VIBRATION TESTING METHODOLOGY OF TURBO-GENERATOR FOUNDATIONS – IZIIS EXPERIENCE

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Abstract

Presented in the paper are the results obtained by full-scale dynamic testing of a turbo-generator foundation, as well as the results for measured vibrations at selected points on the foundation slab under working conditions of the generator. Such measurements are of a great importance in the case when the system is subjected to permanent vibration. Definition of the initial state - initial dynamic characteristics of the structure, as well as temporary checking of the dynamic characteristics and measuring of the vibration level at characteristic points of the structure will enable definition of the actual state through comparison of the measured values of frequencies of the structure and working frequencies of the machine as well as comparison of the measured displacements and the values allowed by the corresponding codes and criteria.

1 Introduction

The theory of vibrations, as a fundamental science, covers a wide variety of problems related to the vibration influence upon physical systems in different vibration frequency and amplitude ranges. The resonance occurrence in a system, which during its serviceability period will be exposed to vibration effects is a phenomenon requiring particular design attention. Also, the control of the behavior of the system under work conditions is very important, considering the possibility for material fatigue occurrence, in case of systems subjected to long-term vibration effects, i.e., considering the possibility of development of non-allowable stresses, displacements and alike. The resonance conditions develop in case of coincidence of the natural frequency of the system and the excitation frequency, when vibrations are intensified, causing possible instability of the system, particularly when it is of low damping capacity. It is doubtless that the resolving of the problems of the vibration theory of mechanical systems is not possible only by using available analytical methods, but also by application of experimental methods, which includes the effect of all the phenomena that cannot be analytically simulated. Presented in this paper is the approach and the results obtained by tests carried out on a turbo-generator foundation: definition of the dynamic structural characteristics applying the forced vibration method and vibration measurements with the turbo-generator under work conditions.
2 Description of foundation structure

The structure supporting the turbo-generator consists of an upper-slab (which the machinery is placed on), supported by 12 reinforced concrete rectangular cross-section columns, fixed to a 3.5 cm thick foundation slab. The turbo-generator bearing structure consists of six transversal reinforced concrete Π-shaped frames, with a height of approximately 13.5 m, considering from the fixation point to the beam. The frames are inter-connected by two longitudinal beams, which with the transversal frame columns form two five span longitudinal frames. Fig. 1 shows the slab level plan, longitudinal and cross section of the foundation structure. The maximum power of the turbo-generator is 200 MW, while the operation cycles number of the rotor is 3000 c/min.

3 Testing equipment

For forced vibrations generation in horizontal and vertical direction of the turbo-generator supporting structure, two types of vibration generators are employed: GSV-101 (Geotronix, USA) vibration generators are used for generating frequencies in the range from 0.5 to 9.0 Hz, while EX-50 (Itoh Seiki, Japan) vibration generator is used for generating frequencies higher than 9.0 Hz. The vibration generator set-up is shown in Fig. 1. The excited vibrations, i.e., accelerations at the individual measuring points, marked in the same Figure, are recorded by Kistler type accelerometers (dynamic range of 50 g), combined with corresponding signal amplifiers. HP-model 3582A spectral analyzer is employed for signal processing, i.e., for obtaining amplitude and phase spectrum (Fast Fourier Transform).
4 Testing program

The following phases were included in the test program:

1. Determination of the dynamic characteristics of the turbo-generator supporting structure in longitudinal, transversal and vertical direction and for rotation, in frequency range from 0 to 44 Hz, by forced vibrations generation (developing resonance conditions in the structure).

2. Measurement of vibrations at the characteristic points of the structure under turbo-generator working conditions, in the following three phases: (a) at gradual starting of the turbo-generator, until operation cycles number is reached (3000 c/min.); (b) measurement under operational conditions, immediately after operation starting (cool state); and (c) measurement of vibrations under operational conditions, several days after starting (warmed up state). During vibration measurement under operational conditions of the generator accelerations are also measured, on the basis of which displacement amplitudes at some points are determined using expression \( D = \frac{a}{(2\pi f)} \), where \( D \) is displacement at \( (\mu) \), \( a \) is acceleration in \( % \) of \( (g) \), \( f \) is frequency in Hz.

5 Test results

The dynamic characteristics of the foundation structure have been defined in a frequency range of 0 - 44 Hz. Fig. 2. shows the resonant frequency curves recorded at point T3 under vibration in transverse direction. The resonant frequency of the fundamental mode is 4.08 Hz. A much pronounced frequency under vibration in this direction is that of 40.0 Hz that belongs to one of the higher modes.

![Graphs showing resonant frequency curves](image)

Figure 2  Resonant frequency curves recorded in transverse direction
Fig. 3 shows the horizontal shapes of vibration along the measured profile in transverse direction where it is clear that the structure vibrates with pronounced torsional effects under lower frequencies, whereas under higher frequencies it is evident that the central part of the structure tends to deform to a greater extent, since the amplitude at the referent point T3 is considerably higher than the amplitudes at other points of the profile. Fig. 4 presents schematically the spatial vibration of the concrete structure during generation of harmonic excitation in transverse direction.

By generation of forced vibrations in longitudinal and vertical direction as well as torsional vibrations, defined are the resonant frequencies and the vibration modes in these directions. Table 1 provides a review of the recorded frequencies in different directions and the damping coefficients defined from the resonant curves.

In order to define the vibration level at characteristic points of the turbo-generator foundation under different operating conditions of the generator, measured are the horizontal and vertical components of acceleration at the level of the upper slab. Fig. 5 shows the characteristic spectra recorded at point A4 under operating conditions of 3000 cycles per minute (50 Hz) and power of 125 MW, whereas Fig. 6 shows the values of displacement amplitudes (in μ) measured at the defined points at the level of the upper slab of the foundation under these operating conditions.

Table 1. Resonant frequencies and damping coefficient for corresponding direction

<table>
<thead>
<tr>
<th>direction</th>
<th>frequency (Hz)</th>
<th>damping coeff. (%)</th>
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<tbody>
<tr>
<td>transversal (T3)</td>
<td>4.08</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>5.52</td>
<td>5.9</td>
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<tr>
<td></td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19.8</td>
<td>3.6</td>
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<tr>
<td></td>
<td>27.2</td>
<td></td>
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<tr>
<td></td>
<td>40.0</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>44.0</td>
<td>3.6</td>
</tr>
<tr>
<td>torsion (T1)</td>
<td>5.52</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>4.40</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>6.40</td>
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<td></td>
<td>13.8</td>
<td>4.7</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>43.2</td>
<td>2.3</td>
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<td>longitudinal (T3)</td>
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<td>37.6</td>
<td>4.5</td>
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<tr>
<td></td>
<td>44.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Figure 3  Horizontal vibration shape - profile in transverse direction
Figure 4  Schematic presentation of the spatial vibration of the structure

Figure 5  Amplitude spectra, point A4, operating conditions - 3000 c/min, 125 MW

Figure 6  Displacement amplitudes measured under operating conditions of 3000 cycles/per minute, 125 MW
By comparison of the vibration shape in transverse direction under higher frequencies (27.2, 40.0 and 44.0 Hz) and the displacement profile recorded during the operation of the turbo-generator frequency of 50 Hz (3000 cycles per minute), it has been concluded that the central part of the spatial frame structure tends to deform to a larger extent, i.e., the displacement amplitudes are the largest in this part (Fig. 7).

Figure 7 Comparative presentation of the vibration modes in transverse direction under forced vibrations and vibrations at operating conditions of 3000 cycles per minute, 120 MW

Conclusions

The structures, i.e., the systems exposed to permanent (long-term) vibrations induced by operation of machines or similar require special attention regarding both design and conditions for their utilization. Hence, there is a necessity to define their initial state in the sense of defining their dynamic characteristics prior to putting into operation of the corresponding system and monitoring, from time to time, the state under operational conditions, i.e., searching for possible changes in the dynamic characteristics and measuring of the level of vibrations at characteristic points of the structure.

The measured intensity of vibrations under conditions of gradual putting into operation of the turbo-generator and the values of displacement components measured under operational conditions allow, i.e. enable evaluation of the current state in the sense of comparison of the measured values and the values allowed by the corresponding regulations and criteria for such type of structures. The greater tendency for deformation (larger displacements) of the central part of the turbo-
generator foundation observed during the tests under resonant conditions (under higher frequencies) and during the measurement of the vibrations under working conditions (working frequency 50 Hz), points to the fact that one should search for the reasons for intensified deformations in the structure itself as well as to the necessity of its strengthening in order to provide a peaceful working of the machine.

6 References


