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Revamp of supporting surfaces of turbogenerating sets foundation frames by composite materials

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Abstract. Paper shows results of experimental studies of loading capacity of composite material ‘Multimetal Stahl 1018’ under static and vibrational loads at high temperatures in order to possibly use this material as a leveling layer on supporting surfaces of large-sized units of turbogenerating sets when they are mounted on foundation frames. Tensile strengths of composite samples were obtained at static loading for temperature range +20°C...+80°C on experimental machine ‘PM-20’; obtained values do not exceed the maximum compressive stress of the material σ = 160 MPa. Experimental studies have been conducted on a specially created vibration unit because construction of foundation of turbogenerating sets is subjected to vibrations with wide spectrum of frequencies. Parameters of oscillatory process were measured using vibration velocity meter, signals were fixed using ADC ‘E 14-140M’ and amplifier ‘LE-41’; signals processing was performed on ‘DSP’ processor module. Differential equation of forced oscillations is compiled, amplitudes and dynamics coefficients are determined for constructed dynamic model of vibration unit. Dependence of oscillation amplitude on height of the test samples is presented graphically. Table summarizes values of the dynamic coefficients at different samples heights for the same temperature spectrum as in case of static loads. It was concluded that the dynamic coefficient decreases with increasing temperature for larger height of sample. It was experimentally established that studied composite material withstands dynamic loads significantly exceeding those that can occur when installing turbogenerating sets on foundation frames. This allowed to recommend material ‘Multimetal Stahl 1018’ for use in installation of turbogenerating sets. Technology has been proposed for revamp of supporting surface of foundation frame in order to perform such works. Industrial tests that were carried out at two thermal power plants when revamping supporting surfaces of foundation frames under turbogenerating set ‘TGV 200’ and under low pressure cylinder of turbine ‘K-20-180 LMP’ that confirmed effectiveness of proposed method and its operability.

1. Introduction

Each year many power generating enterprises plan revamping work on equipment of thermal power plants (TPPs) during which large-sized equipment is dismantled and then installed. Necessity to develop new technologies for these works is dictated by facts that installation of heavy equipment of TPPs and multi-stage operation of fitting supporting surfaces are long and laborious processes [1–7] because height of supporting / contact surfaces can differ significantly from design values due to their operation.

What is the reason for changing design level of contact surfaces of foundation frames and, as a consequence, necessity for its restoration in the horizontal plane? Foundation on which foundation frames are installed and fastened depending on design and can experience various loads, e.g. shrinkage cracks may appear in elements of upper reinforced concrete frame foundation which can affect flatness of supporting surface due to uneven shrinkage of concrete during its hardening. In addition, thermal expansion

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of turbogenerating sets units can cause their move along plane of foundation frame and can cause wear on contact surfaces. Another reason (and it may be the main one) is vibration loads and subsidence of foundation with significant weight of equipment installed on foundation frame.

As it was shown earlier [8–14] one of ways to solve this problem can be usage of modern composite materials which will qualitatively plan surfaces of foundation frames and protect them from corrosion during operation. The material "multimetall- steel 1018" of the German company Diamant metalplastic GMBH was chosen as the test material, since its modulus of elasticity exceeds the modulus of elasticity of standard similar materials by 2.5 times and is 14 × 103 MPa, while for example, the material "multimetallic-steel standard" has this indicator 6 × 103 MPa. However, the properties of composite materials when operating in conditions close to the operation of turbine units have not previously been studied. Therefore, necessity arises for in-depth study of strength characteristics of composite materials. This task is quite difficult to solve in real operating conditions of equipment of turbogenerating sets. That is why Department of Mechanical Equipment of Ferrous Metallurgical Plants (DMEFMP) of Pryazovskyi State Technical University (PSTU) conducted experimental research in laboratory conditions simulating specific operating conditions.

It is known that design of foundation with reliable mounting of turbogenerating sets must withstand permissible values of deformations and amplitudes of vibrations arising during their operation in addition to significant static loads [15]. Vibration of turbogenerating sets is complex and it is in three mutually perpendicular directions. The most common are vibrations with three frequencies. Vibration prevails with so-called ‘reverse’ frequency equal to shaft speed. Vibration of doubled revolution frequency occurs during bending anisotropy of rotor when moment of resistance of its cross section changes twice in one revolution. Low-frequency vibration occurs with frequency close to half of reverse frequency. These vibrations are self-sustaining and like oscillations with doubled frequency they cannot be eliminated by ordinary balancing. The most intense vibrations occur when frequency of disturbing forces coincides with frequency of natural vibrations. Vibration of turbogenerating sets is transmitted to their foundation and may cause its subsidence. Therefore, amplitude of loading elements oscillations of foundations (crossbars, beams, racks) is limited to 0.01...0.02 mm. These standards are often violated, e.g. grid of measurements of elevations of foundation frame of low-pressure cylinder at turbogenerating set ‘K-300’ as a result of operational loads at one of TPPs (refer to Fig. 1).

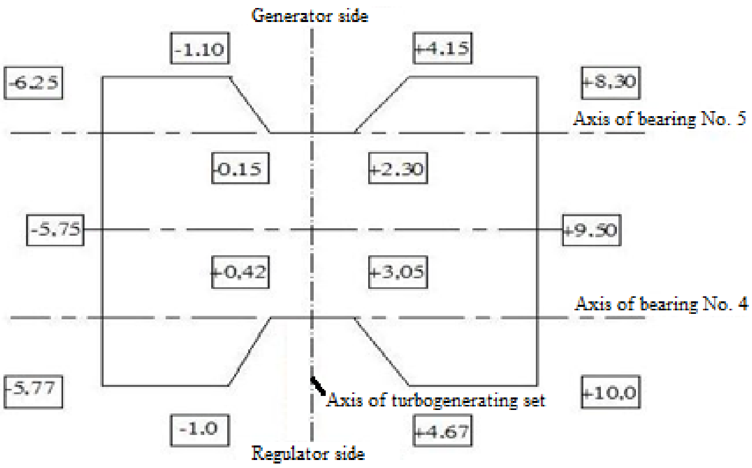

Figure 1. Scheme for measuring vertical coordinates (in mm) of control points on surface of the foundation frame relative to zero level.

First of all, analysis of grid of elevations measurements of the foundation frame indicates that construction of the foundation frame was skewed most likely due to one-sided subsidence of the foundation (from –0.15 mm to –6.25 mm). At the same time, the other side of the turbogenerating set has positive values from +2.3 mm to +10 mm. As a result, further operation of the turbogenerating set with such flatness on the supporting surface leads to additional gaps in connections with the foundation frame and to increase of vibration loads.

Purpose of this work is theoretical and experimental analysis of mechanical strength characteristics of composite material ‘Multimetal Stahl 1018’ to solve the problem of revamp of the supporting surfaces of turbogenerating sets of TPPs. It is possible to develop a technology for installing turbogenerating sets using the composite material on the basis of obtained results.

2. Methods

Difficulty in solving problem of reducing amplitude of oscillations is that dynamic stresses that can be determined can only be determined by knowing dynamic coefficient K_d for a specific calculation scheme. Methods for determining mechanical properties of the proposed modern polymeric materials under vibration at different temperatures are also complicated.

Task of estimation of strength characteristics of the material under static conditions was solved by the department staff on experimental machine 'PM-20' with preheating of samples in furnace. Performed experiments allowed to obtain limits of static strength σ of samples which are equal to:

- at t^o = 40°C, σ = 143 MPa;
- at t^o = 60°C, σ = 120 MPa;
- at t^o = 80°C, σ = 111 MPa.

Technical characteristics of this material were obtained at 20°C earlier [16–18] which are equal to:

- maximum compressive stress σ = 160 MPa;
- Young's modulus E = 14·10^3 MPa;
- density ρ = 2.4·10^{-9} kg/m^3.

These results allow the composite material to be used as a leveling element. However, values of stresses under dynamic loading are not known.

That is why special studies were carried out by the second experimental machine for testing under vibration conditions. Scheme of the second experimental machine is shown on Fig. 2. It was manufactured and installed in laboratory of DMEFMP of PSTU. Cylindrical samples with diameter d = 12 mm and height h = 4...8 mm within temperature range +20°C...+80°C and vibration frequency of 100 Hz were tested.

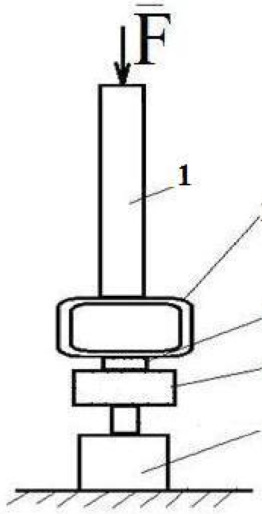

Figure 2. Scheme of the second experimental machine:
1 is pressure screw; 2 is steel ring; 3 is sample; 4 is spacer; 5 is vibration generator.

Parameters of oscillatory process were measured using vibration velocity meter. Signals were fixed using ADC 'E 14-140M' and amplifier 'LE-41'. Signal processing was carried out by programming on a module of digital and signal processor (DSP) produced by company 'Analog Devices'.

3. Results and Discussion

Example of oscillogram of vibration loading the sample with height h = 8 mm at temperature of +40 °C is shown on Fig. 3 where part 2 of the oscillogram is characteristic of stable oscillatory process. Fig. 4 shows graph of dependence of the vibration amplitudes on height of the sample at temperature t^o = 20 °C.

It is advisable to theoretically evaluate effect of dynamic and thermal loads on loading capacity of composite material 'Multimetal Stahl 1018' compared to static load in order to make decisions about possibilities of using the composite material as compensating and leveling layer for foundation frames.

Dynamic coefficient K_d of considered loading cases is determined as a result of theoretical analysis of vibration processes taking into consideration obtained experimental data. According to [19] K_d is equal to:

$$K_d = 1 + \frac{A_{\max}}{\delta_{st}}; \quad (1)$$

where $A_{\max}$ is maximum amplitude, mm;

δ_{st} is static deformation of the sample, mm.

Design scheme of the second experimental machine was used (refer to Fig. 2) to determine A_{max} and δ_{st} for various geometrical parameters of the samples and temperatures under vibration loads.

Differential equation of motion of object has below given view if for generalized coordinate vertical displacement x is taken which is measured from position of static equilibrium:

$$m\ddot{x} + cx = F_{\max} \cdot \sin \omega t \quad (2)$$

where m is mass of the oscillating object, kg;

m is generalized stiffness coefficient, $\frac{N}{m}$;

$F_{\max}$ is amplitude of disturbing force, N;

ω is circular frequency which is associated with oscillation frequency of the vibrator by formula $\omega = 2\pi n$ (n = 100 Hz). Amplitude of forced oscillations is equal to (at absence of resonance and according to [19]):

$$A = \frac{F_{\max}}{\left| c - 4m \cdot \pi^2 \cdot n^2 \right|} \quad (3)$$

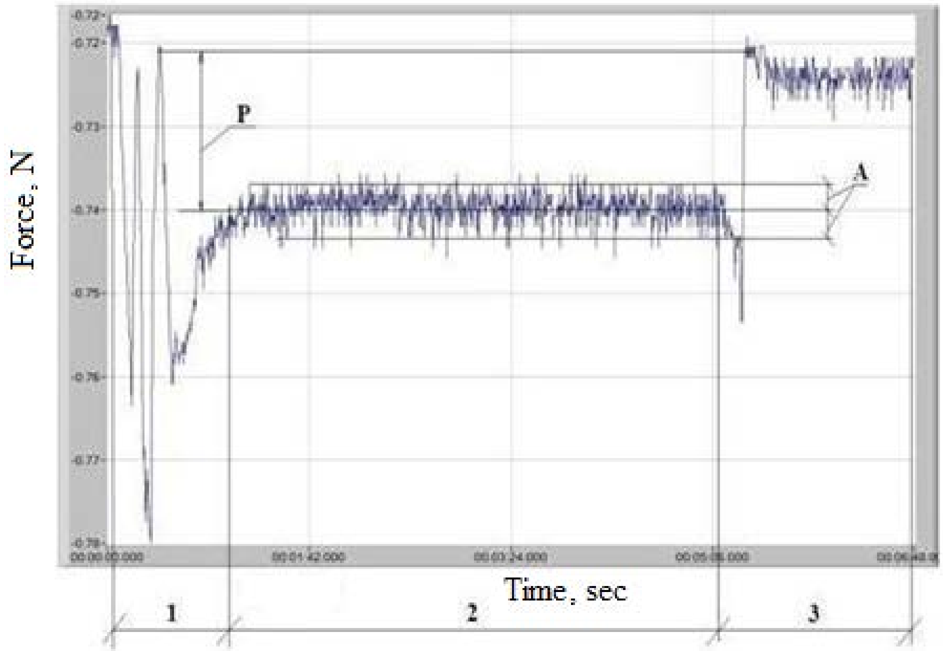

Figure 3. Oscillogram of vibration loading the sample with height *h* = 8 mm at temperature of +40°C: P is force of preliminary pressing; 2A is amplitude of the load; 1 is area of pre-loading the sample; 2 is area of stable vibration loading; 3 is area of unloading.

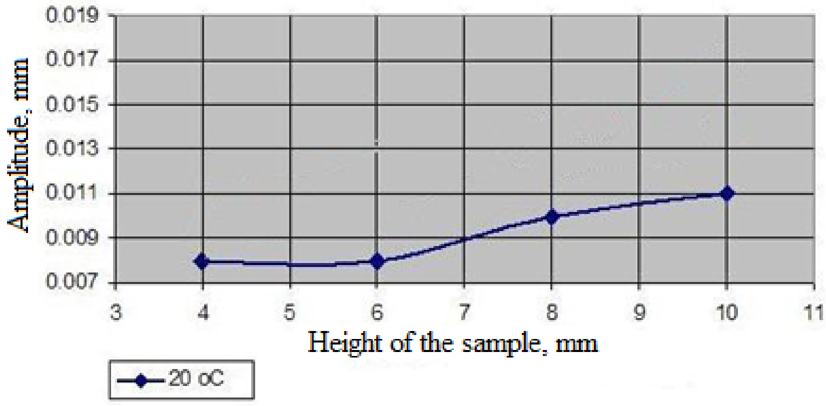

Figure 4. Graph of dependence of the vibration amplitudes on height of the sample at temperature *t*° = 20°C.

Values F_{max} ≈ 220 N and δ_{st} were determined at different temperatures using oscillograms. Generalized coefficient of rigidity of the second experimental machine c was calculated by formula [19]:

$$\frac{1}{c} = \sum_{i=1}^{4} \frac{1}{c_i}, \tag{4}$$

where c_1, c_2, c_3, c_4 are linear stiffness coefficients of the pressure screw, the steel ring with strain gauges, the sample (made from composite material) and the rubber spacer (refer to Fig. 2).

Stiffness coefficients of the screw and the sample were determined using well-known formulas [19] of linear stiffness coefficients of cylindrical bodies. Stiffness factors of the ring and the spacer were determined experimentally.

Dynamic coefficient K_d at various temperatures were obtained for the sample heights h = 4, 6, 8 mm by the formula (1). Results are presented in Table 1.

Table 1. Values of dynamic coefficients K_d

t,°C / *h*, mm	**40**	**60**	**80**
4	1.2	1.12	1.09
6	1.15	1.08	1.075
8	1.15	1.056	1.052

As can be seen from Table 1, vibrational loads acting on the composite material within limits of the experiment only slightly reduce allowable ultimate compressive stresses obtained under static loading. It is also clear that the dynamic coefficient decreases with increasing sample temperature and its height. Explanation of this fact (according to (1)), can be as follows: the stiffness coefficient of the sample decreases at higher temperatures that leads to increase in the amplitude of forced vibrations (3) but value of static deformation increases more intensively with increasing sample height than the amplitude.

Obtained results made it possible to develop and introduce at two TPPs technology for revamping supporting surfaces of foundation frames when installing turbogenerating set 'TGV – 200' and a low-pressure cylinder of turbine 'K-20-180 LMP' using composite material 'Multimetal Stahl 1018' instead of known and single way to fit frames by scraping or cladding of surfaces with following machining [12]. The technology for performing such work in general is given below. It is based on example of the low-pressure cylinder (LPC):

- make a test lift of lower half of the LPC by 10–15 mm, make sure that gap between the LPC inlet ports and foundation plates is uniform. Raise the LPC to a height of 500–600 mm, install supports on the foundation plates and lower the lower half of the LPC onto the supports. Make sure that all supports are loaded and that the LPC firmly and stably lays on the supports;
- clean surfaces of the LPC inlet ports from rust and dirt, check by plate and scrap (maximum by 0.5 mm) to eliminate non-flatness of the supporting surfaces. Treat these surfaces with release agent;
- sling the lower half of the LPC, raise it until the supports are released. Remove the supports and lower the lower half of the LPC onto the foundation plates;

- prepare and install adjustment screws;
- raise the lower half of the LPC and install it on the supports. Calculate thickness of applied layer of composite material 'Multimetal Stahl 1018' on the basis of the gaps measurements results;
- mix components of 'Multimetal Stahl 1018' and put its calculated amount in advance in center of place under the inlet ports;
- put and rubbing into the surface (on the foundation plate) adhesive layer of 'Multimetal Stahl 1018' by spatula with some effort;
- apply the next layer to the plates using all 'Multimetal Stahl 1018' prepared for application;
- lowering the LPC into its working place. Lowering should occur smoothly, without jolts. 'Multimetal Stahl 1018' must be laid with excess in gaps so that some of it is extruded from all sides, ensuring uniform filling of the gaps without air bubbles;
- extruded surplus of 'Multimetal Stahl 1018' should be removed by spatula until it is hardened;
- lower the LPC onto the adjustment screws and leave it in this position for 24 hours at +20 ^{0}C.

Surface of the supports is easily formed and composite 'Multimetal Stahl 1018' is evenly distributed in different directions during assembly due to perfectly balanced viscosity of the composite. Thus, ideal fit of the surfaces is achieved without any processing directly on site that is based on excellent shaping of used composite material.

Effectiveness of this method of gaps compensating during installation (which has been repeatedly tested on practice) was also confirmed by The German Institute Of Structural Engineering [20] which in 2013 issued an admission to use composite 'Multimetal Stahl 1018' for complete alignment or filling of irregularities between metal elements of various metal structures in particular for: supporting parts of spans of bridge structures, crane and rail guides, prefabricated steel structures.

4. Conclusions

1. Done experiments show that compressive stresses on the supporting surfaces that occur during operation of turbogenerating sets are much less than those that can withstand composite material 'Multimetal Stahl 1018' without fracture.

2. Obtained results allowed to recommend this material for use as a leveling and aligning spacer between supporting surfaces of turbogenerating sets and foundation frames on which they are installed. Unfortunately, it was not possible to conduct tests of the material in an extreme situation when the frequencies of perturbing forces coincide with the frequency of natural oscillations, since the natural frequencies of the experimental setting k = 9.53 × 10^{-3} c^{-1}, and the frequency of the perturbing force ω = 629 s^{-1}. At the same time, the study of the material behavior in relation to turbine units does not seem quite relevant, since the resonance mode during their operation is considered unacceptable. Successful implementation of these works at existing TPPs, their subsequent operation are confirmed effectiveness of the proposed method which can be recommended for widespread use.

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