1992

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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 discribing 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–proessure 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 approximatively; When the compressor working condition is stable, the oil and gas in the back–pressure chamber are conservative respectively in a cycle, as follows.

$$\int_0^{2\pi} dm_g = 0$$

$$\int_0^{2\pi} dm_e = 0$$

where m_g is the gas mass, m_e 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 indentical.

(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.

$$dP_b = \frac{kR}{m_g v_g}(T_{gin} - T_b) \cdot dm_{gin} + \frac{kP_b}{v_g} dv_g$$

$$dV_g = m_g dv_g + v_g dm_g$$

$$\frac{dP_b}{P_b} = \frac{dm_g}{m_g} + \frac{dT_b}{T_b}$$

$$dm_g = dm_{4g} - dm_{1g}$$

$$dm_e = dm_{2e} + dm_{3e} + dm_{4e} - dm_{1e}$$

$$V_g = V_b - \frac{m_e}{\rho_e}$$

$$x_b = \frac{m_g}{m_g + m_e}$$

$$P_b(0) = P_{bo}$$

$$T_b(0) = T_{bo}$$

$$m_e(0) = m_{eo}$$

where k is the adiabatic exponent, R is the gas constant, v_g is the gas specific volume, T_{gin} is the temperature of the gas entering into the back–pressure chamber, m_{gin} is the mass. P_b and T_b are the pressure and temperature in the back–pressure chamber, V_g and V_b are the volume of the gas and the back–pressure chamber respectively, ρ_e is the oil density. m_{ie} and m_{ig} are the masses of oil and gas through the every clearance, P_{bo} , T_{bo} , m_{eo} 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 $x = \frac{m_g}{m}$

density $\rho_m = \frac{\rho_g \cdot \rho_e}{x\rho_e + (1-x)\rho_g}$

adiabatic exponent $k_m = \frac{xc_{pg} + (1-x)c_e}{xc_{vg} + (1-x)c_e}$

gas constant $R_m = xR_g$

coefficient of dynamic viscosity $\mu_m = \frac{\mu_e \mu_g}{(1-x)\mu_g + x\mu_e}$

coefficient of kinematic viscosity $v_m = \frac{\mu_m}{\rho_m}$

where m is the mixture mass, ρ_g is the gas density, c_{pg} is the specific heat at constant pressure, c_{vg} is the specific heat at constant volume, c_e is the oil specific heat, μ_g and μ_e 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 is Fig. 2, the force equilibrium is given as follows:

$$prd\varphi dy+2pdrdy\ \sin\frac{d\varphi}{2}-(p+dp)(r+dr)d\varphi dy+\tau rd\varphi dr-(\tau+d\tau)rd\varphi dr=0$$

simplified as $\frac{d\tau}{dy}=-\frac{dp}{dr}$

where τ is shearing stress, p is the pressure, according to the Newtonian shearing stress formula

$$\tau=-\rho_m v_m\frac{du}{dy}$$

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

$$d^2u/dy^2=\frac{1}{\rho_m v_m}\frac{dp}{dr}$$

The flow boundary conditions is given by

$$y=o \qquad y=\delta_1$$
$$u=o \qquad u=0$$

consequently $\mu=\frac{1}{2\rho_m v_m}(\delta_1-y)y\frac{dp}{dr}$

the leakage mass rate is obtained as follows:

$$\frac{dm_1}{dt}=\delta_1^3\pi r/6v_m\quad\frac{dp}{dr}$$

owing to $\int_{R1}^{R2}\frac{dm_1}{dt}\frac{dr}{r}=\int_{Ps}^{Pb}\frac{\delta_1^3\pi r}{6v_m}dp$

therefore $dm_1/dt \quad =\frac{\delta_1^3\pi(P_b-P_s)}{6v_m l_n\frac{R^2}{R_1}}$

where P_s is the suction pressure.

gas leakage rate $dm_{1g}/dt \quad = x_b\frac{dm_1}{dt}$

oil leakage rate $\frac{dm_{1e}}{dt}=(1-x_b)\frac{dm_1}{dt}$

Leakage through Clearance (2), (3)

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 $\delta_3 << r_1$, it is reasonable to simplify the flow through the clearance (3) as the one through the clearance of two plates whose distance is δ_3. The width of these plates is $2\pi r$, and the length is l_3. The analysis of the forces acting on the flow microunit is shown in Fig. 3, the force equilibrium is presented by

$$(P+dP)\cdot 2\pi r_1 dy-P\cdot 2\pi r_1 dy+\tau\cdot 2\pi r_1 dl-(\tau+d\tau)\cdot 2\pi r_1\cdot dl=0$$

simplified as

$$\frac{d\tau}{dy}=\frac{dP}{dl}$$

as mentioned above $\frac{d^2u}{dy^2}=-\frac{1}{\rho_e v_e}\frac{dP}{dl}$

$$u=\frac{1}{2\rho_e v_e}(\delta_3-y)y\frac{dP}{dl}$$

accordingly $\frac{dm_{3e}}{dt}=\frac{\delta_3^3\pi r_1}{6v_e}\quad\frac{P_d-P_s}{l_3}$

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_i 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_i, when P_i 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 $$dp+\rho_m c dc+\lambda\frac{\rho_m c^2}{2}\frac{dx}{D}=0$$

energy equation $$dh_m+cdc=0$$

continuity equation $$d(\rho_m c)=0$$

state equation $$\frac{p}{\rho_m}=R_m T$$

where $$\lambda=\begin{cases}\dfrac{96}{R_e} & R_e<3560\\ \dfrac{0.3165}{R_e^{0.25}} & R_e\geqslant 3560\end{cases}$$

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 follws:

$$\frac{dm_4}{dt}=\alpha\cdot\frac{\pi D^2}{4}\rho_m c$$

$$\frac{dm_{4g}}{dt}=x\frac{dm_4}{dt}$$

$$\frac{dm_{4e}}{dt}=(1-x)\frac{dm_4}{dt}$$

where $x=\begin{cases}x_i & P_i\geqslant P_b\\ x_b & P_i<P_b\end{cases}$, α 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.

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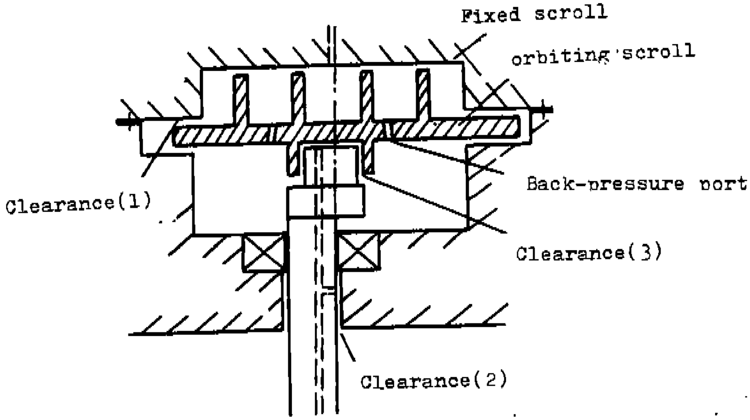

Fig.1 Structure of back-pressure chamber

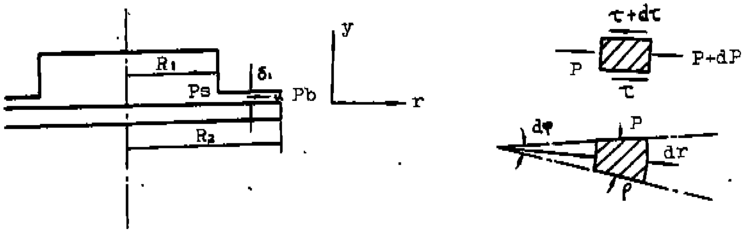

Fig.2 Force analysis in Clearance(1)

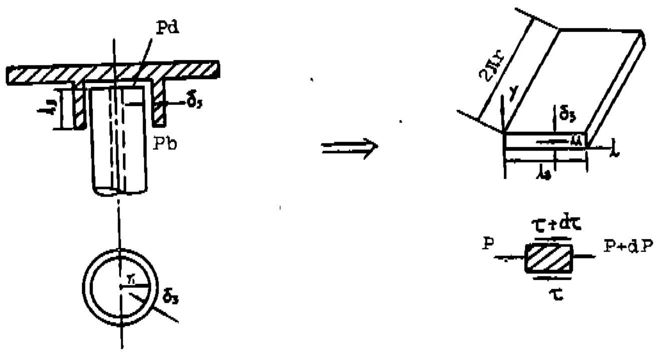

Fig.3 Force analysis in Clearance(3)

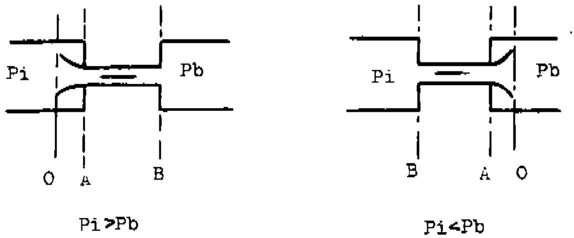

Fig.4 Flow model via back-pressure port