1998

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VANE JUMPING IN ROTARY COMPRESSOR

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ABSTRACT

The vane jumping is the irregular contact between vane tip and roller outer wall under start-up operation. Also, it causes very loud noise under the condition. The previous studies estimate that the possibility of vane jumping from the ratio of vane inertia and vane spring forces. In this paper, the analytical method for vane jumping and its preventing techniques are introduced. The vane jumping is visualized by image process techniques, and irregular contact is analyzed by numerical approach. It is also revealed that the vane collide with the roller around bottom dead point.

1. INTRODUCTION

Sometimes, airconditioners generate very noisy sound under start-up operation. Loud sound continues for seconds or minutes until pressure difference between compression and suction chamber reaches limit value. We found that abnormal behavior of vane caused such loud sound. However, we could not explain the behavior of vane and roller and could not find the main source of noise whether impact noise caused by metallic contact between vane and roller or frictional noise caused by friction between vane and vane slot. In general, vane maintains contact between a vane tip and a roller wall under steady state operation. Since the back pressure is not sufficient to maintain contact under start-up operation, jumping phenomena occur, which cause loud impact noise.

In order to know the key factor to prevent such phenomena, we analyze the behaviors of vane by simulating scheme and identify vane jumping phenomena by visualization techniques.

2. THEORETICAL ANALYSIS OF VANE JUMPING

Rotary compressor has roller which eccentrically rotates in cylinder inner space, reciprocating vane and spring which contacts with vane as shown in Fig.1. The locus of roller is the function of rotating angle ($\theta$), roller eccentricity ($e_c$) and roller radius ($R_r$), as shown in following eq.(1).

$$x_{roller} = e_c \cos \theta + \sqrt{e_c^2 \left( \cos^2 \theta - 1 \right) + R_r^2}$$

The behaviors of vane, however, are somewhat complicated[1] as indicated in eq(2). There are
many external forces such as spring forces, frictional forces, contact forces and pressure forces, as shown in Fig. 2.

\[ m \frac{d^2 x_v}{dt^2} + C \frac{dx_v}{dt} + kx = F_p + F_r \quad (2) \]

where \( m \) is vane mass.

The frictional forces, which can be simplified as non-conservative damping force, exist between vane side and cylinder slot. Damping coefficient \( C \) can be obtained by experiment. We select reasonable damping coefficient by comparing measurement and simulation of vane behaviors.

\( \Delta x \) can be described as eq. (3).

\[ \Delta x = x_{so} - R_{sh} + x_{vane} + h_v - d_v \quad (3) \]

where \( k \) is spring constant, \( \Delta x \) is compressed length of spring, \( x_{so} \) is spring free length, \( R_{sh} \) is radius of compressor shell, \( h_v \) is vane height, \( d_v \) is the length of spring groove and \( x_{vane} \) is the length between cylinder center and vane tip.

The pressure force \( F_p \) becomes

\[ F_p = A(P_c(\theta) - P_d) \quad , \quad P_c(\theta) = P_{co} \left( \frac{v}{v_c(\theta)} \right)^n \quad (4) \]

where \( A \) is cross-sectional area of vane rear face, \( P_{co} \) is initial compression pressure, \( P_d \) is discharge plenum pressure, \( V_c(\theta) \) is compression volume and \( n \) is polytropic index.

\( F_r \) is reaction force of roller. When vane is not contact with roller, this force is equal to 0. To solve the behaviors of vane we use penalty method[2] which is effective to analyze these kind of contact system. In penalty method, If vane tip penetrates roller, wall contact spring which has very large spring constant \( (k_c) \) prevents excessive penetration as shown in eq.(5).

\[ F_r = \begin{cases} 
    k_c \delta - C_c \frac{dx_v}{dt} , & x_{vane} \leq x_{roller} \\
    0 , & x_{vane} > x_{roller} 
\end{cases} \quad \delta = x_{roller} - x_{vane} \quad (5) \]

where \( C_c \) is contact damping coefficient. Runge-Kutta Method is used to solve eq. (2).

Fig. 3 shows the results of eq.(2). The pressure difference between discharge plenum pressure \( P_d \) and suction pressure \( P_s \) is 0.3 Bar. Two curves are not same and non-contacting gaps exist. These non-contacting gaps, vane jumping, are maintained during 0° - 220°. In Fig.4, the behaviors of vane and roller are plotted for ASHRAE condition. There is no vane jumping phenomena in this figure. The sufficient back pressure maintains contact of vane and roller.

To improve the non-contact phenomena we calculate many situations by varying some parameters such as spring constant \( k \), spring free length \( x_s \) and vane mass \( m \) as shown in Fig.5 - Fig.7. The influence of spring constant \( k \) is shown in Fig.5. Though \( k \) is increased 50%, improvement of jumping is very small. Changing spring constant is not effective way to improve vane jumping phenomena. Fig.6 shows the behaviors of vane and roller when the spring free length is increased (19% up). The gaps between two curves are much closer than those of Fig.5. But changing spring free length is not sufficient way to prevent vane jumping. Fig.7 shows the gaps between vane and roller as vane mass is decreased (50% down). Gaps are closer than those of previous two cases. The mass of vane is decreased by lowering vane density. From this results, we conclude that the influence of vane mass is the most important in vane jumping. Fig.8 is the simulation results of changing spring free length and vane mass simultaneously. There is no vane jumping phenomena in this case.
3. VISUALIZATION OF VANE JUMPING

To verify the source of abnormal noise in start-up operation, vane behaviors were observed by visualization apparatus. Test apparatus has a sight glass through which we can see vane movement and gap between vane tip and roller wall. The sight glass was attached in sub bearing end wall as shown in Fig.9. Moving vane can be observed at the outside of compressor case. A stroboscope is synchronized with rotating speed of compressor (3340rpm), we take a photograph of the vane behaviors under the synchronized light of stroboscope. In order to see the moving vane position from bottom dead point to top dead point, the sight glass location and size are properly determined.

Fig.10 shows moving vane behaviors. When loud noise occurs, vane jumping is observed. This noise disappears as pressure load is increased. When loud noise disappears, vane jumping vanishes. In case of vane jumping, vane tip starts to separate from roller wall at top dead point, this separation is maintained up to bottom dead point and then vane tip collides with roller wall near 220°. Loud noise is generated by this collision and the noise level is proportional to the length of gaps between vane tip and roller wall.

Vane jumping is affected by operating environment, room temperature. No vane jumping occurs at room temperature above 25° C. As room temperature gradually decreases, jumping noise increases. There is no impact noise and no jumping phenomena under ASHRAE condition (Pd = 21.89kgf, Ps = 6.37kgf). These stable behaviors coincide with previous simulation results as shown in Fig.4. Vane jumping disappears as pressure difference is greater then 0.5 Bar.

4. CONCLUSIONS

Based on the results of both analytical and experimental studies presented in this paper, we know that; vane jumping occurs under abnormal condition such as low room temperature, low pressure difference (Pd - Ps). Vane jumping causes loud impact noise under start-up operation. Noise level is proportional to the length of jumping gaps. If we use light vane and long spring, jumping phenomena can be prevented. Vane jumping, however, causes leakage between suction chamber and discharge chamber and it delays the rise time to reach sufficient pressure difference between compressor case and suction chamber. In other words, vane jumping is coupled with pressure difference. However, we did not consider pressure change caused by leakage between suction chamber and compression chamber. Therefore, further studies, to find the influence of leakage, are necessary.

ACKNOWLEDGMENT

The authors would like to thank Sang-Yong Lee and Hoi-Sun Kim for their experimental contributions and Kwang-Ha Seo for his specific support.

REFERENCES

Fig1. Geometry of Rotary Compressor

Fig2. Free Body Diagram

Fig3. Simulation Results of Vane Jumping Behaviors ($P_d - P_s = 0.3\text{Bar}$)

Fig4. Simulation Results of Vane Behavior (ASHRAE Condition)
Fig. 5. Simulation Results of Vane Jumping Behaviors ($k; 50\%$ up)

Fig. 6. Simulation Results of Vane Jumping Behaviors ($x_s; 19\%$ up)

Fig. 7. Simulation Results of Vane Jumping Behaviors (Vane Mass; 50\% down)
Fig. 8. Simulation Results of Vane Behaviors (xs: 19% up, vane mass: 50% down)

Fig. 9. Experimental Apparatus

Fig 10. Vane Jumping Procedure