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FLANK SEALING FORCE OPTIMIZATION IN A SCROLL COMpressor WITH SWING LINK

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ABSTRACT

A study is presented on the effect of a fixed scroll to crankshaft center offset upon the flank sealing force when using a swing link radial compliance mechanism. By introducing an offset the crank arm and radial compliance angle are affected so as to flatten cyclic variations in crankshaft torque and flank sealing force. Similarities and differences of the slider block and swing link mechanisms are presented. Comments are made with respect to advantages and disadvantages of the fixed scroll to crankshaft offset.

NOMENCLATURE

e orbiting radius (eccentricity)
b distance from drive pin centerline (P) to orbiting scroll center of mass (O)
d distance from drive pin centerline (P) to eccentric swing link center of mass (R)
r drive pin to crankshaft centerline distance
F force
M mass
O orbiting scroll center line and center of mass
P drive pin center line
R swing link center of mass
S crankshaft center line and rotation axis

RPM rotations per minute

Subscripts

b swing link
fs flank sealing
ib swing link inertia
P drive pin
s orbiting scroll
tg tangential, gas
rg radial, gas
tp tangential, eccentric pin
rp radial, eccentric pin

Greek symbols

θ radial compliance angle
α swing link center of mass angular offset
ξ crankshaft angle

INTRODUCTION

There are three issues that distinguish the scroll compressors among other gas compression machines, respectively the quiet operation, the ability to pump liquid, and high energy efficiency.

The scroll compressor has an advantage over the reciprocating or rotary compressors in that it does not suffer mechanical damage during liquid ingestion. This is because the scrolls are provided with a radial compliance mechanism that allows the scrolls to disengage in the event of liquid compression. In such a case, the compressor turns merely into a pump. Typical radial compliance mechanisms also split the driving force into a tangential force meant to balance the friction and compression forces and a radial component to ensure the flank contact between wraps and thus the sealing between compression pockets.

Another advantage is the smoother variation of the crankshaft torque as the compressing gas is distributed in multiple pockets with only two openings each crankshaft cycle.

The crankshaft torque is directly proportional to the compression force and the torque arm, respectively the distance between the compression force vector and crankshaft rotation axis. A means of further leveling the crankshaft torque
variation is to provide varying distance to the vector, with a minimum value of this distance in phase to the maximum compression force. However, a corresponding increasing variation in flank sealing force may result. The swing link radial compliance mechanism can level this variation as well.

**SWING LINK RADIAL COMPLIANCE MECHANISM MODELING**

**Dynamic model**

A radial compliance mechanism often used in scroll compressors is a slider block. The ability of the slider block version to reduce the torque variation in scroll compressors is presented in [1]. The slider block allows the orbiting scroll to move the center of mass during crankshaft rotation. A side effect of the center of this movement is that the centrifugal force and thus the radial flank sealing force varies with crankshaft angle.

The radial compliance mechanism considered in the present study is a swing link. The force diagram for this swing link is presented in Figure 1.

The force balance in X and Y directions as well as the moments about orbiting scroll centerline (O) are presented in equations 1-3:

\[ \sum F_x = F_{ls} - F_{fs} - F_{fg} = F_{rp} + F_{ib} \cos(\alpha) \]  
\[ \sum F_y = F_{tg} - F_{tp} - F_{rg} + F_{ib} \sin(\alpha) \]  
\[ \sum M_O = F_{rp} b \cos(\theta) - F_{tp} - F_{rg} b + F_{ib} e \sin(\alpha) \]

where:

\[ F_{ls} = M_b (2 \pi RPM/60)^2 \]  
\[ F_{ib} = M_b (2 \pi RPM/60)^2 \sqrt{e^2 + ((d-b) \cos(\theta))^2} \]  

The fixed scroll may be physically translated by an offset defining a locus shown in Figure 1. Consequently the orbiting radius (eccentricity) will vary with the crankshaft angle.

As proven in [1], the offset causes flank contact force variation only because of the variation in centrifugal force. The swing link brings an additional effect. The centrifugal force changes in same manner the flank sealing force, respectively a positive offset increases the distance between the orbiting scroll center of mass (O) and crankshaft rotation axes (S), thus the flank contact force is increased. However, the positive offset causes an increase of the radial compliance angle \( \theta \). The increased radial compliance angle decreases the flank contact force due to the radial component of the drive force. Thus, the swing link mechanism has an inherent compensating effect.

The offset (assumed along line e) causes a change of the radial compliance angle. Table 1 shows the relation between offset values and the radial compliance angle.

<table>
<thead>
<tr>
<th>Offset, inches</th>
<th>-0.10</th>
<th>-0.08</th>
<th>-0.06</th>
<th>-0.04</th>
<th>-0.02</th>
<th>0.00</th>
<th>0.02</th>
<th>0.04</th>
<th>0.06</th>
<th>0.08</th>
<th>0.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compliance angle, degree</td>
<td>-14.1</td>
<td>-10.2</td>
<td>-6.8</td>
<td>-3.8</td>
<td>-1.1</td>
<td>1.4</td>
<td>3.7</td>
<td>5.9</td>
<td>8.0</td>
<td>10.0</td>
<td>12.0</td>
</tr>
</tbody>
</table>

**Offset effect**

Figure 2 plots values of the flank contact force versus orbiting radius variation due to the offset for different instantaneous values of the tangential gas force obtained by solving the system of equations 1-3.
Figure 2 shows the flank contact force for a gas tangential force varying from 100 to 1000 lbf. The gas radial force is assumed to be 10% the gas tangential force value. Other numerical values substituted in equations 1-3 are for a typical four ton scroll compressor. The variable on the X axis represents the fixed scroll offset. A positive offset corresponds to the orbiting scroll center line moving further from the crankshaft centerline.

Equations 1-3 show that the following changes have opposite effects:
• generally, an increase of the gas tangential force reduces the flank sealing force;
• an increase of the orbiting scroll and swing link centrifugal forces increases the flank sealing force.

The curves in Figure 2 show also that the offset effect on flank sealing force depends on the amplitude of the tangential gas force. For gas tangential force less than 400 lbf, the flank contact force increases by increasing the orbiting radius. For gas tangential force greater than 400 lbf, the flank contact force decreases by increasing the orbiting radius. There is negligible change in the value of flank sealing force for a gas tangential force of 400 lbf. For an offset of -0.075", the flank contact force is constant.

The value of the orbiting radius, e, varies with crankshaft angle in a sinusoidal manner. The flank sealing force presented in Figure 2 is plotted vs. the crankshaft angle, $\xi$, in Figure 3 for a 0.010" offset. The orbiting scroll eccentricity is a function of crankshaft angle and it is calculated as follows:
$$e(\xi) = \text{offset} \cdot \sin(\xi)$$

where $\xi$ is the crankshaft angle.

Figure 3 shows the variation of flank sealing force with crankshaft angle for several values of tangential gas force for a phase angle of the offset. The flank sealing force is inversely proportional to the tangential gas force. However, the offset effect changes qualitatively when increasing the tangential gas force. For an optimal choice of the phase angle, the offset reduces the maximum sealing force and increases the minimum sealing force. This selective effect can be seen for the phase angle case depicted in Figure 3 at a crankshaft angle value of about 180°.

Example
For an example, the tangential gas force variation versus crankshaft angle as determined for a scroll compressor operating at a highly loaded condition is plotted in Figure 4. The radial gas force, $F_r$, for this condition is about 10% the average tangential gas force, $F_w$.

Figure 5 shows the flank sealing force versus the crankshaft angle for an offset of 0.020" and a tangential gas force variation as shown in Figure 4. Eight different values for the phase between offset and pressure variation are considered. This figure shows the offset effect emphasized in Figure 3 for the tangential gas variation illustrated in Figure 4. The flank sealing force is inversely proportional to the variation of the gas tangential force. Flank sealing force variation can be reduced for a phase angle about 90°.

Figure 6 shows the values calculated for torque versus crankshaft angle.

For a better understanding of the offset effect on torque variation the peak-to-peak variations are plotted in Figure 7 for several offset values versus the phase angle. In Figure 7 one can determine for a given offset the phase angle range where a flattening of the crankshaft torque variation can be obtained. Next from Figure 5 the specific phase angle to minimize flank sealing force variation can be obtained.

CONCLUSIONS
The effect of the fixed scroll offset is more complex in the case of a swing link compared to a slider block. It is shown that the centrifugal force has an opposite effect than the radial compliance angle upon the flank sealing force. An appropriate choice of the fixed scroll offset will reduce the torque variation and at the same time reduce the variation of the flank contact force. This implies a reduced value of the maximum flank contact force while the minimum flank contact force still suffices for sealing. The lower value of the maximum sealing force means less friction loading, thus an opportunity for a more efficient compressor as well as a quieter scroll compressor.

REFERENCES
FIGURES

Flank Sealing Force, Lbf

Ftg = 100 Lbf

Orbiting radius variation, in

Figure 2

Ftg varies from 300 to 900 Lbf (top to bottom) w/ 0.010" offset

Figure 3
Figure 4

Figure 5

Flank Sealing Force, %

Phase angle

Offset = 0.020"