Preface

A Large Steam Turbine had been in operation for several years and this turbine experienced the wear damage of governor linkage. Then, measured the vibration velocity profile on Governor side pedestal to identify the excited vibration mode and frequency. According to collected data, investigated the possible root causes and conducted 3D vibration response analysis to the existing and the improved pedestal. And, improved pedestal was supplied to the client and applied for actual machine during turnaround. And, finally, the advantage of new improved pedestal was confirmed. This case study introduces the typical phenomena, RCA investigation, detail vibration analysis, countermeasures and verification results as technical process.

Contents

1) Vibration situation for CGC Large Steam Turbine
2) Root cause analysis and evaluation method
3) Countermeasure with result
1. Specification of Steam turbine with Gov, side pedestal

Turbine specification:
Max. power: 60MW
Speed: 2830 – 3845 rpm
Plant start: from 2002

Major specification of bearing pedestal with cover assembly:
1) Fabricated welding structure
2) Separated fabricating casing support
3) Material is Carbon steel (Eq, ASTM A36)
2.1 **Background**

Historical events at field:

- Turbine start up in 2002
- Gov, side pedestal Vibration increase from around 2005
- Vibration up to 20 mm/s in 2012 by turbine load/speed up
- Vibration causes linkage lever wear and required control limit

![Site measurement points (View from Gov, side)](image1)

![Pedestal vibration record from 2005 to 2012](image2)
2.2 Background

GV linkage damage condition

Operation condition;
- It was shifted actual inlet steam flow against E/H actuator signal.
- Occurred Impossible control area.
### 2.3 Background

Site vibration measurement record;

- Bump test result; 73 Hz (Natural frequency)
  - Rotating speed
    - (48.8 to 64 Hz (2830 to 3845 rpm))

**Bump test result of pedestal**

**The out-of-phase mode**

**Pedestal**

**Power cylinder**

**E/H actuator**

**Exh, side**

**Casing support**

**Original position**

**Measured vibration mode at 3555 rpm**

**Site measurement points (No, 30)**

**The main characteristic of the vibration mode is an out-of-phase (counter-motion) mode between main pedestal and casing support**

**Measured vibration mode under operation**

(View from Exh, side)
3. Root Cause Analysis for Bearing Pedestal Vibration

Root cause failure analysis found on 3 main items as below;

1. Excessive external force
2. Increase of modal mass on bearing pedestal
3. Decrease of dynamic stiffness

- Foundation degradation
- Bearing pedestal stiffness
- Natural frequency excitation

Resonance with rotating speed
4.1 Response analysis of 3D Full modeling

In order to clarify the vibration mechanism, it performed vibration 3D response analysis (cod-Nastran) with current bearing pedestal.

- 3D full FEM modeling
- Rotor modeling with exciting force
- Mass data with Boundary condition
- Dynamic vibration response analysis

Original pedestal → New pedestal
4.2 Response analysis of 3D Full modeling

Rotor modeling with excitation force calculation

Calculation of BRG reaction force by rotor unbalance response (Code=ROT-CAE)

Rotor model:
1st-2nd unbalance mode

U=Unbalance value based 5 times up API limit = 66.85 kg·mm
(U/2=U1=U2)

<table>
<thead>
<tr>
<th>Critical speed</th>
<th>Speed (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2300</td>
</tr>
<tr>
<td>2nd</td>
<td>6600</td>
</tr>
</tbody>
</table>

Step-1: Calculate BRG reaction force (F)

Step-2: Analysis Vibration response
5.1 Analysis result of original pedestal in hot condition
Comparison between Measurement data and Analysis result by animation mode.

Result;
- 3D response analysis method is almost suitable for site operating condition.
- Confirm the out-of-phase(counter-motion) mode between main pedestal and upper casing support, and moving up for pedestal contact surface.

This vibration main cause is the decrease of pedestal stiffness
5.2 Analysis result of original pedestal in **hot** condition

Final analysis results of **fabricated pedestal type**

Result:
- Natural frequency 61.8Hz is in to the turbine operating speed range at hot condition, it shifted from cold condition.
- Vibration level in analysis is 10 to 30mm/s 0-P around normal to max speed as same as site vibration level.
- Equivalent to full contact area of pedestal to be reduced.

Contact surface

Full contact blue colored only

View from pedestal lower side

Operation range; 48.8 – 64.0 Hz
6. Comparison of original and improved pedestals

Requirement for new pedestal design:
1) Full contact condition of pedestal surface.
2) Rigidly connection between pedestal body and casing support without freestanding.

<table>
<thead>
<tr>
<th>Existing pedestal &amp; cover</th>
<th>New pedestal &amp; cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel SS400</td>
<td>Cast steel SC450</td>
</tr>
<tr>
<td>(Eq, ASTM A36)</td>
<td>(Eq, ASTM27-93 Gr65)</td>
</tr>
<tr>
<td>Pedestal: 1590 kg</td>
<td>Pedestal: 1880 kg</td>
</tr>
</tbody>
</table>

Overview

Old fabricated type

Casting pedestal type has more high stiffness than original type
7.1 3D analysis result of improved pedestal in **hot** condition

Final analysis results of **Casting pedestal type**

**Result:**

- **a)** Natural frequency 40.7 Hz to be out of operation range, and satisfied with API standard (less than 41 Hz).
- **b)** Vibration level in operation to be much lower at 0.3 to 1 mm/s 0-P even by 5-times of API unbalanced limit

**Contact surface**

**Operation range:** 48.8 – 64.0 Hz
7.2 3D analysis result of improved pedestal in **hot** condition

Following shows vibration mode of animation for original and improved pedestal.

New casting pedestal has a big advantage against original pedestal.

Original pedestal  

Improved pedestal
8. Site verification result for permanent solution

Result for applying of new improved pedestal

Result:
Vibration level in rotating speed to be much reduced to less than 3.0 mm/sec (0-P), which means reduction of 80% compared with the existing pedestal vibration level.

Vibration [mm/s] (0-P)

Vibration record improved pedestal in 2013

Out view of similar turbine

E/H actuator with linkage

Improved pedestal with cover

Governing valve
9. Conclusion

1) Summary of analysis result

<table>
<thead>
<tr>
<th>Pedestal</th>
<th>Analyzed N F</th>
<th>Vibration level in operation</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabricated type</td>
<td>61.8Hz</td>
<td>Maximum 30mm/s 0-P</td>
<td>Almost same as site bump test (73Hz) with cold condition 69.2Hz.</td>
</tr>
<tr>
<td>(Original design)</td>
<td>(Hot condition)</td>
<td>(H-direction)</td>
<td></td>
</tr>
<tr>
<td>Casting type</td>
<td>40.7Hz</td>
<td>Less than 1mm/s 0-P</td>
<td>17% separation margin against 48.8Hz (Min. speed) satisfied with API</td>
</tr>
<tr>
<td>(Improved design)</td>
<td></td>
<td>(H-direction)</td>
<td>standard of more than 16%</td>
</tr>
</tbody>
</table>

2) 3D response analysis was carried out using field measurement data.
   - Analysis was confirmed root cause of site pedestal vibration.
   - Analysis model used to design new bearing pedestal, and confirmed the expected vibration include separation margin.
   - Improved bearing pedestal retrofit to similar machines.
   - Field record verified the improved vibration response analysis.
10. Lessons Learned

Requirement items to future structure design.

- **The robust design** that can applicable a wide operation speed range.

- **The high stiffness design** include separation margin based on API.

- **Utilize full 3D analysis** based on actual structure modeling with loading data, and establishment of guidelines.

**Sample** ; Design check sheet for Dynamic response analysis

![Diagram](image-url)
Thank you for your attention