Simulation of Crankshaft Torsional Vibration by Flexible-body Dynamics

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The reciprocating compressor, as core equipment, plays an increasingly important role in the modern petrochemical industry.

The large-scale multi-row reciprocating compressor is rapidly expanding.
Introduction

- The crankshaft is the main loading part of reciprocating compressor.
- The crankshaft torsional vibration has become the bottleneck of development of the large-scale multi-row reciprocating compressor.
The engineering case

- We choose the 6M50 reciprocating compressor with 6 rows and the maximum piston force of 50 tons as an example to study.
- The crankshaft material is 35CrMo, and it has 6 cranks.
- Each cylinder was arranged in one row
The engineering case

we choose the 6M50 reciprocating compressor as an example to study

The main technical parameters of 6M50 compressor as follows

<table>
<thead>
<tr>
<th>List</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of rows</td>
<td>6</td>
</tr>
<tr>
<td>Suction pressure((MPa))</td>
<td>0.1</td>
</tr>
<tr>
<td>discharge pressure((MPa))</td>
<td>31.4</td>
</tr>
<tr>
<td>The stroke of pistons((m))</td>
<td>0.45</td>
</tr>
<tr>
<td>Rotational speed((r\cdot min^{-1}))</td>
<td>300</td>
</tr>
<tr>
<td>Crank throw((m))</td>
<td>0.175</td>
</tr>
<tr>
<td>The length of the connecting rod((m))</td>
<td>0.95</td>
</tr>
<tr>
<td>The maximum gas force((kN))</td>
<td>380</td>
</tr>
<tr>
<td>The maximum piston force((kN))</td>
<td>363</td>
</tr>
<tr>
<td>The diameter of the main shaft((mm))</td>
<td>300</td>
</tr>
<tr>
<td>The cylinder diameter of level one((mm))</td>
<td>1390</td>
</tr>
</tbody>
</table>
The engineering case

- The major accidents happened on the crankshaft are the crank pins of the first row and the second column scraping frequently.
- The crankshafts average life were only 202h and 304h respectively.

![Crank pin](image1)
![Crankshaft](image2)
In order to eliminate the accidents, the company made a new crankshaft from the two waste crankshafts. The first and two rows were connected with the other four row-by-a rigid coupling.
Simulation model

- To analyze the crankshaft accidents, this paper proposed a new calculation method of the crankshaft torsional vibration based on flexible multi-body dynamics theory.
- The new crankshaft and the old one were both simulated by ADAMS respectively, and analyzed the crank pin failure reasons.

The modeling steps as follows
Simulation model

1) The crankshaft MNF files
Firstly, the crankshaft 3-D solid model was established in 3-D software
2) the 3-D solid model was imported into ANSYS software, and physical parameters of the crankshaft were input. The crankshaft model is divided into 99519 elements of SOLID73.
3) At last a MNF file was output to ADAMS for torsional vibration model establishment
Simulation model

The seven-order
The eight-order
The nine-order
The ten-order
## Simulation model

<table>
<thead>
<tr>
<th>order</th>
<th>frequency (Hz)</th>
<th>mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>7.36</td>
<td>The first-order bending in XOZ plane</td>
</tr>
<tr>
<td>8</td>
<td>7.94</td>
<td>The first-order bending in YOZ plane</td>
</tr>
<tr>
<td>9</td>
<td>21.54</td>
<td>The second-order bending in XOZ plane</td>
</tr>
<tr>
<td>10</td>
<td>22.61</td>
<td>The second-order bending in YOZ plane</td>
</tr>
<tr>
<td>11</td>
<td>37.87</td>
<td>The first-order torsion</td>
</tr>
<tr>
<td>12</td>
<td>39.24</td>
<td>The third-order bending in XOZ plane</td>
</tr>
</tbody>
</table>
Simulation model

- In ADAMS the crankshaft is connected with the connecting rod, cross head, piston rod and the piston
- Add the movement and boundary conditions to the model
Analysis of result

It can be seen from this picture that the crank pin torsional vibration of the new crankshaft decreased greatly. The maximum torsional displacement of the first row crankpin of the old crankshaft is about -3.30deg
Analysis of result

It can be seen that the new crankshaft fluctuation value has greatly reduced, which is almost similar to the rigid body dynamics.
Analysis of result

The crankshaft torsional vibration has a peak in 5 Hz and its integral multiples. These peaks are the comprehensive effect of the each force results.
the piston force of the old crankshaft has a large torsional vibration amplitude. In the compressor, reciprocating mass of the low stage at the first and the second rows are very large, and the piston pin force of these stage could exceed the design value.
# Failure Analysis of Crankpin Bearing

<table>
<thead>
<tr>
<th></th>
<th>First column</th>
<th>Second column</th>
<th>Third column</th>
<th>Fourth column</th>
<th>Fifth column</th>
<th>Sixth column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design value(MPa)</td>
<td>8.3</td>
<td>7.8</td>
<td>6.6</td>
<td>7.9</td>
<td>9.2</td>
<td>10.6</td>
</tr>
<tr>
<td>Old crankshaft(MPa)</td>
<td>15.2</td>
<td>14.5</td>
<td>7.9</td>
<td>8.4</td>
<td>10.4</td>
<td>11.1</td>
</tr>
<tr>
<td>New crankshaft (MPa)</td>
<td>9.0</td>
<td>8.7</td>
<td>6.8</td>
<td>8.0</td>
<td>9.3</td>
<td>10.7</td>
</tr>
</tbody>
</table>

The maximum crank pin bearing pressure ratio of each row of 6M50 compressors.
## Failure Analysis of Crankpin Bearing

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<thead>
<tr>
<th>Design value</th>
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<th>Fourth column</th>
<th>Fifth column</th>
<th>Sixth column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old crankshaft</td>
<td>2.9</td>
<td>2.8</td>
<td>2.0</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>New crankshaft</td>
<td>1.8</td>
<td>1.8</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>

The crank pin bearing impact coefficient of each row of 6M50 compressor
Conclusion

- This paper proposed a new calculation method based on the flexible multi-body dynamics theory.
- According to this method, the torsional vibration characteristic of a 6 row crankshaft were calculated.
- The results show that torsional natural frequency of the crankshaft before transformation is close to the excitation frequency, so the crankpins of the first and the second row often cracks because of the torsional vibration.
- After transformation, the new crankshaft natural frequency is away from the excitation frequency, and the vibration amplitude of the crankshaft decreases substantially.
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Thank you!