

TURBO-GENERATOR FOUNDATION DYNAMIC ANALYSIS

J. Benčat^{*}, M. Lukáč^{**}

Abstract: *The objective of this paper is the dynamic analysis of turbo-generator foundation structure (TGFS) in power station at CTE Mariel. Main purpose of performed study in 2017 was to check actual dynamic stiffness TGFS after fifty years TG (100 MW) performance. Provide an abstract of your paper no longer than 200 words. Provide an abstract of your paper no longer than 200 words.*

Keywords: structure dynamics, FEM, spectral analysis, experimental tests

1. Introduction

The dynamic analysis of turbo-generator foundation structure dynamic analysis consists of two parts: (i) analytical approach with numerical FEM analysis and (ii) experimental analysis of existing foundation structure via its *experimental dynamic response* due to vibration *mechanical exciter* and *impulse apparatus* (Light Falling Weight Device – LFWD). Results of the experimental tests (ET) in situ then enabled to update *foundation structural model* for final *numerical analysis* and *design* of the existing foundation structure strengthening for the future TG performance. According to the TGFS experimental analysis results and numerical calculation results, using relevant FEM calculation model based on experimental analysis results, was calculated the dynamic response of projected strengthening foundation structure (FS). The objectives of the final numerical calculation results were to check of resonance conditions and amplitude magnitude of renovated TGFS vibrations are restricted within the acceptable code limits e.g. ISO 1940–1 (1993) and the machine manufacturer prescriptions.

2. Methods

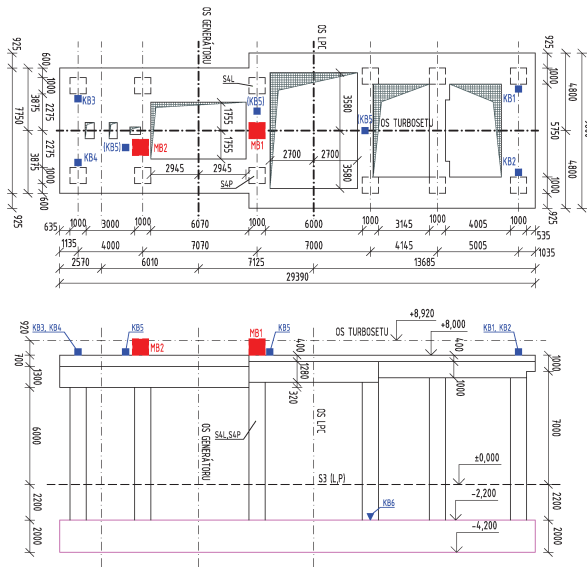
Before the performance of the FEM numerical calculation of TGFS it was needed to perform experimental measurements of existing TGFS and dynamic analysis of them. This was achieved via dynamic tests with *harmonic and impulse forced vibration of foundation structure* to determine the basic foundation *dynamic parameters* and then determine the *natural frequencies* and *damping* for achievable modes of vibration.

Experimental tests (ET). The mentioned TGFS foundation consists of an RCC top deck slab with supporting structure of beams and columns and a foundation rafts system resting on soil, Fig. 1. From the top deck all the equipment including turbine, generator and other rotary equipment before experimental tests were removed. The experimental tests were carried out on the top deck slab and the raft of TGFS–6. The dimensions of the TGFS–6 are described in details in [1]. For the purpose of measuring forced vibration modes of the FS a spatial network of points has been chosen, Fig. 1. In all ET points *time history of structure acceleration amplitudes* were measured in the three perpendicular directions. *Harmonically variable forces* were produced by vibration *mechanical exciter* (Fig. 2) with the max force amplitude 0-11.5 kN acting in relevant positions (see also Fig. 1) to achieve dynamic response of

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structure in one of excepted basic structure vibration mode. It was possible by spectral analysis of the relevant parts of the whole decay amplitude time histories in structure measured points after switch off



LEGEND:

- MB1, MB2 – mechanical exciter positions;
(MB – ZU; 1–15,5 Hz)
- KB1,...KB12 – accelerometers position;
(KB12VD; 1–4000 Hz)

Fig. 1: TGFS with measuring points and exciter positions lay-out.

the exciter working with maximum force amplitude or during application of the sweep tests from 14 Hz to 1 Hz. In the similar way application amplitude analysis were estimated damping parameters. The twelve acceleration transducers of type KB 12VD (1–4000 Hz) were used for amplitude time histories measuring. The signals from the used pick-ups were amplified and filtered by the signal amplifiers and low-band pass filters and then recorded by portable notebook with relevant software coupled with needful hardware facilities in test measuring station. The signals from measurement devices were transmitted to the recording technique in the measuring station (MS) by special low noise cables. The amplitude, correlation and spectral analysis of recorded signals were performed in laboratory UZ Zilina, see also (Bencat et al., 2017). These results were then utilized in calculation process.



Fig. 2: Mechanical exciter at MB1 position on TGFS-6

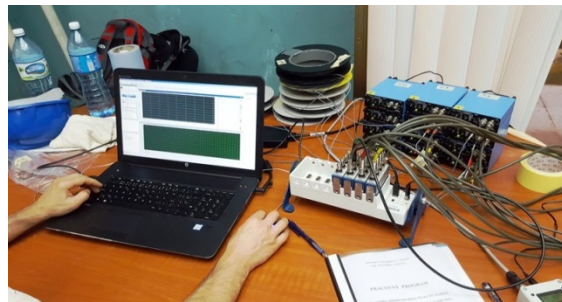


Fig. 3: Measuring station MS1 – UZ with NI software and hardware facilities

The recorded signals from experimental tests were analysed by on-line methods in laboratory conditions or partly in situ using amplitude, frequency and amplitude-phase analysis, by the method of spectral or correlation analysis. The TGFS-6 structure vibrations frequencies were obtained using spectral analysis of the recorded response of dynamic components via accelerometers, which are considered as ergodic and stationary (Bendat and Piersol, 1993). Spectral analysis calculation results (spectra, cross spectra – $S_{kk}(f)$, $S_{ik}(f)$; power spectral densities – PSD – $G_{ii}(f)$; cross power spectral densities – CPSD – $G_{ik}(f)$; coherence function – CF – $\gamma_{ik}^2(f)$; phase function – PHA – $\Theta_{15}(f)$, ect.) was performed via National Instrument software package NI LabVIEW and partly by Modal Analysis (LabVIEW MA) and PC MODAL. Fully application of the PC modal software packages was not possible utilized because of presence irrelevant vibration signals with high energy due to performance of others adjacent turbo-generators. Natural frequencies $f(j)$ have been obtained by using the spectral analysis from recorded amplitude time histories $u(t)$, $v(t)$, and $w(t)$, due to various series of TGFS dynamic forced loading. As an example of the spectral analysis results are depicted on Fig. 4. The results of the spectral analysis are fully described in (Bencat et al., 2017).

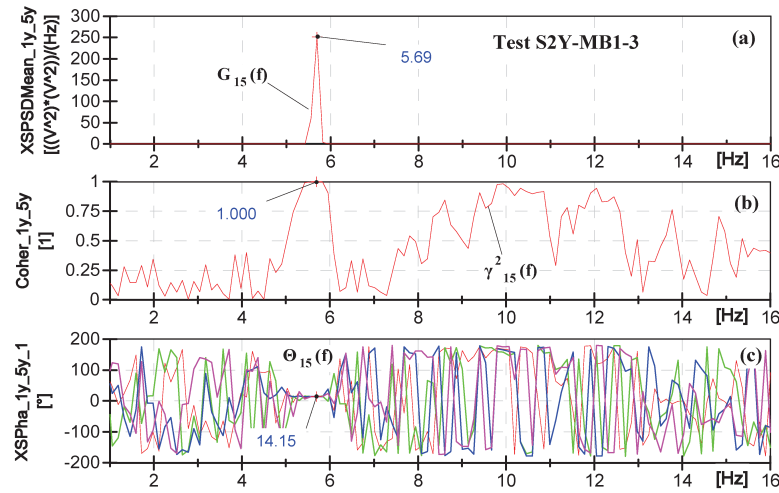


Fig. 4: Example of spectral analysis results: a) CPSD- $G_{15}(f)$; b) CF- $\gamma^2_{15}(f)$; c) PHA- $\Theta_{15}(f)$.

2.1. Results of numerical analysis

Results of experimental analysis enabled to start a procedure for the FE modelling (Tomko, 2016) of existing foundation structure TGFS-6 along with supporting soil and numerical dynamic analysis of it. For creating FE model (FEM1) were as an input data used mainly relevant *Project* parameters (1973). Dynamic numerical analysis was solved using ANSYS software package which provides an effective computational environment to perform these types of analyses. *Calculation of the natural frequencies and corresponding modes of vibration* forms basis for the determination of the dynamic parameters of TGFS. As an example of the comparison FEM1 and experimental results of the natural frequencies value $f(j)$ of the TGFS-6 vibration are presented in Table 1. The Figure 5 shows an example of the FEM1 basic natural modes calculation results.

The *numerical determination* of the natural frequencies and modes of foundation structure vibration was in this case fairly difficult and it was advised their verification by *experimental measurements*. Results of TGFS experimental analysis were fully utilized for updating FEM2 calculation model of the TGFS – 6 which also comprising of the designer strengthening elements and whole FS. The updated FEM2 (Tomko, 2017) for future offers calculation for reconstructed TGFS-6, e.g.: (i) *natural frequencies and corresponding modes of vibration* (free vibration analysis, eigen analysis); (ii) *dynamic amplitude calculation due to turbine operation and critical regimes to check that the same are within the acceptable code limits or as prescriptions limits of the equipment supplier* (forced vibration analysis); (iii) *dynamic response due to seismic acting* (earthquake analysis) and (iv) *dynamic stresses amplitude calculation to check the stresses induced in the different structural element like beams, columns and slabs* (pseudo-static analysis).

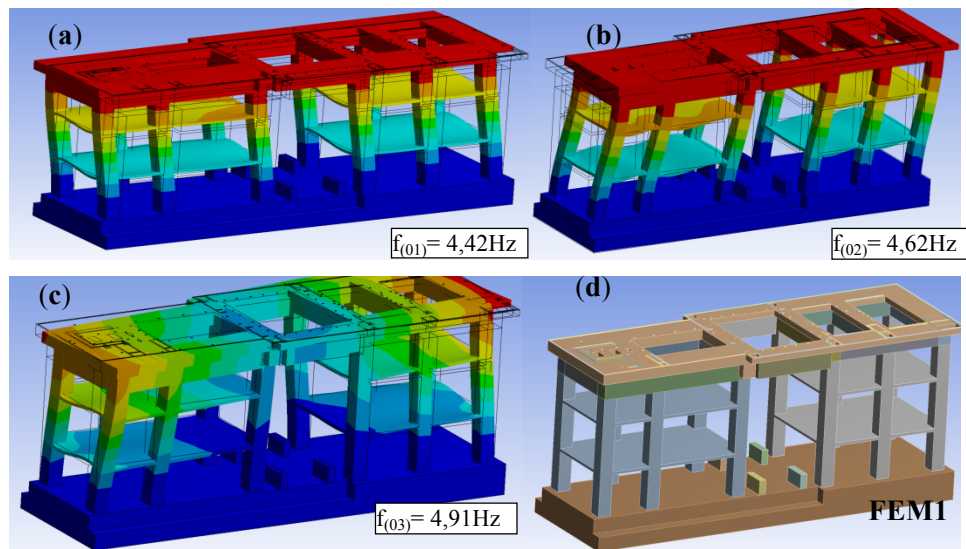


Fig. 5: Example of FEM analysis results: (a), (b), (c) – Basic modes of TGFS-6 vibration; (d) – FEM1.

Tab. 1: Natural frequencies – numerical and experimental values comparison.

TGFS – 6 Values of Basic Natural Frequencies – f_{0i} (Hz)			
No. (i)	Numerical	Experimental	Differences / Δ
	FEM1	SPECTRAL ANALYSIS	
1	4.42	3.57 ^{*)} (3.40)	$\Delta = 19.2 \%$
2	4.62	4.30 ^{*)} (4.28)	$\Delta = 7 \%$
3	4.91	Not evaluated	–
4	9.74	5.69 ^{*)} (6.99; 7,03)	$\Delta = 41.8 \%$
5	12.59	9.94	$\Delta = 33.36 \%$

NOTE: Δ Natural frequencies numerical and experimental values differences

^{*)}..... Natural frequencies experimental values determined by cross power spectral densities and proved by coherence and phase functions.

3. Conclusions

The dynamic analysis methods both analytical and experimental, were a good tool for verification TGFS–06 dynamic behavior of in CET Mariel after the more than fifty years turbine performance and before it is put into operation a new turbo–generator. The comparison of the analytical and experimental result enabled optimization of the foundation structure calculation model and determining the dynamic parameters of the existing fundament structure. Finally it has enabled specifying the real behavior of the TGFS – 6 after the reconstruction and strengthening of structure with the possibility of the determination of failures or operation life. The results of the experimental analysis also point out on the differences between measured and calculated natural frequencies of structure value which finally make a decision on reconstruction and strengthening of fundament structure. The utilization of the dynamic analysis method for the investigations of Industrial Structures is necessary to be more investigated, see also (Bencat, J. and Podhorsky P. (1999); Bencat, J. et al. (2011), etc.).

Acknowledgement

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