40th Turbomachinery Symposium

Higher reliability of oil operated bolt tensioner for larger-sized steam turbine casings with higher inlet steam pressure

Mitsubishi Heavy Industries Compressor Corporation
Kyoichi Ikeno
Customer need for bolt tightening of steam turbine

Customer need = More safety maintenance working without heating operation

Necessity of using bolt tightening tool with explosion proof type

Applicable tool = Oil operated bolt tensioner
Tightening method:
To extend and tighten bolts by hydraulic oil pressure
Note: a) Not necessary to heat bolt, b) Satisfied with explosion proof
Classification of casing bolt tightening tool

Over M72 bolt size (Bolt diameter $\geq$ 72)

Use special tool for tightening

Non explosion proof type

Explosion proof type

Bolt heater
Extend and tighten a bolt by heat

Oil operated bolt tensioner
Extend and tighten a bolt by oil pressure

Upper casing
Lower casing
Casing bolt with hole
Casing bolt without hole
## Comparison of heater and oil operated types

<table>
<thead>
<tr>
<th>Function</th>
<th>Coil heating type bolt heater</th>
<th>Oil operated types bolt tensioner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working time</td>
<td>⬤ (45-60 min/each)</td>
<td>⬤ (5-10 min/each)</td>
</tr>
<tr>
<td>Work ability</td>
<td>⬤ (Weight : 1-2kg)</td>
<td>⬤ (Weight : 30-50kg)</td>
</tr>
<tr>
<td>Life cycle</td>
<td>⬤ (Coil : Consumable)</td>
<td>⬤ (Semi permanently)</td>
</tr>
<tr>
<td>Safety</td>
<td>⬤ (Heating operation)</td>
<td>⬤ (High oil pressure operation)</td>
</tr>
<tr>
<td>Bolt pitch</td>
<td>⬤ (Narrow)</td>
<td>⬤ (Wide)</td>
</tr>
</tbody>
</table>

Advantages of Oil operated bolt tensioner:
1) Saving work-time
2) More safety working without heating operation
3) Reducing maintenance cost thanks to longer life-time in use
**How to use oil operated bolt tensioner**

1. To set ram chair and cylinder with piston
2. To supply pressurized oil to extend bolt
3. To tighten nut by bar under oil supply
4. To release oil supply, then, bolt to be tightened with remain extension

- Extension = \( \bar{\nu} \)
- Shrinkage = \( \bar{\nu} \)

\[
\text{Bolt tightening with remain extension (} \, \bar{\nu} \, \text{1} - \, \bar{\nu} \, \text{2})
\]

Nut to be up

Nut to be down

Oil supply

Oil release
Conventional type of oil operated bolt tensioner

Technical issues

Bolt tension force

Oil leakage

1) Oil leakage from tensioner tool
   - High oil supply pressure
2) Water leakage at casing hydro test
   - Low tightening force
     (Insufficient bolt tension force)

Experienced problem

Necessity of Tensioner improvement
**Advanced type of oil operated bolt tensioner (1/3)**

Solution to technical issues of conventional oil operated

Advanced type to be developed by Double piston & Hybrid sealing structures

**Features of Advanced type:**
1) To prevent oil leakage
   - Hybrid sealing of back-up-ring and O-ring
2) To increase bolt tightening force
   - 2.5 times up of oil pressure surface by double piston
**Advanced type of oil operated bolt tensioner (2/3)**

**Size comparison to conventional oil operated type**

<table>
<thead>
<tr>
<th>Bolt size</th>
<th>Conventional Outer dia.</th>
<th>Advanced Outer dia.</th>
<th>Conventional Height</th>
<th>Advanced Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>M80</td>
<td>206</td>
<td>203</td>
<td>165</td>
<td>212</td>
</tr>
<tr>
<td>M90</td>
<td>222</td>
<td>222</td>
<td>185</td>
<td>238</td>
</tr>
<tr>
<td>M110</td>
<td>260</td>
<td>260</td>
<td>225</td>
<td>265</td>
</tr>
</tbody>
</table>

**Advanced type ;**
Compact design to keep almost same outer diameter

**Effect;**
Not necessary to extend casing bolt pitch
- Keeping same casing seal performance
**Advanced type of oil operated bolt tensioner (3/3)**

### General specification

**Piston B**

**Piston A**

**Cylinder A**

**Cylinder B**

**General**

1) Structure = Double piston type

2) Oil seal = Back-up ring and O-ring

3) Oil supply pressure
   
   = About Max. 150MPa

4) Maximum bolt tension force

   Up to 80% of bolt material yield force

5) Applicable bolt size

   M80, M90, M100, M110

   Note: M ʷʷ, ʷʷ = Bolt diameter [mm]

**Back-up-ring**

(Fluorocarbon Polymers)

**O-ring**

(Nitrile Rubber)

---

**Advantages compared to conventional type**:

1) 1.5 times up of bolt tension force

2) Enhancement of oil seal performance

3) Applicable to same bolt size and pitch
**Reliability check of advanced type (1/4)**

**Reliability check list of oil operated bolt tensioner**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Check point</th>
<th>Evaluation</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevention of brittle fracture</td>
<td>Impact value</td>
<td>Material test</td>
<td>Over 37.6J/cm² (Brittle fatigue limit)</td>
</tr>
<tr>
<td>Prevention of tension failure</td>
<td>Average stress</td>
<td>3D FEM analysis</td>
<td>Less than material yield stress</td>
</tr>
<tr>
<td>Prevention of low cycle fatigue failure</td>
<td>Peak stress</td>
<td>Langer’s equation</td>
<td>Over 2,000 cycles*1</td>
</tr>
</tbody>
</table>

*1: 2000 cycles > 30 casing bolts per turbine □ 2 numbers (Disassembly/Assembly) □ 30 years

**Material test**

Application of 17-4PH material = Higher tensile strength material

To prevent brittle fracture □ Impact value required to be over 37.6J/cm²

<table>
<thead>
<tr>
<th>Specification</th>
<th>Yield stress</th>
<th>Tensile stress</th>
<th>Elongation</th>
<th>Reduction area</th>
<th>Hardness (Brinell)</th>
<th>Impact (V-notch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test piece No.1</td>
<td>1043</td>
<td>1081</td>
<td>20.4</td>
<td>64.0</td>
<td>341</td>
<td>110</td>
</tr>
<tr>
<td>Test piece No.2</td>
<td>1010</td>
<td>1140</td>
<td>18.8</td>
<td>46.9</td>
<td>375</td>
<td>113</td>
</tr>
<tr>
<td>Test piece No.3</td>
<td>1040</td>
<td>1086</td>
<td>21.6</td>
<td>60.5</td>
<td>341</td>
<td>128</td>
</tr>
</tbody>
</table>

Result; Enough satisfied with Spec. □ Acceptable
Reliability check of advanced type (2/4)

Stress distribution under maximum oil pressurizing at 180MPa
(For advanced type, Bolt size M110)

![Stress distribution diagram]

Stress table

<table>
<thead>
<tr>
<th>Cross section</th>
<th>Average stress</th>
<th>Safety factor for material yield stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.8</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>70.9</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>49.5</td>
<td>1.6</td>
</tr>
<tr>
<td>4</td>
<td>50.1</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>12.2</td>
<td>4.3</td>
</tr>
<tr>
<td>6</td>
<td>26.0</td>
<td>3.9</td>
</tr>
<tr>
<td>7</td>
<td>5.6</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>42.1</td>
<td>2.4</td>
</tr>
</tbody>
</table>

ása = Casing bolt, Others = Bolt tensioner

Result; Adequate safety margin
Reliability check of advanced type(3/4)

Evaluation of low-cycle-fatigue for bolt tensioner

Peak stress (Max. principal) distribution

Langer-equation

\[
\Delta \sigma_p = \frac{E}{2\sqrt{N}} \ln \left( \frac{1}{1 - \phi} \right) + 2\Delta \sigma_w
\]

\(\Delta \sigma_p\) : Allowable stress
\(E\) : Modulus of elasticity (=2.1 \(\times 10^4\))
\(N\) : Allowable repeat cycle (=2000)
\(\phi\) : Reduction of area (=0.45)
\(\Delta \sigma_w\) : Endurance limit (=49)

Result;
Allowable stress = 240MPa > 170MPa (Peak)
Adequate safety margin for no low-cycle-fatigue failure in 2000 cycles
**Reliability check of advanced type (4/4)**

**Summary result of reliability check**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Criteria</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevention of tension failure</td>
<td>Less than material yield stress</td>
<td>Highest average stress to be Min. Safety 1.4 for allowance</td>
</tr>
<tr>
<td>Prevention of low cycle fatigue failure</td>
<td>Over 2,000 cycles</td>
<td>Peak stress to be min. safety 1.4 for allowance</td>
</tr>
<tr>
<td>Prevention of brittle fracture</td>
<td>Over 37.6J/cm² (Brittle fatigue limit)</td>
<td>More than 100J/cm²</td>
</tr>
</tbody>
</table>

Advance type;
1) More safety operation of bolt tensioner
2) Much longer life time to use in over 2000 cycles
3) Tensioner material to be more toughness without brittle fracture
**Application to large-sized steam turbine (1/4)**

**Seal analysis of large-sized steam turbine under hydro test**

- **Mechanical design of HP section turbine casing**
  - Pressure = 1830 psig (126 barg)
  - Temperature = 894 degF (479 degC)
  - (Turbine power = Max. 86 MW, Inlet flow = Max. 650 Ton/Hr)

- **Hydro pressure = Max. 2280 psig (157 barg)** in casing integrity test

- **3D model**

- **Casing bolt arrangement**

- **Analysis 3D model of turbine casing**

- **Hydro test pressure condition**
**Application to large-sized steam turbine (2/4)**

**Seal analysis of large-sized steam turbine under hydro test**

Comparison of bolt tightening force (Conventional & Advanced bolt tensioner)

<table>
<thead>
<tr>
<th>Bolt size</th>
<th>Conventional</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>M110</td>
<td>2.8 x 10^6 N (340MPa)</td>
<td>3.8 x 10^6 N (480MPa)</td>
</tr>
<tr>
<td>M80</td>
<td>1.3 x 10^6 N (310MPa)</td>
<td>1.8 x 10^6 N (440MPa)</td>
</tr>
</tbody>
</table>

(M64 = Tightening by Power wrench)

**1.4 times up of tightening force by advanced type**

Bolt arrangement and tightening force
Application to large-sized steam turbine (3/4)

Seal analysis of large-sized steam turbine under hydro test

Analysis result

Conventional
Not contact

Advanced
Contact

Not sealed on bolt hole edge
Leakage

Complete seal on bolt hole edge
Sealing

Contact condition of horizontal casing surface in hydro casing integrity test
Hydro test of turbine casing

Advanced bolt tensioner

Test result of casing integrity and joint leakage;
Neither leaks nor seepage through casing is observed

Successful hydro test of turbine casing by advanced bolt tensioner
Conclusions

Advanced type of oil operated bolt tensioner is successfully designed to enhance the reliability for large-sized steam turbine with higher inlet steam pressure as follows;

a) Compared to conventional type, the following items are improved.
   a-1) Achievement of 1.5 times up of bolt tension force by double piston
   a-2) Enhancement of oil seal performance by hybrid sealing
   a-3) Applicable to same bolt pitch by compact design

b) Bolt tightening work time can be saved with more safety compared to bolt heater type thanks to no heating time and operation.

c) By 3D FEM analysis and material test, adequate strength against tension, fatigue, brittle fracture are verified. Also, life time can be obtained in more than 2000 cycles. Finally, the advanced type can achieve successful hydro test of turbine casing with no leakage or seepage.

d) To get a reliability increase of turbine casing seal performance in the future, minimization of casing bolt pitch is necessary with modification structure to be studied in next technical issue.