotong University, China

ABSTRACT

This paper is based on the working principle of scroll compressor and after investigating the gas flow condition, in especial analysis the gas leaking situation between two scroll parts mutual gearing, which influence the compressor performance very much. The working process calculating model is set up, employ the scroll compressor geometric parameter, sizes error of parts manufactured as well as compressor operating condition, the main performance parameter of scroll compressor can be calculated. The results of computer simulation model compare with experimental, the results are satisfied.

INTRODUCTION

In recent years the high efficiency compressors are required as the technology development and the energy shortage, although more efforts have been made to improve the efficiency and reliability of the traditional reciprocating compressor. The scroll compressor has inherent advantages, such as high efficiency, quiet operation, light weight and small size. So it is popular for the refrigerating applications and the other small size compressor increasingly. In this paper, the character of gas flowing in scroll compressor is analyzed on the basis of the principle of scroll operating, and the method of calculating the tangential leak in the mesh position of scroll vane profile is given, then a mathematical model of describing the working process is established, by means of computer, the performance parameters are calculated, at last, the experiment on air compressor is made, the calculation results are consistent with the experimental data very well. The results of this paper are useful for optimization design of scroll compressor.

WORKING PROCESS ANALYSES

The main components of the scroll compressor are the fixed scroll, orbiting scroll, anti-rotation coupling, crankshaft and crankcase. There are the outside suction port and the outside discharge port in fixed scroll as shown in Fig. 1, the inside suction ports are located at the vane profile termination,the inside discharge ports are located at the vane profile start.The area of the inside suction ports varies with the crakshaft rotation periodically.The compression pockets begin to discharge after the discharge angle,the area of inside discharge ports increases until the inside discharge process completing. The gas is inhaled from the outside suction port,then it gets into the suction pockets tangentially through the inside suction ports, after compressed,it gets out of the displacement volume tangentially through the inside discharge ports, then enters the central pocket,at last,it gets out of the compressor axially through the outside discharge port. In order to analyzing clearly we divide the working process into five stages: the steady suction,suction closing,compression,initial discharge , steady discharge stage. In steady suction stage,the displacement volume increases from zero to the maximum,the crank angle range is broad and the suction time is long. In suction closing stage,the volume begins to decrease gradually, but the inside suction ports are not closed off, so the gas returning phenomenon arises and the pressure of the closed pockets is higher than the nominal suction pressure, this makes the volumetric efficiency increase. In compression stage, the leakage has main influence on the compressor efficiency. In initial discharge stage, the compressor starts to discharge forcedly, the gas scurries through the inside discharge ports when the pocket pressure is different from the central pocket's. In steady discharge stage, the gas gets out of the compressor, the effective area of the outside discharge port decreases because of the orbiting scroll interference, so the discharge velocity increases.

LEARAGE MODEL

The leakage paths of the scroll compressor are in the vane ends and profile mesh position. In the compressor adopt the tip seals, the main leakage paths are shown in Fig. 2. The leak through path one is less than the other path's according to the working principle of the sealing ring. As to path two, the pressure on the back of the seal element is equal to the pressure of the high-pressure side on the basis of neglect of it's thickness effect, so the leak through path two is calculated in light of the small port flow between two large containers. The leak through path three is described as the steady, one-dimensional, isentropic flow model.

MESH LEAKAGE

Because the mesh clearance δ exists, the tangential leak through path four occurs. The main factors whcih effect on the clearance are as follows: the machining tolerance in scroll vane profile and eccentric radius of the crank - shaft, the crakshft eccentricity in bearings because of the forces and moments. As shown in Fig. 3, if the scroll vane profile is the circle involute, the fixed scroll vane and orbiting scroll vane should contact at point C while the crank angle θ, because of the mesh clearance δ, the contact points C', C'' don't coincide, $C'C''=\delta$, $BC=a\left(\frac{4N+5}{2}\pi-\theta-\alpha\right)$, $AC=a\left(\frac{4N+3}{2}\pi-\theta+\alpha\right)$. $AB=r-\delta$

$\alpha=\frac{t}{2a}$ where a is involute generating radius, N is the number of rotations, t represents the scroll thickness, r is the orbiting radius. The medium viscosity must be taken into account because the path is long and narrow relative to the vane height. Firstly, the model is simplified as the leak between the cylinder with radius AC and the tube with radius BC when they are assembled with the eccentricity $(r-\delta)$. Then it is turned into the model which consists of the high pressure side, the nozzle, the straight pipe with friction and the low pressure side.

(1) Length of the straight pipe

The section of the straight pipe is rectangled, the height of the section is mesh clearance δ, the width is the scroll vane height h. the friction region is both sides of the contact position within the range of $\frac{\pi}{6}$ angle. When the medium viscosity varies less, the pipe length is as follows:

$$l_f=\frac{\delta\cdot BC\cdot(\tau_2-\tau_1)}{r\left[1-\left(1-\frac{\delta}{r}\right)^2\right]^{\frac{1}{2}}}$$

where

$$\tau=\arcsin\left[\left(1-\left(1-\frac{\delta}{r}\right)^2\right)^{\frac{1}{2}}\sin\varphi\Big/\left(1+\left(1-\frac{\delta}{r}\right)\cos\varphi\right)\right]$$

In the suction closing stage, when $\theta<\frac{13}{6}\pi$, $\varphi_1=3\pi-\theta$, $\varphi_2=\frac{7}{6}\pi$

In the compression stage, when $\theta<2(N-1)\pi+\theta^*-\frac{\pi}{6}$, $\varphi_1=\frac{5}{6}\pi$, $\varphi_2=\frac{7}{6}\pi$

When $\theta>2(N-1)\pi+\theta^*-\frac{\pi}{6}$, $\varphi_1=\frac{5}{6}\pi$, $\varphi_2=(2N-1)\pi+\theta^*-\theta$

where θ^* is the discharge angle described in reference [1]

(2) LEAK

On the basis of the flow theory in friction pipe. When the exit (e) velocity is equal to the speed of sound in the simplified model, the inlet Mach number (M_t) should accord with the follow equation :

$$\lambda \frac{l_f}{2\delta} = \frac{1-M_t^2}{KM_t^2} + \frac{K+1}{2K} \log \frac{(K+1)\ M_t^2}{2+(k-1)\ M_t^2} \tag{1}$$

where
$$\lambda = \begin{cases} \dfrac{96}{R_e} & R_e \leq 3560 \\ \dfrac{0.3164}{R_e^{0.5}} & R_e > 3560 \end{cases}$$

$R_e = \frac{2q_m}{\mu h}$, q_m represents the leak, μ represents the viscosity factor, K represents the specific heat ratio. Consequently the pressure ratios in the model as follows:

$$\frac{P_t}{P_e} = \frac{1}{M_t} \left(\frac{K+1}{2+(k-1)\ M_t^2} \right)^{\frac{1}{2}} \tag{2}$$

$$\frac{P_1}{P_t} = \left(1 + \frac{K-1}{2} M_t^2 \right)^{\frac{K}{k-1}} \tag{3}$$

The flow is clogged (M_e=1) when P_{1e} $(=\frac{P_1}{P_t} \cdot \frac{P_t}{P_e})$ is less than $\frac{P_1}{P_2}$, and $P_e = \frac{P_1}{P_{1e}}$. The exit temperature T_e , velocity V_e and discharge q_m are as follows:

$$T_e = \frac{2\ T_1}{2+(K-1)\ M_e^2} \tag{4}$$

$$V_e = M_e\ (KRT_e)^{\frac{1}{2}} \tag{5}$$

$$q_m = \frac{\delta\ h\ P_e V_e}{R\ T_e} \tag{6}$$

where R is the gas constant. When the flow is not clogged, the length l_f^* is calculated according to the equation (1) where M_t is choiced, $\frac{P_t}{P_*}$ and $\frac{P_1}{P_t}$ are computed in light of the equation (2),(3), the exit Mach number M_e is calculated according to the follow equation:

$$\lambda \frac{l_f^*-l_f}{2\delta} = \frac{1-M_e^2}{K\ M_e} + \frac{K+1}{2K} \log \frac{(K+1)M_e^2}{2+(K-1)M_e^2}$$

$\frac{P_e}{P_*}$ is calculated in the equation (2) where M_t is replaced with M_e.

$$\frac{P_1}{P_e} = \left(\frac{P_1}{P_t}\right) \left(\frac{P_t}{P_*}\right) / \left(\frac{P_e}{P_*}\right)$$

M_t which was choiced previously and M_e are correct if $\frac{P_1}{P_e}$ is equal to $\frac{P_1}{P_2}$, the leak is computed in the same method as above. If $\frac{P_1}{P_e}$ is not equal to $\frac{P_1}{P_2}$, M_t should be choiced once again. In the simplified leak model as above, the movement of the orbiting scroll has no effect on the leakage because the effects of two pockets counteract each other.

PERFORMANCE SIMULATION

The Mathematic Model

Because the performance is affected by many factors, this paper just analyze the main factors and give the change regularity of the main properties. So the assumptions as follows must be given firstly.

(1) The medium in working pockets is even state and regarded as the ideal gas, the constant of special heat ratio.

(2) The flows in every port and various clearance are stable, the kinetic and potential energies are negligable , the heat transfer and the oil effects can be eliminated.

The leakage, suction and discharge in the compressor are the mass exchange between the working pocket and ambient environment. The models which describe the five stages in working process can be unified as the same form from the point of view of the change mass thermodynamics. The differential equation series which describe the medium property in working pockets are obtained on the basis of the law of conservation of energy and mass, the state equation of the gas. (the crank angle O is independent variable).

$$\frac{dP(\theta)}{d\theta} = \frac{K}{V(\theta)}\left[\frac{P(\theta+2\pi)\ V(\theta+2\pi)}{m\ (\theta+2\pi)} \cdot \frac{dm_o\ (\theta+2\pi)}{d\theta} - \frac{P(\theta)\ V(\theta)}{m(\theta)} \cdot \frac{dm_o(\theta)}{d\theta} - P(\theta) \cdot \frac{dV(\theta)}{d\theta}\right]$$

$$\frac{dm(\theta)}{d\theta} = \frac{dm_o(\theta+2\pi)}{d\theta} - \frac{dm_o(\theta)}{d\theta}$$

$$P(o) = 0$$

$$m(o) = 0$$

where $P(\theta)$, $V(\theta)$ and $m(\theta)$ represent the pressure, volume and the mass in working pocket, $m_o(\theta)$ is the exchange mass.

Simulative Calculation

The computer simulative program is worked out according to the mathematic model established above, the program simulates the working process and calculates the performance parameter on the basis of the scroll profile parameter, the machining tolerance of the components, the operating condition and so on, the flow chart of the program is shown in Fig. 4. The main functions are as follows:

(1) The geometric parameters at any instant are calculated out, such as the pockets volume, the area of the inside suction ports, the inside and outside discharge ports.

(2) The medium state in working pockets, the returning mass in suction process and the flow velocity through the outside discharge port are obtained.

(3) The leak, the discharge capacity, the volumetric efficiency and the required power can be calculated.

RESULT ANALYSES

The performance experiment of the air compressor is carried out in order to make the comparison between the calculation results and the measured data. The main measured parameters are the discharge capacity, the power and so on, one of the operating conditions is analyzed in detail. The calculated and measured volumetric efficiencies at the different operating conditions are shown in Fig. 5, the adiabatic efficiencies are shown in Fig. 6 correspondingly. The calculation results coincide with the experiment's very well. Fig. 7 to 10 describe the variable regularily of the main properties on an operating condition. In the pressure -- volume diagram and the mass diagram,the volumetric efficiency increases by 3.3 percent and the suction closing pressure increases by 4.8 percent because of the effect of the returning gas at the suction closing stage. The compression line with the constant process exponent and no leak is also drawn in p-V diagram. The indicated work increases 12.1 percent because of the leakage. In the leak diagram the leak is the returning mass at the initial stage, the leak increases with the pockets pressure. The leak decreases rapidly because the pockets pressure approaches to the discharge's promptly after the discharge angle. The leaking passage is clogged and the leak varies less because the pressure of the next pocket is low. The leak decreases with the increment of the next pocket pressure. Because the pocket pressure near the discharge angle is higher than the discharge's, the leak is negative. Fig. 10 shows the pockets volume.

CONCLUSIONS

(1) The medium flowing character in the scroll compressor is analyzed in detail according to the working principle.

(2) The calculating model of the leakage through the scroll profile mesh clearance is set up.

(3) The mathematical model and the computer model simulating of the scroll compressor working process are developed.

(4) The performance experiment is achieved and the calculation results tally with the experimental data.

REFERENCES

[1] Morishita, E., et al., "SCROLL COMPRESSOR ANALYTICAL MODEL", Proc. of the 1984 Intern. Compr. Eng. Conf. (Purdue), July 1984, pp.487-495.

[2] Yanagisawa, T. and Shimiza, T., "Leakage Losses With a Rolling Piston Type Rotary Compressor, I. Radial Clearance on the Rolling Piston", International Journal of Refrigeration, March 1985, Vol.8, No.2, pp. 75-84.

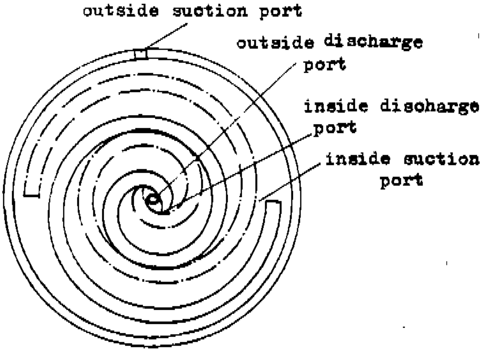

Fig. 1 The ports

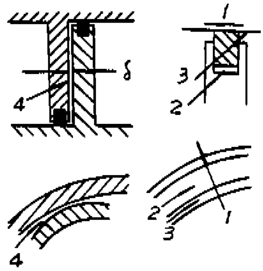

Fig. 2 The leaking paths

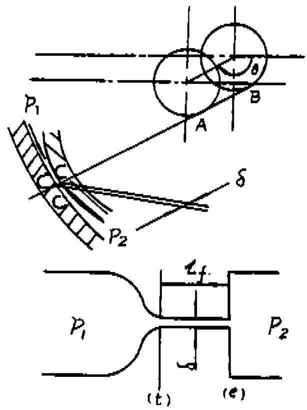

Fig. 3 The leaking model

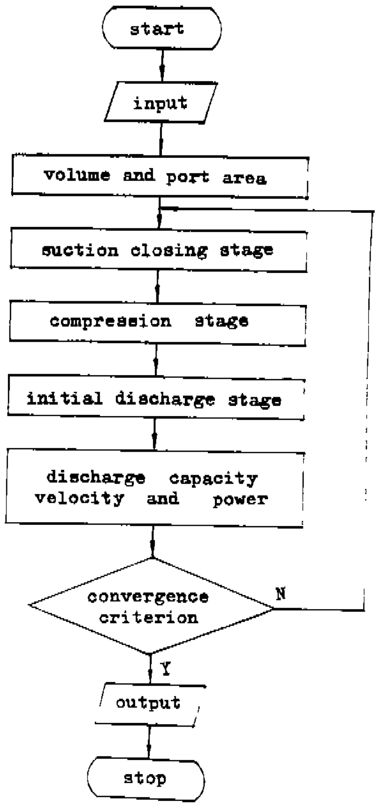

Fig. 4 Programme flow chart

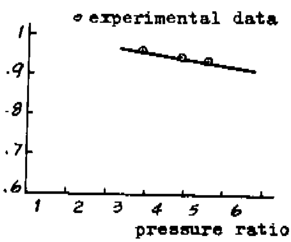

Fig. 5 The volumetric efficiency

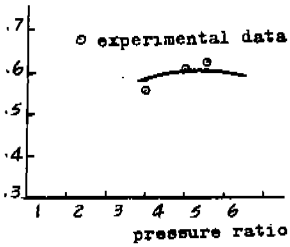

Fig. 6 The adiabatic efficiency

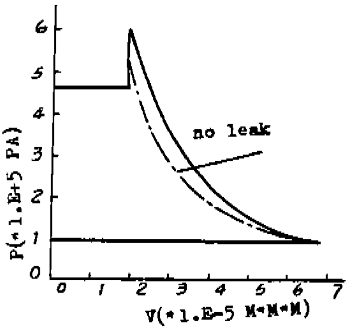

Fig. 7 P-V diagram

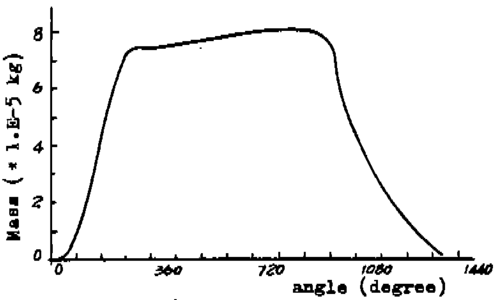

Fig. 8 The mass

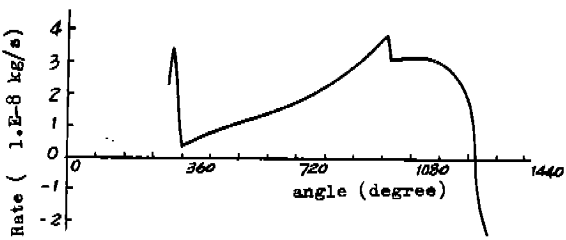

Fig. 9 The leaking mass rate

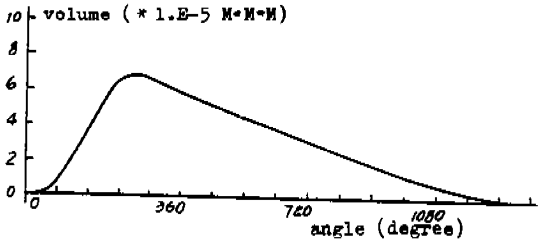

Fig. 10 The volume