Nonlinear Contact Stress Analysis of Bolted Poles
Hengfeng Chen, Senlin Huang
TECO FA Global Wuxi R&D Center, Wuxi TECO Electric&Machinery Co.Ltd, Jiangsu, China

Abstract
ANSYS has powerful functions of mechanical analysis, such as contact stress analysis, which can include structure large deformation and material nonlinear property. In electric machine, such as salient synchronous motor with bolted pole configurations, structural forces (centrifugal force and bolt pull force) and magnetic forces (torque) are applied on the poles, and contact stress of interfaces between poles and rims becomes very complicated, which is the key consideration of the bolted pole design. In this paper, we carry out a nonlinear contact stress analysis of the bolted pole using ANSYS. The results give us a good guide of bolted pole design.

Introduction
Comparing to dovetail pole structure, bolted pole configuration is much easier to be installed, and is widely used in large salient pole motor. For large motor with very low speed, centrifugal force is not large, while magnetic pull torque may be very large and becomes a key consideration. Even the magnetic torque may be large enough to pull the pole off the rim. Therefore, for bolted pole configuration, bolt pull force is very important, which withstands not only the centrifugal force, but also the magnetic pull torque. The bolt pull force must be applied properly, and will not be small to cause pole pulled off and large to make pole or rim yielding. In the following, some nonlinear contact stress analyses of the bolted pole are carried out using ANSYS. The results give us a good guide for bolted poles design.

Geometry and FEA model
A 3D model of a large synchronous motor with 18 salient poles is shown in Figure 1. Each laminated pole is bolted by 8 bolts on the spider rim. The stud and spider rim help to fix pole. Since the poles are symmetric in circumference and long distance in axial direction, a 2D 1/18 FEA model (one pole) is created. As the contact area between the poles and the spider rim is high stress and strain region we care, element size of it should be small enough to make contact stress converge. Table 1 shows material properties of pole, stud and spider rim.

![Figure 1. FEA model](image-url)
### Table 1 Material properties

<table>
<thead>
<tr>
<th>Item</th>
<th>Density (Kg/m³)</th>
<th>Possion’s Ratio</th>
<th>Elastic Modulus (MPa)</th>
<th>Yield Strength (MPa)</th>
<th>Tangent Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pole (lamination)</td>
<td>7870</td>
<td>0.29</td>
<td>75269</td>
<td>241.38</td>
<td>784.08</td>
</tr>
<tr>
<td>Bolt</td>
<td>7870</td>
<td>0.29</td>
<td>97244</td>
<td>370</td>
<td>478.81</td>
</tr>
<tr>
<td>Spider Rim</td>
<td>7870</td>
<td>0.26</td>
<td>76597</td>
<td>248.28</td>
<td>771.10</td>
</tr>
</tbody>
</table>

### Nonlinear Contact Stress Analysis

As we know, contact problem is highly nonlinear and requires significant computer resources to solve, and it presents two significant difficulties. First, we generally do not know the regions of contact until we've run the problem. Contact surfaces can come into and go out of contact with each other in a largely unpredictable and abrupt manner. Second, most contact problems need to account for friction. Frictional response can be chaotic, making solution convergence difficult. Therefore, solution convergence is the main consideration of contact problem.

In the following analyses, two parameters, i.e. contact stiffness and element size, are modified to make stress solution converge. For each FEA model with certain element size, contact stiffness should be modified from 0.01 to 1 until the solution is convergent.

The following contact options are set for all analyses.

- Contact face: inner face of pole, Conta172 element
- Target face: outer face of spider rim, Targe169 element
- Unsymmetrical contact
- Friction coefficient =0.2
- Default options otherwise specified

#### Contact stress for minimal and maximal bolt pretension

As stated above, the pole is fixed by bolts with pretension that cannot be small to cause pole pulled off and large to make pole or rim yielding. With minimal and maximal pretension, the motor should run normally in rated condition and 20% over speed condition and in the case we want to know how large the contact stress is. The minimal and maximal pretensions are 320272 N per bolt and 651998 N per bolt, respectively.

As table 2 shows, for each element size, after many contact stiffness modifications, the contact solution arrives at convergence and a maximal contact stress can be obtained. Also, when the element size becomes smaller, the maximal contact stress is convergent and almost unvaried. Figure 2 shows the contact stress for minimal pretension, and figure 3 shows the contact stress for maximal pretension.
### Table 2 Maximal Contact Stress (MPa)

<table>
<thead>
<tr>
<th>Boundary Conditions</th>
<th>Element size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Minimal pretension</td>
<td></td>
</tr>
<tr>
<td>Running speed</td>
<td>112</td>
</tr>
<tr>
<td>Minimal pretension</td>
<td></td>
</tr>
<tr>
<td>20% over speed</td>
<td>98.2</td>
</tr>
<tr>
<td>Maximal pretension</td>
<td></td>
</tr>
<tr>
<td>Running speed</td>
<td>166</td>
</tr>
<tr>
<td>Maximal pretension</td>
<td></td>
</tr>
<tr>
<td>20% over speed</td>
<td>158</td>
</tr>
</tbody>
</table>

**Figure 2. Contact Stress (for minimal pretension)**

- 227Mpa (Running speed)
- 207Mpa (20% over speed)

**Figure 3. Contact Stress (for maximal pretension)**

- 288Mpa (Running speed)
- 281Mpa (20% over speed)
Maximal torque calculation

For minimal and maximal pretension, we want to know how large the pull torque is that the motor can withstand. However, the maximal torque calculation is an inverse problem. Given a torque, a contact analysis is carried out, and the contact status of the system is determined. When the contact status is open but near contact, the maximal torque is obtained. Therefore, the calculation is trial running and time-consuming.

For minimal pretension, after many torque trials, when a torque (23872601 N.m) is applied on the pole, the contact status is shown as figure 4. The pole and the spider rim are closely abrupt from contact. Also the contact stress is very little (6.74MPa) as figure 5 shows.

![Figure 4. Contact Status and Slide (2-closed and sliding, 1-open but near contact)](image1)

![Figure 5. Von Mises Stress (Max. 88Mpa) and Contact Stress (Max. 6.74 MPa)](image2)

Also, for maximal pretension, after many torque trials, when a torque (73453808 N.m) is applied on the pole, the contact status is shown as figure 6. The pole and the spider rim are closely abrupt from contact. Also the contact stress is very little (61.2MPa) as figure 7 shows.
Conclusion

Through nonlinear contact stress analysis, the minimal and maximal bolt pretension can be obtained, and also the maximal torque can be determined. These can help to apply proper pretension on the bolt, and determine the proper speed and mechanical power of a large motor.

Acknowledgement

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References

1. ANSYS Help Document