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Preliminary Calculation of Inclining Movement for Ring Type Suction Valves

W. Yezheng

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INTRODUCTION

The valve is an important part in reciprocating compressors. Its performance greatly influences the efficiency and the service life of a compressor. It is known that the performance of a ring type valve depends not only on the translational movement but also on the inclining movement of the valve plates [1] [2].

The translational movement of a valve plate can be predicted by a set of differential equations. But up to now the inclining movement of a valve can not be obtained from calculation. One of the difficulties is that we have no suitable mathematical model to describe the inclining movement of the valve plate caused by both the force and its moment acting on the valve plate.

THE MATHEMATICAL MODEL

The valve in Figure 1 is a suction valve set in the cylinder C. When piston P goes down, the gas pressure inside cylinder C of a compressor reduces. The pressure difference between the space S and the valve chamber D makes the valve open if the force produced by the pressure drop exceeds the spring force exerted on the valve plate. Then the gas passes through the valve and enters to the space S.

It is clear that if the gas pressures at points A, B and E were equal to each other, the inclining movement of the plate would not occur. The pressure drop between points A and E is produced as there is the resistance against the gas flow when it passes through a narrow gap from point A to point E, thus the valve plate is pushed by both the force and its moment, and moves with inclination. The prediction of the inclining movement of the valve plate needs some information about the pressure distribution of the gas between the valve and the cylinder.

To make the calculation simplified two assumptions have been made.

Firstly, the movement of the valve plate is symmetrical because the gas flow is assumed to be of axial symmetry at both sides of a straight line o-o in Figure 2. Secondly, after dividing the valve plate into three parts A<sub>C</sub>, B<sub>C</sub> and E<sub>C</sub> as shown in Figure 3, it is assumed that the displacement in any point of one of the parts equals the displacement of the gravity centre at the same part. Hence, we only need to find out the movement of the gravity centres A<sub>C</sub>, B<sub>C</sub> and E<sub>C</sub> in the three parts, as shown in Figure 4, instead of determining a lot of movement at many points of these parts.

According to the assumptions above, a set of differential equation for predicting the inclining movement of a suction valve plate is obtained.

The flow equation is

\[
\frac{d\varphi_3}{dt} + k_3 \frac{l}{\varphi_3} \frac{d\varphi_3}{dt} = kR^2 \frac{l}{\varphi_3} \cdot \frac{l}{\varphi_3} - \frac{d(m_1 + m_2 + m_3)}{dt} = 0 \tag{1}
\]

where

\[
\frac{dm_1}{dt} = \mu_1 f_1 f_3 \, \varphi_2 \, \sqrt{\frac{2}{\beta RT_0}} (1 - \varphi_3^B)
\]

\[
\frac{dm_2}{dt} = \mu_2 f_2 f_3 \, \varphi_2 \, \sqrt{\frac{2}{\beta RT_0}} (1 - \varphi_3^B)
\]

\[
\frac{dm_3}{dt} = \mu_3 f_3 f_3 \, \varphi_2 \, \sqrt{\frac{2}{\beta RT_0}} (1 - \varphi_3^B)
\]
The motion equation at point \( A_c \) is

\[
\varphi_i = \frac{h_i}{h_3}
\]
\[
\varphi_2 = \frac{h_1}{h_3}
\]
\[
\varphi_3 = \frac{h_3}{h_3}
\]
\[
\beta = \frac{(k-1)}{k}
\]
\[
\alpha = \frac{l}{k}
\]

The motion equation at point \( A_c \) is

\[
\frac{d^2 h_i}{dt^2} = \rho_i h_3 \left( 1 - \varphi_i \right) S_i - \frac{2C}{\varphi_i} \frac{h_i}{h_3} \frac{S_i}{S_j} (2)
\]

and at point \( E_c \) is

\[
\frac{d^2 h_3}{dt^2} = \rho_3 h_2 \left( 1 - \varphi_3 \right) S_3 - \frac{2C}{\varphi_3} \frac{h_3}{h_2} \frac{S_3}{S_j} (3)
\]

The displacement \( h \) at point \( B_c \) can be expressed in terms of \( h_1 \), \( h_3 \), \( a_1 \) and \( a_3 \) in Figure 4,

\[
\frac{a_i}{a_1 + a_3} = \frac{(h_2 - h_i)}{(h_3 - h_1)} (4)
\]

The determination of the pressure at the points \( A_c, B_c \) and \( E_c \)

The simple way to find out the pressure at those points is to make a model taking the same size as that of the real part inside the dotted line in Figure 1, and to measure the pressures at points \( A_c, B_c \) and \( E_c \) of the model. The devise used for this purpose is shown in Figure 5. The compressed air flowing from a fan passes through a tank with two pieces of thin plates at the middle of the tank. There are many small holes in the plate making the air flow smooth. After passing through the tank, the air flows through the model. The pressures and the temperatures at points \( A_c, B_c \) and \( E_c \) can be measured by the pressure gauges and thermometers. Meanwhile, the pressures and the temperatures of the air inside and outside the tank are measured by the similar instruments.

For example

The equations developed are applied to predict the inclining movement of a suction valve-plate in the second stage of an air compressor. To find out the pressure distribution of air located between the valve and the cylinder, a model is put at the top of the tank in Figure 5. The measurement can be carried out when the wind produced by a fan passes through the model.

Table 1 shows all of the situations under which the test has been proceeded.

The data of the pressures \( p_1, p_2, \) and \( p_3 \) obtained has been formulated by two dimensionless equations (5) and (6)

\[
\varphi_i = 0.0348 \cdot \frac{p_3 + 10^{-6}}{h_i + 10^{-6}} (5)
\]

\[
\varphi_2 = 0.0238 \cdot \frac{p_3 + 10^{-6}}{h_2 + 10^{-6}} (6)
\]

Several comparisons between numerically calculated and measured valve motion patterns are shown in Figure 6. The agreement can be seen to be satisfactory.

It has been found from Figure 6 that the inclination of the valve plate reduces with the decrease of the valve lift. When the valve lift reduces to 1.7 mm, the plate inclines slightly. In that case, it can be expected that the valve can run in order. In fact, these ring type valves with a lift of 1.7 mm have worked in a factory for about 4000 hours without any trouble.

Acknowledgement

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Nomenclature

\( P_i \) - gas pressure at point \( i, \) N/m\(^2\)
\( T_i \) - gas temperature at point \( i, K \)
\( P_s \) - gas pressure in a section valve chamber, N/m\(^2\)
\( T_s \) - gas temperature in a section valve chamber, K
\( k \) - gas isentropic index, dimensionless
\( V \) - instant volume inside a cylinder, m³
\( R \) - gas constant, \( m^2/\text{sec}^2 \cdot K \)
\( M \) - mass of the gas flowing into a cylinder, kg
\( m_j \) - mass of the gas passing through part j of a valve plate, kg
\( \mu_j \) - flow coefficient at part j, dimensionless
\( \rho_j \) - drag coefficient at part j, dimensionless
\( m_j^* \) - mass of part j of a valve plate + 1/3 mass of the spring loading on part j, as shown in Figure 3, kg
\( S_j \) - area of part j, m²
\( f_j \) - area of the valve gap of part j between the valve stop and the valve seat, m
\( h_{i1} \) - displacement of point i, m
\( h_o \) - static displacement of a valve plate, m
\( z \) - number of the springs loading on a valve plate
\( C \) - equivalent spring stiffness, N/m

subscript \( i = 1,2,3 \)

where

1-the parameter at point \( A_o \) in Figure 4
2-the parameter at point \( B_o \) in Figure 4
3-the parameter at point \( E_o \) in Figure 4

subscript \( j = 1,2,3 \)

where

1-part \( A_s \) in Figure 3
2-part \( B_s \) in Figure 3
3-part \( E_s \) in Figure 3

REFERENCES


Table 1. The situation of \( h_i \) and \( h_j \)

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<th>( h_j \times 10^3 ) m</th>
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Figure 1 - Schematic diagram of a suction valve set in a cylinder

Figure 2 - A symmetrical axis o-o
Figure 3 - Three parts $A_s$, $B_s$ and $E_s$ of a valve plate

Figure 4 - The center of gravity $A_c$, $B_c$ and $E_c$ of three parts

Figure 5 - A devise for determining pressures
Figure 6 - Displacements at points Ec and Ac in Figure 4

--- Experimental results

---- Analytical results