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Experimental Investigations on Four Electric-Generators Foundation Systems

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EXPERIMENTAL INVESTIGATIONS ON FOUR ELECTRIC-GENERATORS FOUNDATION SYSTEMS

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ABSTRACT

Machinery can affect engineering structures, as well as foundations supporting them and resting directly on the soil. Machines cause distinct dynamic forces depending on its manufacturing purposes, operating conditions, maintenance, design details a.s.o. The study presents the behavior of four *machine – foundation systems* in a dynamic operating regime. Two of the foundation systems support electric generators groups (CATERPILLAR type), operating at a speed of 1500 rpm, the other two sustaining similar PERKINS models, operating at the same speed. Steady state horizontal and vertical vibration tests were performed on the four foundations. The natural frequencies and amplitudes of vibrations were measured and a comparison between the experimental and required values for the frequencies and vibration amplitudes was carried out.

INTRODUCTION

Machine foundations involve a systematic application of principles of soil engineering, soil dynamics and theory of vibrations, so that require the special attention of a foundation engineer. Unbalanced dynamic forces and moments are occasioned by the operation of a machine. The machine foundations thus transmit dynamic loads to the soil below, in addition to the static loads due to the combined weight of the machine and the foundation. It is the consideration of the dynamic loads that distinguishes a machine foundation from an ordinary foundation and necessitates special design procedures. The foundation for the machine must therefore be designed to ensure stability under the combined effect of static and dynamic loads. The behavior of the supporting soil is generally considered elastic. For the range of vibration levels of associated with a well-designed machine foundation, this assumption seems reasonable. The vibration response of the *machine-foundation-soil system* defined by its natural frequency and the amplitude of vibration under the normal operating conditions of the machine are the two most important parameters to be determined in designing the foundation for any machine (Prakash and Puri, 1988). Having in mind the above considerations the aim of this paper is to present the behavior of four electric-generators in a dynamic operating regime, by means of experimental investigations (Fig.1).

Full-scale dynamic measurements can assist an engineer in many ways, including design verification, checking of finite element models, fundamental period estimation, characterization of the vibration environment and vibration problem troubleshooting.

Fig.1 Photos of two types of electric-generators

METHODOLOGY USED DURING THE ACQUISITION OF THE EXPERIMENTAL DATA

Data acquisition and processing systems

The acquisition of the experimental data was achieved with highly sensitive modern equipment. This one was carefully selected, depending on the stated objectives of the experimental investigations and on the conditions of performing the measurements. A particular attention was provided in order to guarantee the compatibility of the component elements of the acquisition system. The acquisition and processing systems consisted of:

a) The SS-1 Ranger Seismometer (KINEMETRICS Inc.), widely recognized as an excellent short-period field seismometer. As a structural dynamics instrument, the SS-1 Ranger pioneered in the determination of multi-modes of vibration under low-level excitation.

b) The VSS-3000 is fully portable and designed for ambient- and forced-vibration field measurements. The system consists of a laptop computer, a 16-bit Analog-to-Digital Converter and an interface panel for connecting up to 16 transducers, all-in-one housing. The system provides programmable software gains and digital filters for all channels. Data acquisition is controlled by Windows-based software with extensive configuration, importation, analysis, graphing, and reporting capabilities. It features an iconic, flowchart-style interface that accommodates a wide variety of user requirements.

c) Computer PC Hewlett Packard Pentium IV, 512 MB RAM, 1000 MHz.

<u>Field procedures. Selection of measuring points</u>

The first step when performing experimental investigations is to select the measuring points (location in the structure where motion will be recorded). The response of the structural components can thus be recorded by suitable choice of measuring points and orientation of the instruments. Consequently, several schemes for positioning the transducers on the four electric-generators foundation systems were adopted.

There were used 6 seismometers in simultaneous configurations, in order to record the response of these foundation systems at microtremor levels and during the normal operation of each generator unit.

The alternative settings of the pick-ups are presented, as follows. For each electric generator group three mountings were performed; the sensors S1…S6 have been positioned on the horizontal direction (longitudinal and transversal), as well as on the vertical direction (as sketched in Fig.2 and Fig.3).

The v*ibration sources* for each of the records were:

- the ambient vibrations on the site;
- microtremors and vibrations induced by the machine, during the onset of the motor, during the normal operating conditions and during the stopping of the equipment.

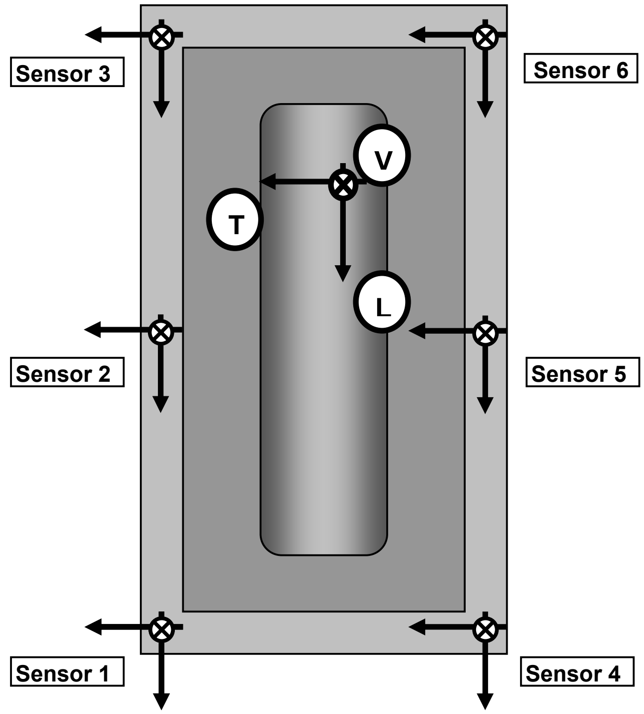

Fig.2 GROUP 1- Location of the sensors.

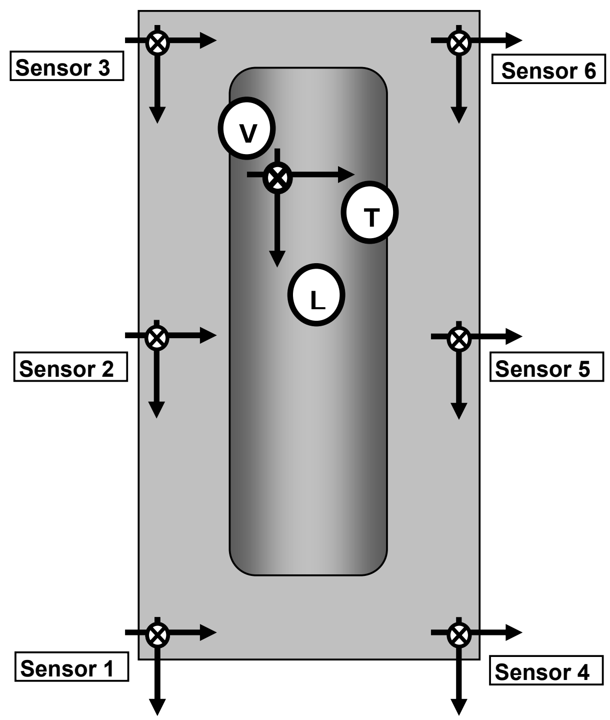

Fig.3 GROUP 3- Location of the sensors.

These arrangements were used in order to point out the following aspects:

- the motion at certain points of interest located on the foundation of each of the four electro-generators;
- the frequency content of the recorded signals;
- the maximum displacements at the foundation levels, during the operation of each machine.

<u>Methodology adopted for data processing</u>

As it was previously mentioned, the pick-ups provide an electric signal proportional with the velocity of the location of the sensor. The program used for the experimental investigations is a data acquisition, process control, and analysis system, which takes full advantage of the features and the graphical interface provided by Microsoft Windows. The signals (voltages) from the transducers are digitized by the acquisition board and are stored on the HDD of the PC.

The sampling frequency, amplification factor, duration of recording and order of channels can be chosen by the user. For the experiments described in this paper the sampling rate/ channel was set to 500 Hz.

The following typical types of analysis have been carried out:

- numerical integration in time domain, obtaining thus from the basic signal (velocities) the vibration displacements;
- Fast Fourier Transform (FFT) of the real signal, both for velocities and displacements (Fourier Amplitude Spectra);
- auto-correlation functions, by means of which it is possible to detect an inherent periodicity in the signal itself and to determine the damping ratio.

Figures 4…17 illustrate some of the results obtained by means of instrumental data.

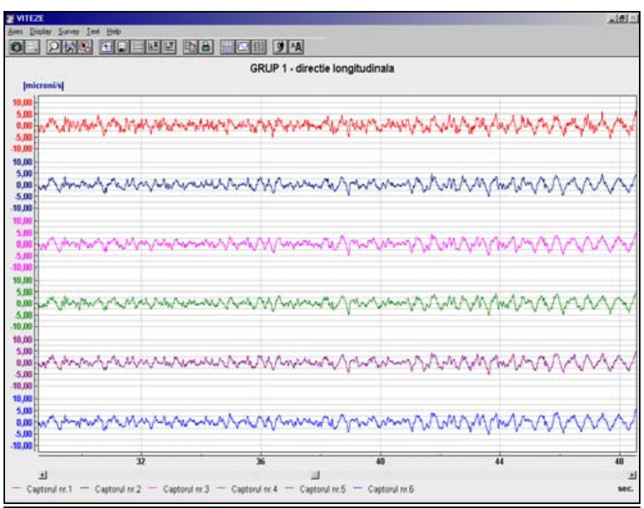

Fig.4. GROUP 1. Velocities [μm/s].
Source of vibrations: ambient vibrations.

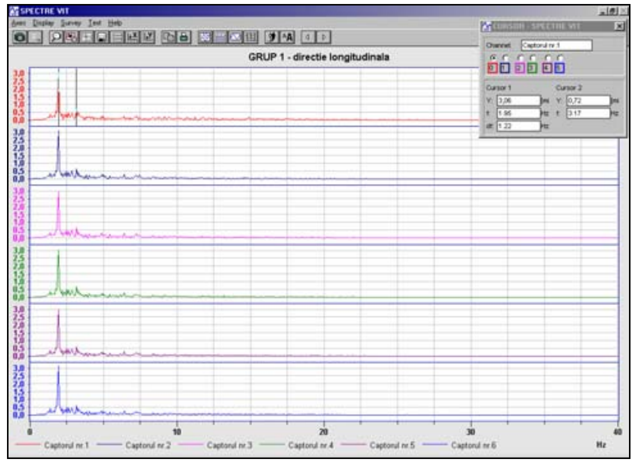

Fig.5 GROUP 1. Velocities [μm/s]. Amplitude Fourier spectra. Source of vibrations: ambient vibrations.

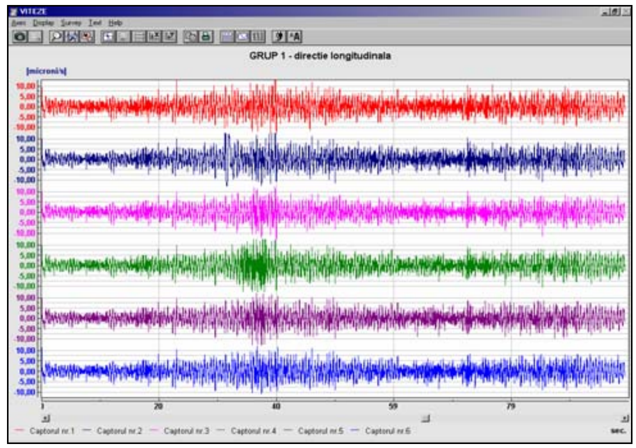

Fig.6 GROUP 1. Velocities [μm/s].
Source of vibrations: normal operating regime.

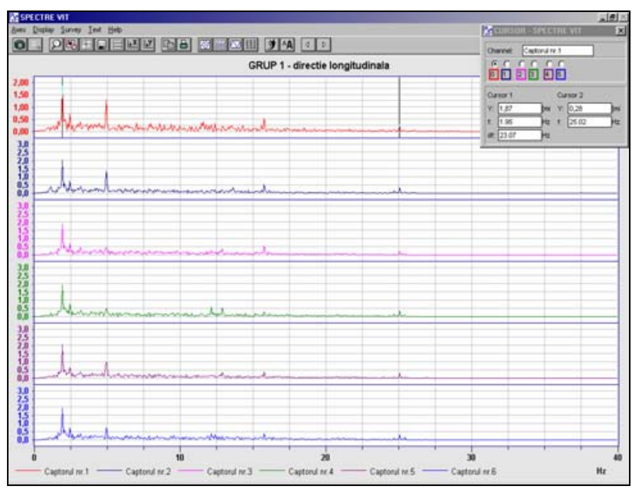

Fig.7 GROUP 1. Velocities [μm/s]. Amplitude Fourier spectra. Source of vibrations: normal operating regime.

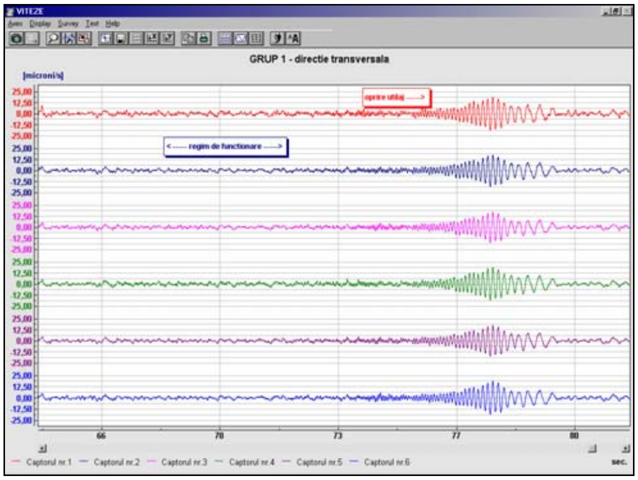

Fig.8 GROUP 1. Velocities [μm/s]. Source of vibrations: normal operating conditions and stopping of the equipment.

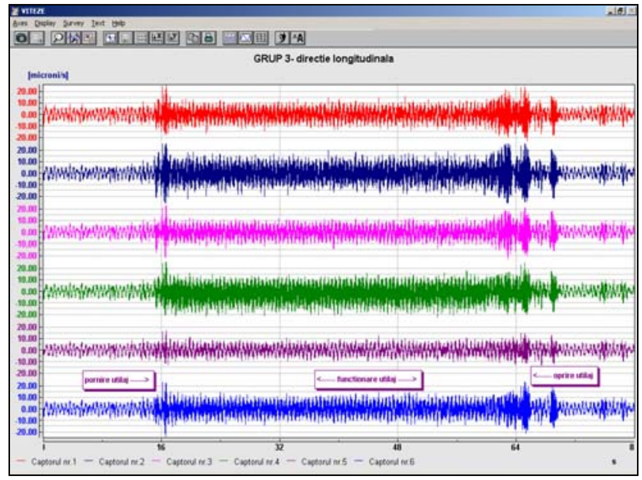

Fig.11 GROUP 3. Velocities [μm/s]. Source of vibrations: starting moment-normal operating regime-stopping moment.

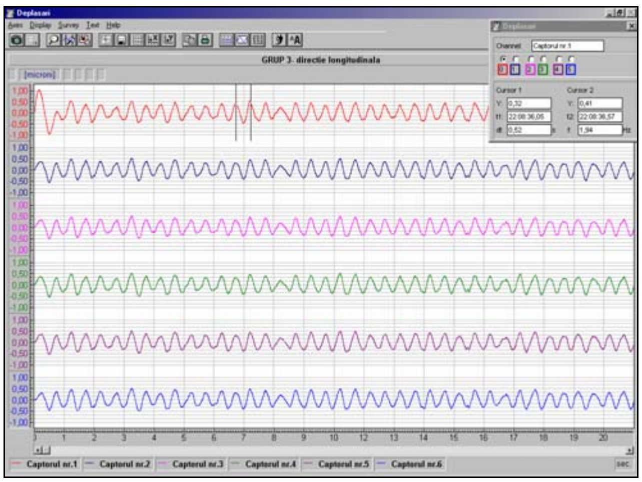

Fig.9 GROUP 3. Displacements [μm]. Source of vibrations: ambient vibrations.

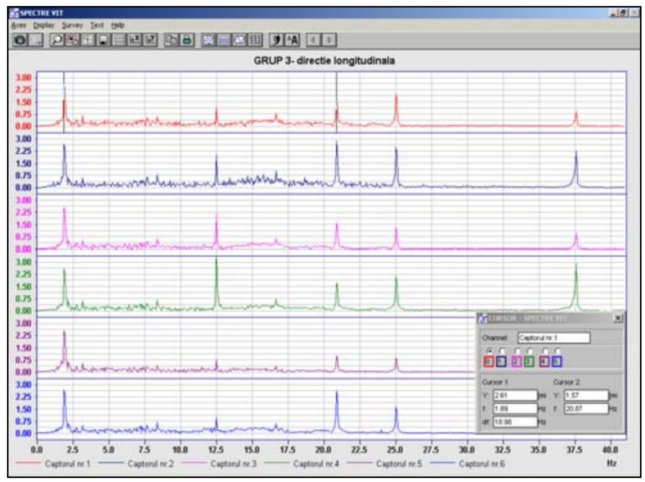

Fig.12 GROUP 3. Velocities [μm/s]. Amplitude Fourier spectra. Source of vibrations: normal operating regime.

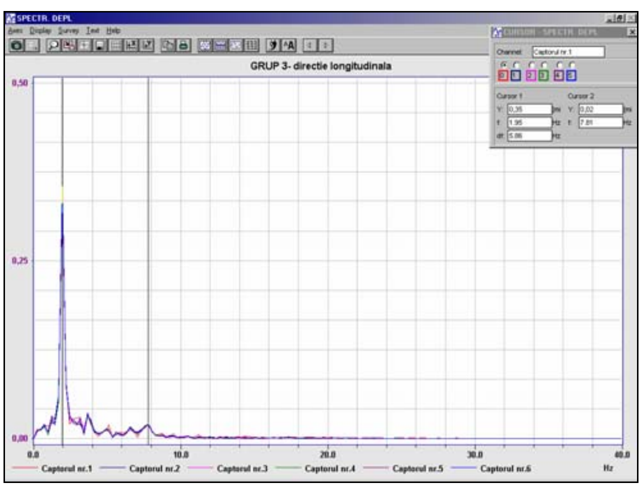

Fig10. GROUP 3. Displacements [μm]. Amplitude Fourier spectra. Source of vibrations: ambient vibrations.

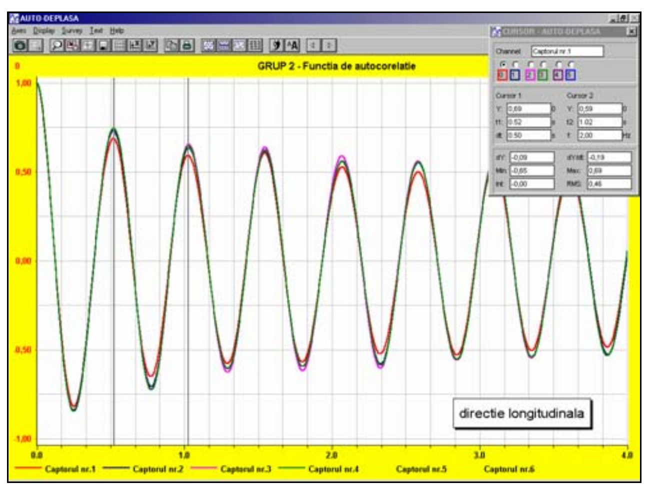

Fig.13 GROUP 2. Displacements [μm]. Auto-correlation functions.

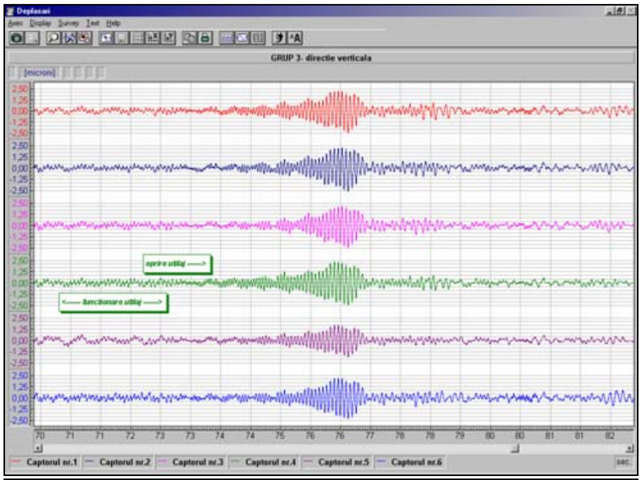

Fig.14 GROUP 3. Displacements [μm]. Source of vibrations: normal operating regime-stopping moment. Vertical direction.

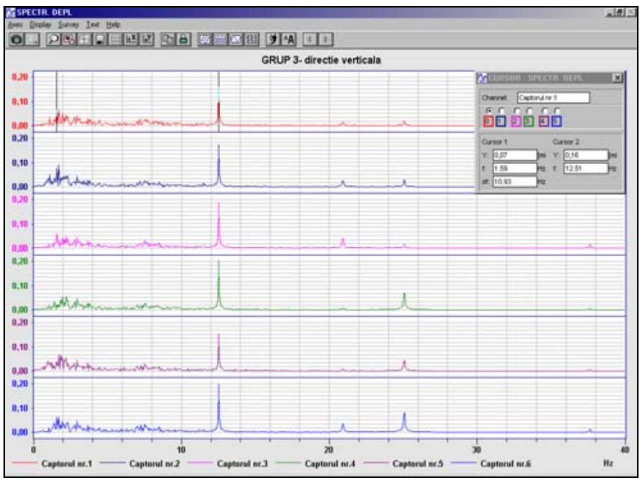

Fig.15 GROUP 3. Displacements [μm]. Amplitude Fourier spectra. Source of vibrations: normal operating regime.

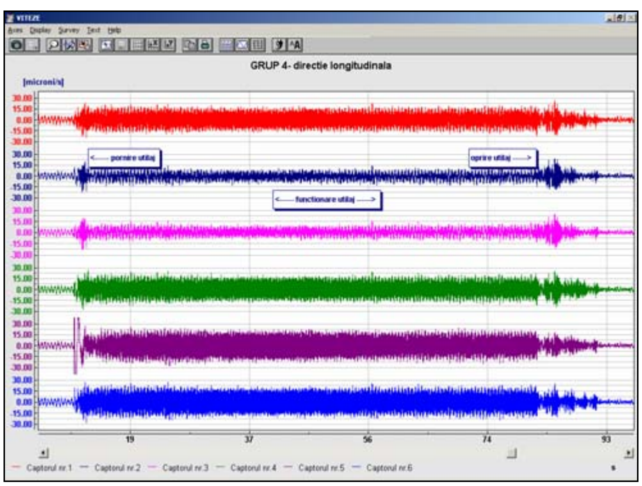

Fig.16 GROUP 4. Velocities [$\mu m/s$]. Source of vibrations: normal operating regime.

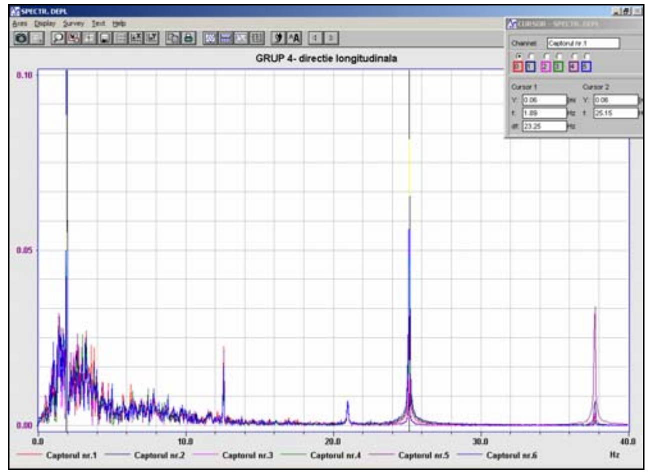

Fig.17 GROUP 4. Displacements [μm]. Amplitude Fourier spectra. Source of vibrations: normal operating regime.

The Fourier Amplitude Spectra and the auto-correlation functions emphasized the frequency content of the recorded motions, as well as the increase of the dominant compounds.

<u>Results of the tests carried on the four electric-generator foundations</u>

On the basis of auto-correlation functions of the recorded signals, it turned out that the values of the fraction of critical damping obtained on the basis of specific processing are:

- GROUP 1: L = 1,0%; T=6,0%; V= 3,8%
- GROUP 2: L = 2,4%; T=2,9%; V= 4,5%
- GROUP 3: L = 1,0%; T=6,3%; V= 5,7%
- GROUP 4: L = 8,7%; T=2,5%; V= 4,9%

By processing the experimental data, the following natural frequencies/periods for the four groups of electric-generators foundations were identified. These *measured values* are shown in Table 1.

One of the simplest and most widely used measures of vibration severity is the vibration amplitude, which may be expressed in terms of displacement, velocity, or acceleration.

Taking into account that the machines are mounted on special isolation systems (in order to keep their movement within limits compatible with the proper operation of the machine), the amplitudes of vibration were significantly reduced, their recorded values being comprised between 0.007mm and 0.025mm.

For this type of machine ($f_{operation}$ < 3000 rpm) the amplitude requirements (Indian Standard IS:2974) are:

- vertical: 0.04 ÷ 0.06 mm;
- horizontal: 0.07 ÷ 0.09 mm.

Table 1. Fundamental natural periods/frequencies of vibration corresponding to the four electric-generators foundations

	Direction	Eigenvalues	
		Frequency [Hz]	Natural period [s]
GROUP 1	L	1.95	0.51
	T	2.62	0.38
	V	3.23	0.31
GROUP 2	L	1.95	0.51
	T	2.70	0.37
	V	2.00	0.50
GROUP 3	L	1.95	0.51
	T	3.23	0.31
	V	1.71	0.58
GROUP 4	L	1.95	0.51
	T	2.70	0.37
	V	1.70	0.58

CONCLUSIONS

1. The paper presents the behavior of four *machine – foundation systems* in a dynamic operating regime.

2. The visual examination of the supporting zones of the units did not put to evidence local damage to concrete, or dislocation of the steel supporting systems.

3. The data acquisition system was conceived and developed in order to provide continuous recording of the vibrations of the four electric – generators foundation systems, during the three phases presented previously in the paper.

4. The experimental checking of the four electric-generator foundations proved that these units were in good condition, as the following aspects were satisfied:
   - no vibration damage was done to the structure in which the four electric-generator foundations are housed, nor to adjacent structures;
   - no settlements were observed;
   - no damage was done to the generator units;
   - the performances of the equipment, or that of the adjacent machines was not impaired;
   - the performance or health of workers in the vicinity was not impaired.

5. The values of the fraction of critical damping, obtained on the basis of specific processing, pertain to an interval of expected values.

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