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A STUDY ON THE VARIABLE DISPLACEMENT MECHANISM OF SWASH PLATE TYPE COMPRESSOR FOR AUTOMOTIVE AIR CONDITIONING SYSTEM

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ABSTRACT

To meet the demand for improved comfort, drive ability and fuel economy standard, the compressor for automotive air conditioning system has been developed to get high performance, high reliability, low noise and low vibration. To satisfy these requirements, the variable displacement swash plate type compressor, which can control the compressor displacement by increasing or reducing the swash plate angle has been developed.

In the reciprocating compressor, the suction valve is one of the very important parameter to decide compressor performance. Specially, in the variable displacement swash plate type compressor, a stopper height of suction valve must be very important parameter in order to control the swash plate angle.

The objectives of the present study are to develop a simulation program for performance analysis of variable displacement swash plate type compressor, and to describe the effect of the stopper height of suction valve on the variable displacement controllability.

1. INTRODUCTION

Recently, due to a surge of public interest in environmental conservation, the automobile manufacturers now is facing the demands to improve the fuel consumption by improving efficiency and reducing weight. Automotive air conditioning system also is not an except from the reduction in the power consumption. It is generally required that the automotive air conditioning system must keep the cabin temperature comfortable in spite of changing of engine speed, and improve the fuel consumption during all the seasons.

To satisfy these requirements, the variable displacement swash plate type compressor with the new capacity control mechanism is developed. The new mechanism changes the swash plate angle by increasing or reducing the pressure of swash plate chamber using the internal or the external control valve.

In the reciprocating compressor, the suction valve is one of the very important parameter to decide compressor performance. It is known that increasing the effective flow area of suction valve reduced the related valve loss and thus help to get better the volume efficiency of compressor. However, a larger effective flow area tends to increase the valve stopper height that may reduce the reliability of the suction valve. Specially, in the variable displacement swash plate type compressor, a stopper height of suction valve must be very important parameter in order to control the swash plate angle.

The objectives of the present study are to develop a simulation program for performance analysis of variable displacement swash plate type compressor, and to describe the effect of the stopper height of suction valve on the variable displacement control ability.

2. VARIALBE DISPLACEMENT SWASH PLATE COMPRESSOR

The overall structure of the variable displacement swash plate type compressor for automotive air conditioning system is shown in Figure 1. This compressor can be divided into three major parts, namely: the power transfer part, the variable displacement mechanism part and the compression part. As shown in Figure 1, refrigerant firstly enters the suction plenum through the inlet port and then the flow will be divided into seven cylinders through suction valve. Here, it will be compressed and then exhausted to the discharge plenum through the discharge valve.

The power transfer part consists of a pulley rotating with the engine, a clutch, a shaft, a lug plate and a swash plate. As shown in Figure 3, the swash plate, which is at a inclination from the shaft, drives reciprocating seven pistons arranged at equal intervals around the shaft.

Figure 2 shows the pressure control valve used in this study. As shown in Figure, when the suction pressure (P_s) is lower than the set pressure, the valve will be opened and then the swash plate chamber pressure (P_{cr}) will be high due to the discharge pressure (P_d). The increasing of swash plate chamber pressure also will reduce the piston stroke because of decreasing the swash plate angle.

3. Dynamic Behavior of Swash Plate

Figure 3 shows the variable displacement mechanism used in this study, which consist of a lug plate with hinge hole, a swash plate with guide pin and a shaft. The sphere shaped portion of the guide pin that is a press fit into the swash plate, is moved within the guide hole of the lug plate. At the same time the center of the swash plate also is moved along the shaft. Therefore, this mechanism acts to increase or decrease the swash plate angle.

As can be seen in Figure, the instantaneous center of swash plate locates at the point of intersection between a vertical line extending from the swash plate center to the shaft and normal line of the guide hole which passes through the guide pin center.

3.1 Dynamic behavior analysis of swash plate

As shown in Figure 3, the forces acting on the swash plate are as follow:

$$F_{gas} = \sum A_p \cdot (P_c(n) - P_{cr}) \tag{1}$$

$$F_{inertia} = \sum (m_P + 2m_S) \cdot \omega^2 \cdot P.C.R \cdot tan(\beta) \cdot cos(\theta_{(n)} - \theta) \tag{2}$$

$$F_u = m_u \cdot y_u \cdot \omega^2 \tag{3}$$

$$F_d = m_d \cdot y_d \cdot \omega^2 \tag{4}$$

$$F_{spr} = k \cdot (L_{free} - L_{compression}) \tag{5}$$

Here, F_{gas} is the force generated by the different pressure between the gas pressure in cylinder and swash plate chamber pressure, $F_{inertia}$ is the reciprocal inertia force of pistons and shoes, F_u and F_d mean the centrifugal force of upper and down of swash plate respectively, and F_{spr} is the spring force between swash plate and lug plate.

Also, n means the number of cylinder and is seven in this study. PCR is the length from the center of swash plate to the center of piston, β means the swash plate angle, and θ presents the rotation angle of shaft as shown in Figure 3(b). From above equations, the moments applied to the swash plate can be obtained as follow:

$$M_{gas} = \sum \frac{F_{gas}}{cos(\beta)} \cdot e(n) \tag{6}$$

$$M_{inertias} = \sum \frac{F_{inertia}}{cos(\beta)} \cdot e(n) \tag{7}$$

$$M_{centrifugal} = F_u \cdot z_u + F_d \cdot z_d \tag{8}$$

$$M_{spr} = F_{spr} \cdot L_{spr} \tag{9}$$

As shown in Figure 3, the moment(M_{gas}) generated by gas force and inertia moment($M_{inertia}$) of piston act to decrease the swash plate angle, while the centrifugal moment($M_{centrifugal}$) of swash plate and spring moment (M_{spr}) tend to increase the swash plate angle. Therefore, in order to control the compressor displacement, the moments acting on the swash plate must be equal zero as follows:

$$\sum M = M_{gas} - M_{spring} - M_{centrifugal} + M_{inertia} = 0 \tag{10}$$

It can be obtained the swash plate chamber pressure according to equation(1) – equation(10).

$$P_{cr} = \sum P_c(n) + \frac{\sum F_{inertia}}{A_p} - \frac{\left(F_{spr} \cdot L_{spr} + F_u \cdot z_u + F_d \cdot z_d\right) \cdot cos(\beta)}{\sum e(n) \cdot A_p} \tag{11}$$

From the above equations, the swash plate chamber pressure can be calculated by four parameters: gas pressure in cylinder, inertia force, spring force and centrifugal force.

3.2 Analysis results

The results are obtained from the performance analysis program combining the compression process model with the dynamic behavior model. Figure 4 and Figure 5 show the variation of the force and the moment respectively with the rotation angle of shaft for 1000 rpm. As shown in Figure, it can be seen that the force and moment generated by gas pressure in cylinder are larger than the others. Figure 6 also shows the variation of the moment applied to the swash plate with the compressor speed. As can be seen, when the compressor speed increases, the moment generated by gas pressure intends to decrease due to the reduction of gas pressure during suction process, while the inertia moment and the centrifugal moment show trends to increase in proportion to the compressor speed.
The variation of gas pressure in swash plate chamber with the swash plate angle for 4000rpm are shown in Figure 7.
These all data are obtained from the performance analysis without valve loss. 'Gas pressure' marked in Figure 7 means the basic data and the others present to add each force to basic data. It can be also seen that the swash plate chamber pressure is almost constant as 3.6 kg/cm^2 during all swash plate angle. In this case, it should be note that it is impossible to control the compressor displacement due to the fact that the swash plate angle become maximum or minimum when the swash plate chamber pressure exceeds or drops 3.6 kg/cm^2.
Therefore, recently the hollow piston has been used to reduce the inertia force of the piston, and the material of swash plate also has been replaced aluminum with steel in other to increase the centrifugal force of the swash plate.

3.3 Controllability on the stopper height of suction valve

Figure 8 show the variation of gas pressure in cylinder with the stopper height of suction valve during suction process for 4000rpm. The gas pressure is shown to decrease as the stopper height decrease. Thus it can be seen that the swash plate chamber pressure depends on the stopper height of suction valve.
Figure 9 shows the effect of swash plate angle on the swash plate chamber pressure in terms of the stopper height of suction valve. At a given swash plate angle, the swash plate chamber pressure decreases as the stopper height of suction valve decreases. It can be also seen that it easy to control the swash plate angle due to the wilder range of swash plate chamber pressure, while the volume efficiency decrease due to the increase of valve loss, as the stopper height of suction valve decrease. Therefore, in the variable displacement swash plate type compressor, the appropriate stopper height of suction valve is very important parameter for the performance and the controllability.

4. CONCLUSIONS

A performance simulation program has been developed for the variable displacement swash plate type compressor in the automotive air conditioning system, which combines compression process analysis with a dynamic behavior analysis of swash plate. The following conclusions have been from this study.

1) The swash plate chamber pressure for controlling swash plate angle depends on the gas pressure in cylinder, inertia force of piston and shoe, and centrifugal force of swash plate.

2) It is possible to select the most appropriate stopper height of suction valve for swash plate angle controllability by executing the performance simulation program developed in this study.

NOMENCLATURE

A	area	(m2)	
F	force	(N)	
k	spring constant	(N/m)	
M	moment	(Nm)	
m	mass	(kg)	
y	length between centers	(m)	
ω	angular velocity	(θ/sec)	

Subscripts

c	cylinder
cr	swash plate chamber
d	lower
p	piston
s	shoe
spr	spring
u	upper

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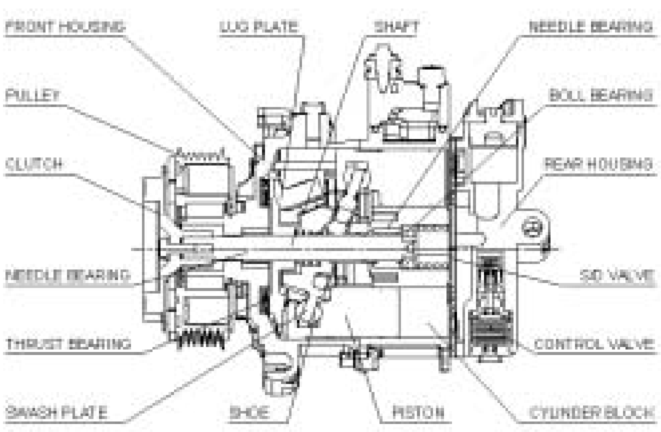


Figure 1 The overall structure of variable swash plate compressor

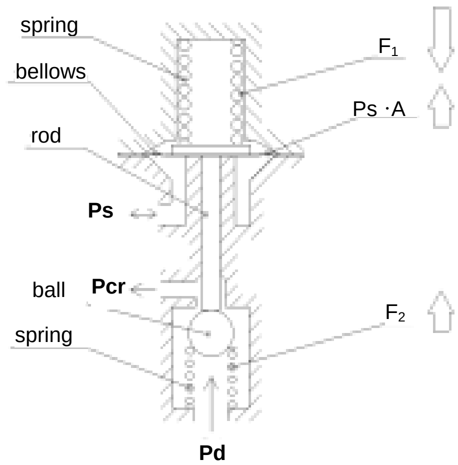
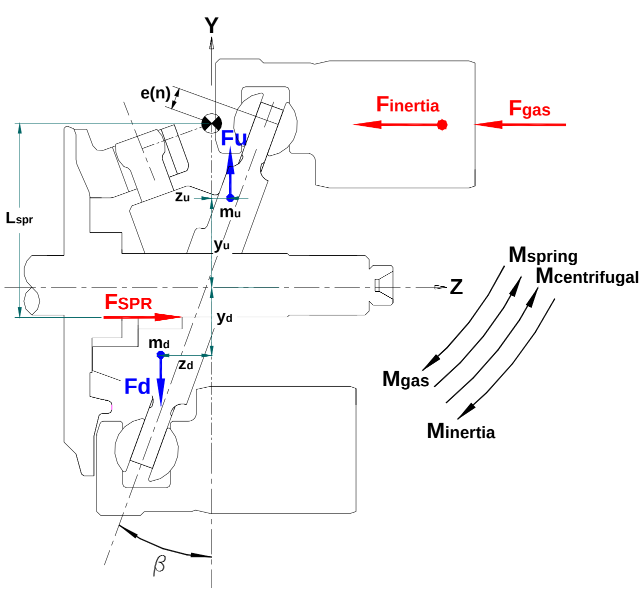
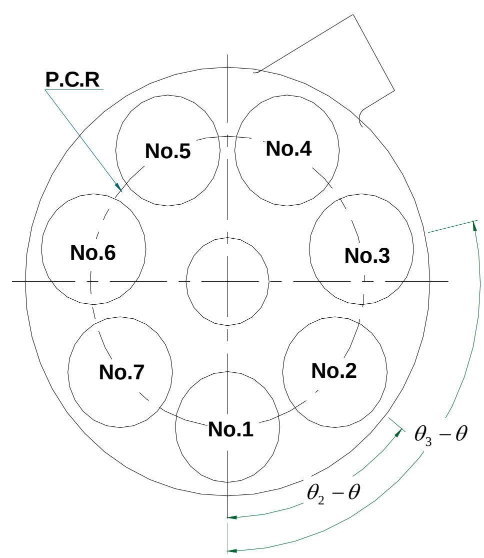


Figure 2 The pressure control valve



(a)



(b)

Figure 3 The variable displacement mechanism for swash plate compressor

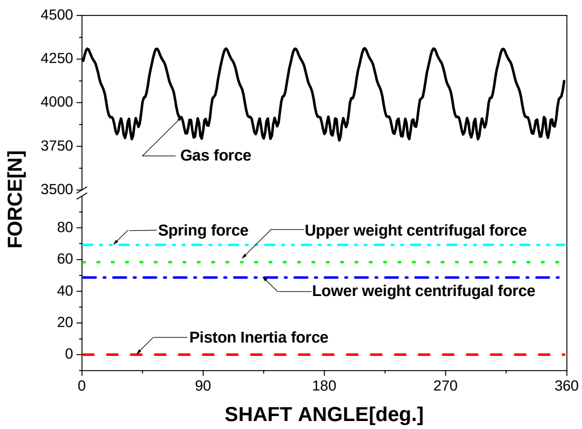


Figure 4 Variation of the forces with the rotation angle of shaft for 1000rpm

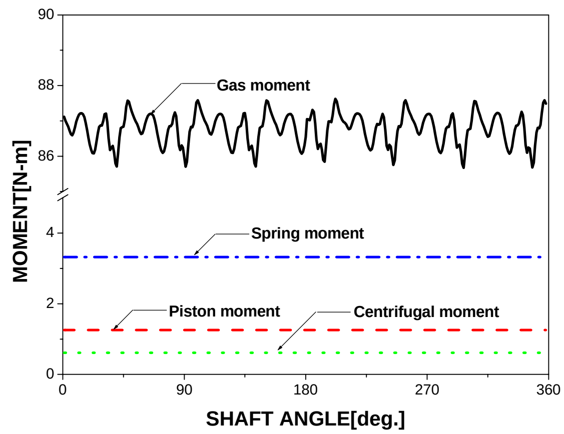


Figure 5 Variation of the moment with the rotation angle of shaft for 1000rpm

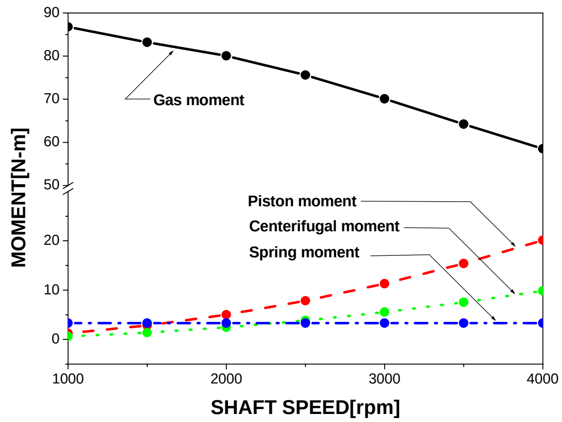


Figure 6 Variation of the moments with the compressor speed

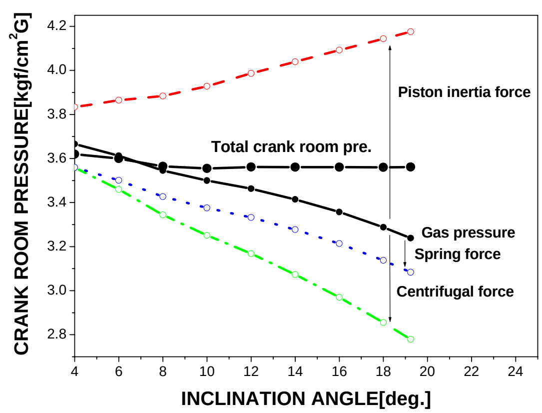


Figure 7 Variation of the swash plate chamber pressure with the swash plate angle for 4000rpm

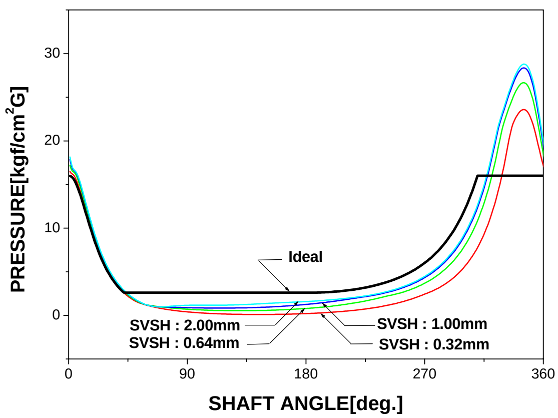


Figure 8 Variation of gas pressure in cylinder with the stopper height of suction valve for 4000rpm

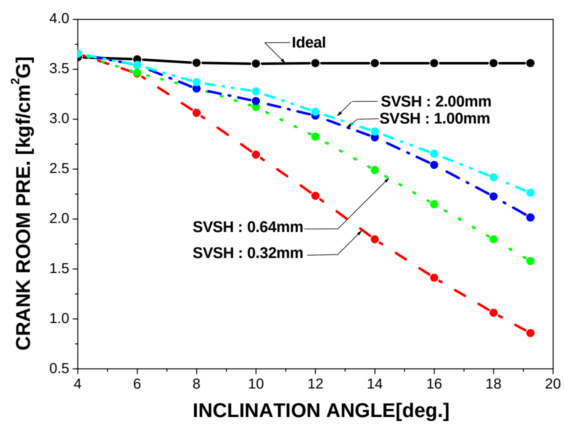


Figure 9 Effect of swash plate angle on the swash plate chamber pressure in teams of stopper height