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THEORETIC MODEL OF BACK-PRESSURE CHAMBER FOR SCROLL COMPRESSOR

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ABSTRACT

In view of the friction of the oil-gas mixture, the media flow characteristics through the back-pressure ports and the clearances in the back-pressure chamber are analysed in this paper, which based on the structure of scroll compressor with a self adjusting back-pressure mechanism. The theoretic model of the back-pressure chamber is developed, and the models describing the medium properties and leakage via the clearance are also set up.

INTRODUCTION

The balance of the orbiting scroll’s axial gas force and overturn moment is one of the main foundations for scroll compressor to operate at high efficiency level, there have been several mechanisms to support the orbiting scroll in the axial direction, such as propping up the orbiting scroll by means of the mechanical spring, arranging the thrust bearing on the back of the orbiting scroll, or drawing the intermediate pressure medium into the back of the orbiting scroll—self adjusting back-pressure mechanism, and the like. The compressor with self adjusting back-pressure mechanism operates steadily and efficiently over a wide range of the working condition. Nevertheless the sealing property of back-pressure chamber has an effect on the machin efficiency in this mechanism. Because the back-pressure chamber influences the working process of the compression pocket, the change of the compression process must be taken into consideration when the position of the back-pressure port is determined.

Under the condition of maintaining the dynamic response, the effect of the back-pressure chamber on the compression pockets should be as minute as possible, the fluctuation of the back-pressure should be rather small. The flow models through the back-pressure port and the clearances of the back-pressure chamber are set up in this paper, so as to analyse the variation of the back-pressure conveniently, the analytical model describing the medium properties in the back-pressure chamber is offered as well. These researches lay the theoretic foundation of the back-pressure balance calculation.
BACK-PRESSURE CHAMBER

Analysis

The function of the back-pressure chamber is to reserve the gas in order to produce the axial force making the orbiting scroll mesh with the fixed one. There are three problems which are of great importance to the back-pressure chamber. The first one is itself sealing property, the second one is the magnitude of its pressure, the last one is the pressure stability. The flow situations through the clearances of the back-pressure chamber and the aperture are examined as shown in Fig. 1. The leakage via the clearance (1) is the outside one, so it has the direct influence on the volumetric efficiency, the leak medium is the oil-gas mixture. The flow condition through the back-pressure port (the clearance 4) is complicate, the port connects the compression pocket with the back-pressure chamber, because the oil content in the back-pressure chamber is higher than that in the compression pockets, so the oil content in different flow direction is not equal although the media are both the oil-gas mixture. The oil which gets into the back-pressure chamber via the clearance (2) and (3) is in fog state owing to the quick stir by the balancer, then the oil enters the compression pocket through the back-pressure ports and the suction cavity through the clearance (1). The oil-gas mixture in the back-pressure chamber is regarded as the homogeneous mixture approximately. When the compressor working condition is stable, the oil and gas in the back-pressure chamber are conservative respectively in a cycle, as follows.

\[ \int_{m_g}^{m_g} d m_g = 0 \]
\[ \int_{m_o}^{m_o} d m_o = 0 \]

where \( m_g \) is the gas mass, \( m_o \) is the oil mass.

Analytical Model

Because the media state in the back-pressure chamber is complicate, it is necessary to neglect the effects of the subordinate factors, so the following assumptions are made.

1. The property of the oil-gas mixture is homogeneous and the state is identical.
2. The heat exchange is neglected, the oil density remains constant.
3. The back-pressure depends only on the gas state.
4. Gravitational and kinematic energies of the oil and gas are both neglected.

The following fundamental equations describing the media property in the back-pressure chamber are obtained on the basis of the first law of thermodynamics and the law of conservation of mass.

\[ dP_b = \frac{kR}{m_g} \left( T \right) \left( T_b \right) \cdot d m_g + \frac{k}{v} dV_b \]

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\[ dV = m_x dv_x + v_x dm_x \]
\[ dP_b = \frac{dm_x}{m_x} + \frac{dT_b}{T_b} \]
\[ dm_x = dm_{x_e} - dm_{x_1} \]
\[ dm_x = dm_{x_1} + dm_{x_e} + dm_{x_1} - dm_{x_e} \]
\[ V_x = V_b - \frac{m_x}{\rho_x} \]
\[ x_b = \frac{m_x}{m_x + m_\rho} \]
\[ P_b(0) = P_{b_0} \]
\[ T_b(0) = T_{b_0} \]
\[ m_\rho(0) = m_{\rho_0} \]

where \( k \) is the adiabatic exponent, \( R \) is the gas constant, \( v_x \) is the gas specific volume, \( T_{g_a} \) is the temperature of the gas entering into the back-pressure chamber, \( m_{g_a} \) is the mass. \( P_b \) and \( T_b \) are the pressure and temperature in the back-pressure chamber, \( V_b \) and \( V_g \) are the volume of the gas and the back-pressure chamber respectively, \( \rho_\rho \) is the oil density. \( m_{x_1} \) and \( m_{x_e} \) are the masses of oil and gas through the every clearance, \( P_{b_0} \), \( T_{b_0} \), \( m_{\rho_0} \) are the initial parameters.

**LEAKING MODEL**

In order to calculate the mixture flow, the mixture properties must be defined at first. Because the flow velocity of the mixture is great, it is reasonable to regard the flow as the homogeneous one. Accordingly, the mixture properties are given as follows:

**gas mass ratio** \( x = \frac{m_x}{m} \)

**density** \( \rho_m = \frac{\rho_{x_1} \cdot \rho_\rho}{x\rho_\rho + (1-x)\rho_{x_1}} \)

**adiabatic exponent** \( k_m = \frac{x c_{x_1} + (1-x)c_{\rho}}{x c_{\rho} + (1-x)c_{x_1}} \)

**gas constant** \( R_m = xR_{\rho} \)

**coefficient of dynamic viscosity** \( \mu_m = \frac{\mu_{x_1} \mu_\rho}{(1-x)\mu_{x_1} + x\mu_\rho} \)

**coefficient of kinematic viscosity** \( \nu_m = \frac{\mu_m}{\rho_m} \)
where $m$ is the mixture mass, $\rho_g$ is the gas density, $c_{pg}$ is the specific heat at constant pressure, $c_{vg}$ is the specific heat at constant volume, $c_o$ is the oil specific heat, $\mu_g$ and $\mu_o$ are the dynamic viscosities of the gas and oil respectively.

**Leakage through Clearance (1)**

The leak medium through the clearance (1) is the homogenous oil–gas mixture whose gas content is $x_b$. The pressure-difference between the two sides of the clearance is great, but the movement velocity of the orbiting scroll is low, so the shear flow in the clearance is very small compared to the pressure-difference flow, it is reasonable to neglect the shear flow while calculating the leakage. The radius of the suction cavity is $R_1$, the orbiting scroll baseplate radius is $R_2$, the forces acting on the flow microunit are shown in Fig. 2, the force equilibrium is given as follows:

\[
\rho d\phi dy + 2p dr dy \sin \frac{d\theta}{2} - (p + dp)(r + dr) d\phi dy + \tau r dr dr - \mu + d - r) r dr r dr = 0
\]

simplified as \[
\frac{dr}{dy} = -\frac{dp}{dr}
\]

where $\tau$ is shearing stress, $p$ is the pressure, according to the Newtonian shearing stress formula

\[
\tau = -\rho \frac{dy}{d\phi} \frac{du}{dy}
\]

where $u$ is the flow velocity. Therefore, the equation of the flow through clearance (1) is presented by

\[
\frac{d^2 u}{dy^2} = \frac{1}{\rho m v_m} \frac{dp}{dr}
\]

The flow boundary conditions is given by

\[
y = 0 \quad y = \delta_i
\]

\[
u = 0 \quad u = 0
\]

consequently \[
\mu = \frac{1}{2p m v_m} (\delta_i - y) y \frac{dp}{dr}
\]

the leakage mass rate is obtained as follows:

\[
\frac{dm}{dt} = \delta_i \frac{\pi r}{6 v_m} \frac{dp}{dr}
\]

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owing to \[ \int_{a_1}^{r_1} \frac{dm_1}{dr} \, dr = \int_{a_1}^{r_1} \frac{\delta_1 \pi r}{6 v_m} \, dp \]
therefore \[ \frac{dm_1}{dt} = \frac{\delta_1 \pi (P_1 - P_e)}{6 v_m l_1} \]

where \( P_e \) is the suction pressure.

The functions of the oil in clearance (2), (3) are to lubricate the friction surfaces, to take out the frictional heat and to seal the gas. The clearance (3) is taken for example to analyze the oil flow condition. Because of \( \delta_3 < r_i \), it is reasonable to simplify the flow through the clearance (3) as the one through the clearance of two plates whose distance is \( \delta_3 \). The width of these plates is \( 2 \pi r \), and the length is \( l_1 \). The analysis of the forces acting on the flow microunit is shown in Fig. 3, the force equilibrium is presented by

\( (P+dP) \cdot 2 \pi r \cdot dy - P \cdot 2 \pi r \cdot dy + T \cdot 2 \pi r \cdot dl - (T+dT) \cdot 2 \pi r \cdot dl = 0 \)

simplified as

\[ \frac{dT}{dy} = \frac{dP}{dl} \]

as mentioned above

\[ \frac{d^2 u}{dy^2} = - \frac{1}{\rho e v_e} \frac{dP}{dl} \]

\[ u = \frac{1}{2 \rho e v_e} (\delta_3 - y) \frac{dP}{dl} \]

accordingly

\[ \frac{dm_{1e}}{dt} = \frac{\delta_1 \pi r}{6 v_e} \frac{P_1 - P_e}{l_1} \]

BACK-PRESSURE PORT MODEL

The back-pressure port is not only the passageway through which the gas flows to and fro but also the oil return path. The flow medium is the oil-gas homogeneous mixture, but when the flow direction is different, the gas content of the mixture is not the same. When the compression pocket pressure \( P_1 \) is higher than the back-pressure \( P_b \), the mixture flows from the compression pocket to the back-pressure chamber, the gas mass content is \( x_1 \), when \( P_1 \) is lower than \( P_b \), the mixture flows conversely, the gas mass content is \( x_b \). Because the diameter of the
back-pressure port is very small, the compression property of the gas and the friction of the port should be taken into account. The flow condition through the back-pressure port is divided into two parts, one is the reversible adiabatic flow in section OA, the other is one-dimensional adiabatic flow with fluid friction in section AB, as shown in Fig. 4.

momentum equation:

section OA  \[ dp + \rho_m c \, dc = 0 \]

section AB  \[ dp + \rho_m c \, dc + \frac{\rho_m c^2}{2} \frac{dx}{D} = 0 \]

energy equation  \[ dh_m + c \, dc = 0 \]

continuity equation  \[ \frac{p}{\rho_m} = R \cdot T \]

state equation  \[ \frac{dh_m}{h_m} = \frac{R}{P_m} \]

where  \[ \lambda = \begin{cases} \frac{96}{R} & R < 3560 \\ 0.3165 \frac{R^{0.25}}{R} & R \geq 3560 \end{cases} \]

\( D \) is the diameter of the back-pressure port, \( h_m \) is the specific enthalpy of the mixture, the flow velocity \( c \) of the mixture under the pressure-difference \( (P_i - P_b) \) is obtained by means of solving the above equations, therefore, the mass flow rate is presented as follows:

\[
\begin{align*}
\frac{dm_1}{dt} &= \alpha \cdot \frac{\pi D^2}{4} \rho_m c \\
\frac{dm_m}{dt} &= x \frac{dm_1}{dt} \\
\frac{dm_x}{dt} &= (1 - x) \frac{dm_1}{dt}
\end{align*}
\]

where  \( x = \begin{cases} x_i & P_i \geq P_b \\ x_b & P_i < P_b \end{cases} \), \( \alpha \) is the flow coefficient, it is determined by the Reynolds number and the cross section ratio of the port to the back-pressure chamber.

CONCLUSION

The flow conditions through the clearance of the back-pressure chamber and the port are presented, which based on the working property of the back-pressure mechanism and the flow character of the oil-gas mixture. The analytical model of the back-pressure chamber is developed, the flow models through the back-pressure port and the clearances of the back-pressure chamber are also set up.
REFERENCES


Fig. 1 Structure of back-pressure chamber

Fig. 2 Force analysis in Clearance(1)

Fig. 3 Force analysis in Clearance(3)
Fig. 4 Flow model via back-pressure port