CAPSTONE PROJECT

The Effects of High Vibration on the Steam Turbo - Generator Machine of the Unit B1-339 MW in Thermal Power Plant "Kosova - B"

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November 23, 2009
This Capstone Project will address the analysis and diagnosis of the Steam Turbo-Generator (STG) machine vibration problems in Thermal Power Plant (TPP) “Kosova-B” that are degrading the normal operations of the Unit B1-339 MW
Introduction

(TPP “Kosova B”, Unit B1 and STG)
TPP “Kosova - B”

- located in Kastriot (Obiliq)
- main Power Station in Kosovo for electricity production
- two units, B1 and B2, with a capacity of 339 MW each
- Units - composed of different machines
  ( turbines, pumps, compressors ... )

- Machine Maintaining
  - preventive maintenance
  - predictive maintenance
The STG machine (installed 1983) - is one the most important machines in unit B1 for generating electricity. It is directly connected to the production of electricity.

- **Steam Turbine** (High Pressure Cylinder HPC, Intermediate Pressure Cylinder IPC and Low Pressure Cylinder LPC)
- **Electrical Generator**

**Monitoring the STG machine’s condition** (vibration measurements)

- Monitoring vibration system
  - (Vibro Meter VM600)

Program Logic Control

Y - vertical sensor position
X - horizontal sensor position
Machine Vibration (back and forth movement of the machine’s components) is one of the main indicators that detects when a machine is developing problems.

- **STG-B1** (monitored by relative and absolute vibration measurements)
  - Measuring Relative Shaft Vibration
  - Measuring Bearing Pedestal (absolute) Vibration
The results of vibration measurements on the several bearing pedestals of the STG-B1 machine compared to ISO 10816-2 show high vibration values.

<table>
<thead>
<tr>
<th>Direction</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
<th>B7</th>
<th>B8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>1.30</td>
<td>2.35</td>
<td>0.72</td>
<td>2.27</td>
<td>2.79</td>
<td>2.57</td>
<td>7.65</td>
<td>9.33</td>
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<tr>
<td>Horizontal</td>
<td>0.66</td>
<td>0.92</td>
<td>0.93</td>
<td>0.90</td>
<td>1.33</td>
<td>2.25</td>
<td>4.94</td>
<td>3.67</td>
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<tr>
<td>Axial</td>
<td>1.18</td>
<td>0.75</td>
<td>0.81</td>
<td>1.18</td>
<td>1.12</td>
<td>13.45</td>
<td>3.60</td>
<td>3.80</td>
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</tbody>
</table>

**ISO standard 10816-2**

- **ZONE A**: New machine condition
- **ZONE B**: Unlimited long term operation allowable
- **ZONE C**: Short term operation allowable
- **ZONE D**: Vibration causes damages

The table shows vibration measurements in velocity (mm/s) RMS for different bearings and directions. The measurements are compared to ISO 10816-2 standards, indicating areas where vibration is high, indicating potential issues for the machine's operation.
C1 - the event when a balancing generator rotor was done (vibrations were decreased)

C2 - the event when the blades of Low Pressure Rotor (LPR) were cracked
By analyzing the above results of absolute vibration measurements on the STG we can ask:

- What is wrong with the machine?
- What is the machine’s vibration problem?
- Why is this machine running at considerable risk?
- What should be the corrective actions?
The effects caused by high vibration on the machine

- Shortening the machine’s life
- One problem can cause other problems (damages)
- Increase the risk for personnel by any catastrophic failure
- By allowing the machine to run until failure, the repair costs will be higher (more parts, longer shut down periods, and more labor to complete)
- Degrading the machine’s reliability

An example, the total destruction of generator rotor (France)
Three main steps of research methods were developed in order to find the source of vibration problems and to make recommendations for corrective actions.

- **First step** - Analysis of the machine's construction design and technical data
- **Second step** - Analysis of the machine's history
- **Third step** - Conduct and collect vibration data and operational parameters on the machine
To identify all the components of the machine that could cause vibration (how the machine works, what were the machine’s elements...)

- **Steam Turbine** - a device that extracts the thermal energy into rotary motion. It rotates 3000 rpm (revolution per minute).
**Electrical Generator** - is a device that converts the rotary motion by steam turbine to electrical energy. It rotates 3000 rpm.

Main components:

- Stator Windings
- Bearing
- Shaft
- Retaining ring
- Water Exchanger
- Hydrogen Direction
- Ventilator
- Coupling
- Rotor Windings
A useful research step to be informed regarding the machine's previous condition (any previous damage or repair)

Three interesting events that happened on the machine

1. Generator Rotor Repair (2001)
   (High relative shaft vibration, some of rotor winding bars in-situ was repaired)

2. Shortened the LP Rotor Blades (2008)
   (a blade of the Low Pressure Rotor was cracked)
The turbine continued to work with limited capacity from 300 MW to 260 MW due to the LP’s shortened rotor blades.

*(High bearing pedestal vibration, in-situ generator rotor balancing)*

<table>
<thead>
<tr>
<th>TPP &quot;Kosovo B&quot; STG-B1 machine</th>
<th>Bearings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balancing Generator Rotor</td>
<td></td>
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<tr>
<td>April 2004</td>
<td></td>
</tr>
<tr>
<td>Direction</td>
<td>B6</td>
</tr>
<tr>
<td>Vertical</td>
<td>2.66</td>
</tr>
<tr>
<td>Horizontal</td>
<td>5.57</td>
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<tr>
<td>Axial</td>
<td>19.51</td>
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</tbody>
</table>

**Unfortunately**, the vibration results after the generator rotor balancing changed and after two months of the STG-B1 machine operation, the vibrations were again high (slide 3- case C1).
The third and most important step of my project research was measuring and collecting vibration data on the STG-B1 machine (amplitude, frequency and phase).

Vibration Instruments used:

1. **VIBSCANNER** - an off-line instrument (measuring and collecting the vibration data on the bearing pedestals)

2. **VIBROMETER VM600** - an on-line monitoring relative shaft vibration system (installed in 2003, STG-B1)

3. **BRUEL & KJEAR Data collector 2526** - an off-line instrument (connected to VM600 system)
To analyze vibration problems in the STG-B1 machine I choose to collect:

**Overall vibration** - the total vibrations measured within a frequency range of 2-1000 Hz with scale factor RMS (root mean square), or Zero - Peak and Peak - Peak. For example, the velocity **7 mm/s (RMS)**

**Waveform spectrum** (WS) - a graphical representation of how the vibration level changes with time (the plot of vibration vs. time).

(ECG - for medical condition of the person’s heart, WS - for nature of the vibration severity)

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An example, when a waveform spectrum is sinusoidal

Problem (Unbalance rotor)
An example, when a waveform spectrum isn’t sinusoidal
Problem (bearing pedestal bolt loosen)

FFT Spectrum (Fast Fourier Transformation Spectrum)

A graphical representation of vibration vs frequency. A useful tool for analyzing vibrations and provides information to help determine the cause of the problem.

Phase - the angular difference between a known mark on a rotating shaft of the machine and the vibration signal. This relationship is useful for balancing and analysis purposes.
### Collected Vibration Data from VIBSCANNER Instrument

The results of absolute vibration measurements on the bearing pedestal B6, B7 and B8 for different loads.

<table>
<thead>
<tr>
<th>STG-B1 machine</th>
<th>Measurement unit (velocity (mm/s) - RMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load Position</strong></td>
<td>1000 rpm</td>
</tr>
<tr>
<td><strong>B</strong></td>
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</tr>
<tr>
<td>Vertical</td>
<td>0.73</td>
</tr>
<tr>
<td>Horizontal</td>
<td>0.28</td>
</tr>
<tr>
<td>Axial</td>
<td>0.82</td>
</tr>
<tr>
<td><strong>B6</strong></td>
<td>Vertical</td>
</tr>
<tr>
<td>Horizontal</td>
<td>0.31</td>
</tr>
<tr>
<td>Axial</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>B7</strong></td>
<td>Vertical</td>
</tr>
<tr>
<td>Horizontal</td>
<td>0.4</td>
</tr>
<tr>
<td>Axial</td>
<td>0.19</td>
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<tr>
<td><strong>B8</strong></td>
<td>Vertical</td>
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<tr>
<td>Horizontal</td>
<td></td>
</tr>
<tr>
<td>Axial</td>
<td></td>
</tr>
</tbody>
</table>

### Diagram

- **Zone D - Fault**
- **Zone C - Alert**

#### During start-up
- When the Active Power changed
- When the Reactive Power changed
FINDING RESULTS (WAVEFORM AND FFT SPECTRUM)

**Bearing B7**
- Waveform spectrum B7/V (it is sinusoidal)
- Zero-Peak = 8.40 mm/s
- Cascade FFT spectrum B7/V for different loads (highest amplitude vibration is 50 Hz)

**Bearing B8**
- Waveform Spectrum B8/V (sinusoidal)
- Zero-Peak = 11.95 mm/s
- Cascade FFT spectrum B8/V for different loads

1x = 50 Hz
2x = 100 Hz
The results of vibration measurements and phase taken on the bearings B7/V and B8/V

<table>
<thead>
<tr>
<th>Rotation Speed (RPM)</th>
<th>Velocity (mm/s, 0-P)</th>
<th>Phase (°)</th>
<th>Rotation Speed (RPM)</th>
<th>Velocity (mm/s, 0-P)</th>
<th>Phase (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>0.05</td>
<td>40</td>
<td>800</td>
<td>0.01</td>
<td>0</td>
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<tr>
<td>1500</td>
<td>0.32</td>
<td>331</td>
<td>1500</td>
<td>0.02</td>
<td>356</td>
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<td>1893</td>
<td>1.79</td>
<td>23</td>
<td>1937</td>
<td>2.67</td>
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<td>2071</td>
<td>1.91</td>
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<td>2071</td>
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<td>2174</td>
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<td>73</td>
<td>2711</td>
<td>2.26</td>
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<tr>
<td>2815</td>
<td>3.22</td>
<td>73</td>
<td>2858</td>
<td>3.07</td>
<td>204</td>
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<td>2968</td>
<td>5.55</td>
<td>55</td>
<td>2998</td>
<td>9.01</td>
<td>231</td>
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<tr>
<td>3000</td>
<td>7.47</td>
<td>61</td>
<td>3000</td>
<td>9.21</td>
<td>232</td>
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<tr>
<td>100 MW</td>
<td>5.65</td>
<td>58</td>
<td>100 MW</td>
<td>7.89</td>
<td>221</td>
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<tr>
<td>150 MW</td>
<td>6.89</td>
<td>66</td>
<td>150 MW</td>
<td>9.27</td>
<td>231</td>
</tr>
<tr>
<td>200 MW</td>
<td>6.40</td>
<td>59</td>
<td>200 MW</td>
<td>9.28</td>
<td>226</td>
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<tr>
<td>250 MW/89 MVar</td>
<td>9.82</td>
<td>56</td>
<td>250 MW/89 MVar</td>
<td>12.54</td>
<td>225</td>
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<tr>
<td>250 MW/115 MVar</td>
<td>7.50</td>
<td>64</td>
<td>250 MW/115 MVar</td>
<td>9.26</td>
<td>228</td>
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<td>250 MW/130 MVar</td>
<td>8.44</td>
<td>55</td>
<td>250 MW/130 MVar</td>
<td>10.96</td>
<td>222</td>
</tr>
</tbody>
</table>
The amplitude vibrations and phase in plane 7 and 8 (3000 rpm, idle running)

\[ V_7 = 7.47 \text{ mm/s (Zero – Peak)}, \ \phi_7 = 61^\circ \text{ and } V_8 = 9.21 \text{ mm/s (Zero – Peak)}, \ \phi_8 = 232^\circ \]

The bent form of Generator Rotor (twice bent)
The relative shaft vibration measurements on the bearings B7 and B8 changed (rapidly) when the reactive power was increased (115, 130 and 155 MVar).
The amplitude vibrations (B7 and B8) were depending on the reactive power (the amplitude vibrations changed when the reactive power was increased) (A symptom of **generator rotor thermal instability**).

Some of rotor winding bars are elongated when the rotor is heating up and after cooling process the vibrations are not returned back in the same position.
The FFT and waveform spectrum taken on the B6/A vibration signal have the same symptoms as on the bearing B7/V and B8/V.

The high vibration value on the bearing B6 is in the axial direction, which indicates another source of vibration problem (*symptom of angular misalignment*)
Angular misalignment vs. Good alignment

LP Rotor
B6
GR axis
LPR axis
Angular misalignment

Generator Rotor (GR)
B7
B8
Three main vibration problems on the STG-B1 machine were found:

1. Dynamic generator rotor unbalance
2. Generator rotor thermal instability
3. Shaft misalignment between LP rotor and Generator rotor
RECOMMENDATIONS (THREE OPTIONS)

To solve the vibration problems in the STG-B1 machine I recommend three opportunity options:

Option-1

- **In-situ generator rotor balancing and correcting the shaft misalignment between the LP rotor and generator rotor** (that should decrease the vibration level on the measurement points B7/V, B8/V and B6/A)

  - The vibration problems will be solved very quickly (maximal three weeks) and the budget will be **337 000 €**.

  - Option-1 will not guarantee the long-term machine operation due to the another problem such as the generator rotor thermal instability.

  - Losses due to the stop-run of the unit B1 (option -1)

    \[(21 \text{ days}) \times (24 \text{ hours/day}) \times (240 \text{ MW/hour}) \times (40 \text{ €/MW}) = 4 834 400 \text{ €} \]

**Total expenditure = 337 000 + 4 834 400 = 5 175 400 €**
The plan of work and timeline for corrective action option-1 (Gantt Chart)

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>31</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
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<th>11</th>
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<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Start run the STG-B1 machine to 3000 rpm and measure the vibration level and phase on the two bearing pedestals of the electrical generator (E7 and B6)</td>
<td>1 day?</td>
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<tr>
<td>2</td>
<td>Stop run the machine, cooling the turbine and discharge H2 from electrical generator</td>
<td>2 days</td>
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<tr>
<td>3</td>
<td>Disassemble necessary elements on the electrical generator and attach the test weight on the plane 7 and 8</td>
<td>2 days</td>
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<tr>
<td>4</td>
<td>Assembly necessity generator elements and prepare it to start run</td>
<td>1 day</td>
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<tr>
<td>5</td>
<td>Start run the machine to 3000 rpm and measure the vibration level and phase with attached test weight</td>
<td>1 day</td>
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<tr>
<td>6</td>
<td>Stop run the machine, disassembly necessity elements on the generator, remove test weight and attached correction weight</td>
<td>1 day</td>
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<tr>
<td>7</td>
<td>Start run the machine to 3000 rpm and check the improvement vibration level</td>
<td>1 day?</td>
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<tr>
<td>8</td>
<td>Cooling turbine</td>
<td>2 days</td>
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<tr>
<td>9</td>
<td>Mounting all elements in electrical generator and prepare it for long-term operation</td>
<td>4 days</td>
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<tr>
<td>10</td>
<td>Checking and correcting shaft alignment between LP and generator rotor</td>
<td>5 days</td>
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<td></td>
<td></td>
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</table>
Option-2

- **General generator rotor repair** (This implies generator rotor winding bars repair and balancing in the workshop). This option also includes correcting the shaft misalignment between the LP rotor and generator rotor.

This corrective action will solve the vibration problems on the STG-B1 for the long-term operation because the three main vibration problems such as the generator rotor unbalance, generator rotor thermal instability and shaft misalignment between the LP rotor and generator rotor will be solved.

This option requires more time (four months) than corrective action option-1 and the budget (approximately) is 2 Mil.

- Losses due to the stop-run of the unit B1 (option -2 )

\[(116 \text{ days}) \times (24 \text{ hours/day}) \times (240 \text{ MW/hour}) \times (40 \text{ €/MW}) \rightarrow 26\,726\,400 \text{ €}\]

Total expenditure = 2,000,000 + 26,726,400 = 28,726,400 €
# RECOMMENDATIONS

The plan of work and timeline for corrective action option-2 (Gantt Chart)

| Task Name                                                                 | Duration | W-2 | W-1 | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 | W11 | W12 | W13 | W14 | W15 | W16 | W17 | W18 | W19 | W20 | W21 |
|--------------------------------------------------------------------------|----------|-----|-----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Stop run the machine and cooling turbine process                          | 3 days   |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Disassembling the necessary elements in the electrical generator to remove its rotor | 6 days   |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Remove the generator rotor from its house                                | 1 day    |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Preparing generator rotor for transportation to workshop (outside of TPP Kosovo B) | 2 days   |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Generator rotor repair (rotor winding bars repair and balancing)          | 90 days  |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Puting the generator rotor in its house                                  | 1 day    |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Assembling the all elements in electrical generator for long-term operation | 6 days   |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Correcting the shafts misalignment between LP rotor and generator         | 5 days   |     |     |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
Option - 3

- **Change the generator rotor with new one.** The time for this corrective action is 22 days and the budget **4,5 Mil.** (Three main vibration problems will be solved)

- **Losses due to the stop-run of the unit B1 (option-3)**

\[
(22 \text{ days}) \times (24 \text{ hours/day}) \times (240 \text{ MW/hour}) \times (40 \, €/MW) = 5 \, 068 \, 800 \, €
\]

Total expenditure = 4 500 000 + 5 068 800 = **9 568 800 euro**

The plan of work and timeline for corrective action option-3 (Gantt Chart)
The results of my analysis and diagnosis vibration issues on the STG-B1, together with recommendations for corrective actions were also very useful for KEK and helped on the decision making that on its business plane 2010 to taking the corrective action (to change the generator rotor with new one). (implementation plan option – 3)

That will insure the long term of the STG-B1 machine operation

The LP rotor must be repaired or changed with a new one because it is limiting the unit’s capacity.
How the courses were related to my Capstone Project

- **Context and trends** (presentation)
- **Asset Management** (preventive and predictive maintenance, FMEA)
- **Introduction To Project Management** (project planning, scheduling and cost estimation)
- **Advance Project Management** (best practices on implementation)
- **Natural Resources and Infrastructure Development** (issue investigation; questionnaires, opinionnaires in project investigation)
The end, acknowledgements…
THANK YOU FOR YOUR ATTENTION

Questions and Comments...