2002

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C10-1

FRICITION AND WEAR OF THE VANE/ROLLER SURFACES DEPENDING ON SEVERAL SLIDING CONDITION FOR ROTARY COMPRESSOR

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ABSTRACT

One of the serious challenges in developing rotary compressor with HFC refrigerant is the prediction of friction forces and wear amounts between vane and roller surface. In this study, the tribological characteristics of sliding surfaces using roller-vane geometry of rotary compressor were investigated. The sliding tests were carried out under various sliding speeds, normal loads and surface roughness. During the tests, friction force, wear scar width, and surface roughness were monitored. Because severe wear was occurred on vane surface, TiN coating was applied on sliding surfaces to prolong the wear-life of vane-roller interfaces. From the sliding tests, it was found that there was the optimum initial surface roughness to break in and to prolong the wear life of sliding surfaces.

INTRODUCTION

Because of the ozone layer depletion issue, alternative refrigerants HCFCs have been examined. In general, HCFCs or CFCs have better lubricity than HFCs. Since HFCs do not have chlorine atom, which react with iron surfaces to form ferrous chloride layers, lower extreme pressure is expected in HFCs. Thus, in order to develop the high efficiency and high reliable rotary compressors with HFCs refrigerants, the improvement in mechanical efficiency and wear resistance are becoming more important.

As the trend of the high speeds and loads was continued for the high efficiency and inverter of the compressor, the sliding condition of the surfaces was severe, such as shaft, bearing, and driving parts so on [1-2]. Therefore, the development of lubricating structure and the investigation of the material were required [3-4]. Also, many researchers exert themselves for the improvement of wear resistance in order to reduce frictional losses and secure the reliability in the bearing parts [5]. In rotary compressors, wear takes place mainly between vane and roller, shaft and bearing, roller and flange. Among these sliding pairs, the wear between vane and roller is the most critical, since these surfaces operate under boundary and mixed lubrication condition.

In this study, the tribological characteristics of vane-on-roller geometry in the mixing environment of polyolester (POE) and lubricant and R410A (HFC32/125, 50/50wt.%) refrigerant were evaluated.
EXPERIMENTS

TiN Coating on Vane Surface

The hard coating has typically been considered more effective than other coatings in resisting abrasive and adhesive wear. Also, the hard coating is expected to be compatible with the vane material, which is made of SKH51. Therefore TiN coating for improving the tribological characteristics were selected and applied on vane surface. The wear characteristics of a coating can depend greatly on the deposition method. Because physical vapor deposition (PVD) can generally produce less distortion of the substrate and a finer surface finish, it was selected for this study. And TiN was deposited by arc ion plating as a manufacturing method. The thickness of TiN coating is 5 μm.

Test Apparatus and Procedure

The vane-on-disk geometry was used in the sliding tester. The disks were cut out from the cylindrical bar of the roller material. The vane sample was also machined from the same type of vane material as is used in the real compressor in order to ensure the mechanical properties. The TiN coating was applied only on the vane surface. The vane material was made of SKH51 and had hardness in the range of 850~900 Hv. The roller material was made of Ni-Co-Mo gray cast iron and had hardness in the range of 550~600 Hv. The surface roughness of the disk was grounded to 0.14 μm Ra, which is close to the original roughness of the roller. The shape of the specimens is shown in Fig. 1.

The sliding testes were carried out repeated pass sliding using a vane-on-disk geometry tribometer under the various normal loads and sliding speeds in R410A/POE mixed environment, as shown in Fig. 2. This tribometer was capable of measuring the frictional forces and normal forces. To maintain a stable rotation, a servomotor was used to rotate the shaft. A vane was located in a holder that was clamped to a fixed arm with a transducer for friction force. The lower flat disk (roller material) was mounted on a rotating shaft in an oil bath. The contact was achieved by pressing the vane against the flat surface under a normal load applied by a spring force, which reduced the variation of normal force during sliding.

And, step load tests were performed in R410A/POE mixed environment. The initial load was 40 kg and it was increased by 20 kg every 5 min to severe wear or scuffing. After each step load test, the surface roughness of vane tip was measured with surface profilometer, and wear scar width was examined using optical microscope. All tests were performed at 50 °C.

RESULTS

Wear and Friction under the Normal Loads and Sliding Speeds

The wear scar widths for various normal loads and sliding speeds are shown in Fig. 3. The amount of wear was lower for TiN coated vane than uncoated original vane because wear resistance of the vane was improved by TiN coating. As shown in Fig. 3a, the amount of wear of TiN coated vane was a few higher in ranges of 30~70 kg. But at 90 kg, wear of uncoated original vane was increased, accompanied by rapid increasing of friction force. Besides, the amount of wear of the vane was increased with increasing normal load. Also, as the sliding speed increased, the amount of wear of the vane increased and decreased beyond 1,000 rpm. That is reason that the
lubrication regime shifted from the boundary lubrication to the mixed lubrication.

Fig. 4 shows the wear coefficient $K$ of TiN coated vane and original vane for the various sliding speeds. At all speeds, the wear coefficient of TiN coated vane was lower than that of original vane. Therefore, the wear resistance of the coated vane is better.

**Analysis of Worn Surfaces**

In Fig. 5, the surfaces of the vane tip with various normal loads after sliding testing at 1,000rpm for 2 hours appear and also EDX analyses before sliding are showed. As the normal load increased, the wear width of vane tip increased and the surfaces was smoother. Fig. 5(c) showed the worn surface that was divided into three-substrate, worn TiN, and TiN coating. In Fig. 5(d) and (e), the TiN quantity before and after sliding changed.

**Changes in Surface Roughness**

The changes of surface roughness of the coated vane depending on the initial surface roughness were observed with three different surface roughnesses. The results of changes of surface roughness are shown in Fig. 6. Loads were increased in steps as seen in lower part of the figure. Smoothing first occurred for the original rough and intermediate surfaces. All surfaces had about the same roughness after about twenty minutes of sliding. After that, as the load increased the surfaces became rougher for all cases. These test series were ended when severe roughening occurred. The surfaces with original intermediate roughness roughened more slowly than did those with the rougher and smoother surfaces.

**CONCLUSIONS**

In order to improve the wear resistance of a rotary compressor TiN coating was applied on the vane surface, and the tribological characteristics of sliding surface using roller-vane geometry were evaluated under the R410A/POE mixed environment. These results suggest the following conclusions.

1. The TiN coating for the vane surface improves the wear resistance, compared with uncoated original vane in roller-vane geometry.
2. As the normal load increased in the vane-on-disk, the wear amount increased. As the sliding speed increased, the amount of wear of the vane increased and decreased beyond 1,000rpm. That is reason that the lubrication regime shifted from the boundary lubrication to the mixed lubrication.
3. From the sliding tests of coated vanes having three different surface roughnesses, it was found that there was the optimum initial surface roughness, which improves the load carrying capacity and prolong the wear life of sliding surfaces.

**REFERENCES**

Table 1 Surface properties of the roller and vane

<table>
<thead>
<tr>
<th>Test Specimen</th>
<th>Surface Roughness (Ra; μm)</th>
<th>Hardness (Hv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller</td>
<td>0.14</td>
<td>550 ~ 600</td>
</tr>
<tr>
<td>Vane</td>
<td>Substrate</td>
<td>850 ~ 900</td>
</tr>
<tr>
<td></td>
<td>After TiN coating</td>
<td>1250~1300</td>
</tr>
</tbody>
</table>

Fig. 1 The shape of roller and vane specimen

Fig. 2 Vane-on-disk geometry of the sliding test
Fig. 3 Wear scar width of the vane tip under various normal loads and sliding speeds.
Fig. 4 Wear coefficient $K$ of the vane at each sliding speeds
Fig. 6 Changes of surface roughness depending on the initial surface roughness

Fig. 5 Microscopic pictures and EDX analysis of the wear of the vane tip at a sliding speed of 1000rpm with various normal loads

Fig. 6 Changes of surface roughness depending on the initial surface roughness