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STRUCTURE UNDER CONTROL AND DESIGN ANALYSIS FEATURES OF GAS-TURBINE UNIT VIBROISOLATED FOUNDATION IN EVER FROST CONDITIONS

Abstract. This article contains an attempt to summarize experience in the design of vibro-isolated foundations for installations with structurally balanced rotating parts, which include gas turbine units. Also, definition of "structure under control" is given and the need for its use for solving this class of problems. Actual problems of the calculation of the "machine — foundation — base" system is defined. The basic approaches to the solution of problem to select vibro-isolation of gas turbine unit foundation as an example of design in the ever-frost conditions are described.

Keywords: controllable construction, system "machine — foundation — ground", vibration isolation, foundation, gas-turbine, stress-strain state, natural frequency, dynamic load.

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УПРАВЛЯЕМАЯ КОНСТРУКЦИЯ И ОСОБЕННОСТИ РАСЧЕТНОГО АНАЛИЗА ВИБРОИЗОЛИРОВАННОГО ФУНДАМЕНТА ГАЗОТУРБИННОЙ УСТАНОВКИ В УСЛОВИЯХ ВЕЧНОЙ МЕРЗЛОТЫ

Аннотация. В данной статье приведена попытка обобщения опыта проектирования виброизолированных фундаментов под установки с конструктивно уравновешенными вращающимися частями, к которым относятся газотурбинные установки. Дано понятие управляемой конструкции и необходимости ее использования для решения данного круга задач. Определены актуальные проблемы расчетного анализа системы «машина — фундамент — основание». Описаны основные подходы к решению задачи по выбору виброизоляции фундамента газотурбинной установки на примере проектирования в условиях вечной мерзлоты.

Ключевые слова: Управляемая конструкция, система «машина — фундамент — основание», виброизоляция, фундамент, газотурбинная установка, напряженно-деформированное состояние, собственная частота, динамическая нагрузка.

The purpose of this work — to summarize existing experience in design of vibro-isolated foundations of machines with structurally balanced rotating parts, show a concrete example of stress-strain state control of such foundations and formulate the basic principles of design analysis of vibro-isolated system "machine — foundation — basement". In the Russian normative and reference documentation for the calculation of foundation vibro-isolation of the machines with dynamic loads single-mass oscillator model is used. Obviously, the use of such a model at the design stage does not allow solving the problem of selecting a constructive solution of vibro-isolation with the required accuracy for practical calculations. To solve this problem in the world design practice FEM analysis is used, most accurately reflecting the real properties of structure and the use of the so-called "structures under control", the use of which allows to compensate inaccuracies of design analysis, develop optimal design solution of the foundation of the machine and improve the reliability and durability of the designed system "machine — foundation — basement".

The main idea, on which design of structures under control is based, is to conduct regular monitoring of their stress-strain state during the entire period of operation, ensuring its normalized adjustment depending on the changed modes of work of engineering equipment, related to such structures. The most actuality this problem has in the design of foundations for machines with continuously changeable operation modes, which are characterized by significant variability of the vibration levels of bearing supports depending on the stress-strain state of the foundation structural elements, used for their installation.

The article reviews an example of realization of the vibro-isolated foundation for 14.7 MW gas-turbine unit (hereinafter GTU).

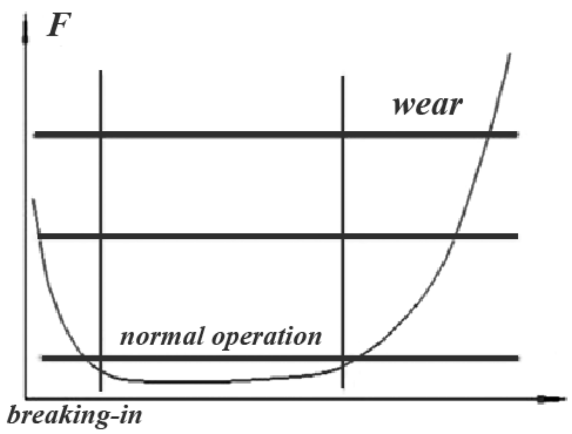

Fig. 1. Graph value of dynamic load (F) variation during the whole period of the unit operation

GTU is a unit with structurally balanced rotating parts, which are due to imbalance disturb the harmonic type of dynamic impact on the foundation. Considered GTU is placed in the main building of the power plant, located in the ever frost conditions. For installation of the unit foundation 1st type foundation is used with ventilated underground. GTU foundation is piled with metal drilled-in piles.

Design analysis problems of this range of tasks.

1) An idea to create system of structures under control appeared due to impossibility of accurate solution of dynamic problem, as rotor misbalance is not known and its value is changed time-to-time during a whole period of unit operation. So, dynamic load values are varied.

Due to that, it is necessary to establish such operating conditions of equipment to minimize the negative influence of inertial forces, imposed from the foundation side on the unit shaft line and support bearings [4], to provide opportunity of machine balancing.

2) System “machine — foundation — basement” is not linear.

Linear system is characterized with the following criteria:

– input signal — exciting force produces a proportional output value of vibration displacement, vibration speed or vibration acceleration;

– when several input signals are exposed simultaneously to a system, they are processed by the system independently of each other without interfering with each other inside it.

The more difficult is the considered system due to a big number of elements different with their physical-and-mechanical properties, the more complicated is to use reference about linearity of this system when executing balancing works. It is known, that the greatest contribution to the nonlinearity of the “machine—foundation—basement” system makes concrete and soil, properties of which have physical nonlinearity. For nonlinear systems modulation is common, i.e when the input signals within the system interact with each other, producing a new set of frequency components and harmonics [6].

Vibro-isolated system is the closest to the linear system, that allows to use this fact in the spectral analysis.

3) In specifications from the manufacturers of equipment (in the Russian Federation mostly imported GTU units are used) information about values of dynamic loads are absent or have no physical sense. This leads to necessity to take amplitudes of dynamic loads based on formula from reference documentation [2]:

$F_{n,v} = F_{n,h} = \mu\sum_{i=1}^{s} G_i$ (where μ — proportionality factor, set; s — number of rotors; G_i — weight of every machine rotor, kN (tf)) or reference materials: $F = k m_p e \omega^2$ (k = 2,5–4 — margin factor, considering misbalance increase; m_p — rotor mass; e — rotor misbalance; ω — angular rotor speed, rad/s).

4) Another problem, but a single example, is due to the complex engineering-geological conditions at the construction site of the power plant. The soils under GTU foundation are on the boundary of two phases: frozen and thawed, so there is no sense to predict their condition over time, and the use of seasonal cooling units and the monitoring system is economically inefficient, especially for thawed soils.

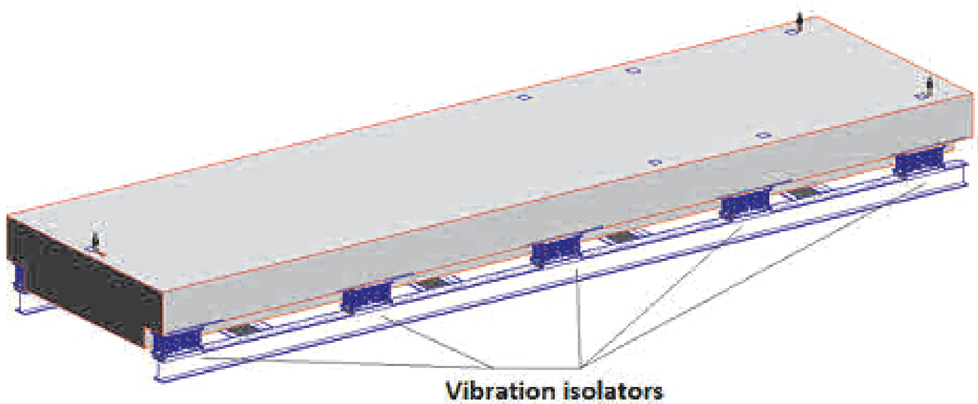

Fig. 2. Foundation plate on vibration isolators (GTU and piles are not shown)

According to information received from the customer's operational service, similar GTU units in this area are performed by the type of rigid coupling of the foundation and frame installation. During operation their foundations had different settlements, that is unrecoverable with this rigid coupling without equipment removal.

Description of realization

GTU is supplied on the factory steel frame. Frame is placed on the metal-concrete slab, that is based (through GERB vibration isolators) on the metal grill, bounding piles.

Fig. 3. Vibration isolator with inbuilt VISCO-damper

Vibration isolator is a structure, consisting of steel cylinder springs, installed between two soldered metal bodies. Furthermore, vibration isolators include viscous friction dampers that reduce vibration transients (through its own frequency), occurred in start-stop mode of machine, and also serve to reduce the oscillation amplitudes of the "machine — foundation" system in emergency cases. At that, they do not affect the stiffness properties of the system.

Vibration isolators are installed free without any fixation that makes it possible to adjust height position of GTU frame in the event of unforeseen settlement of the pile foundation. Adjustment of height position is carried out by jacking of a concrete slab and installing of additional steel plates between this slab and the upper bodies of vibration isolators.

Design analysis features

One of the important points in the design analysis of frequency-response characteristics of the system "machine — foundation — basement" is an accounting of rigidity of the pipelines, gas flues and air ducts, adjacent to the unit. It is noted [5], that in dynamic calculation it is allowed not to account their influence under the total rigidity less in 6 times that the total rigidity of vibration isolators. But, in the calculation of deformations from static and quasi-static loads it is necessary to account loads, transferred through the compensators due to not high horizontal rigidity of vibration isolators. In this way, low load may cause limit deformation of the system sprung part or damage of vibration isolators. Normative documents, valid in the Russian Federation, do not con-

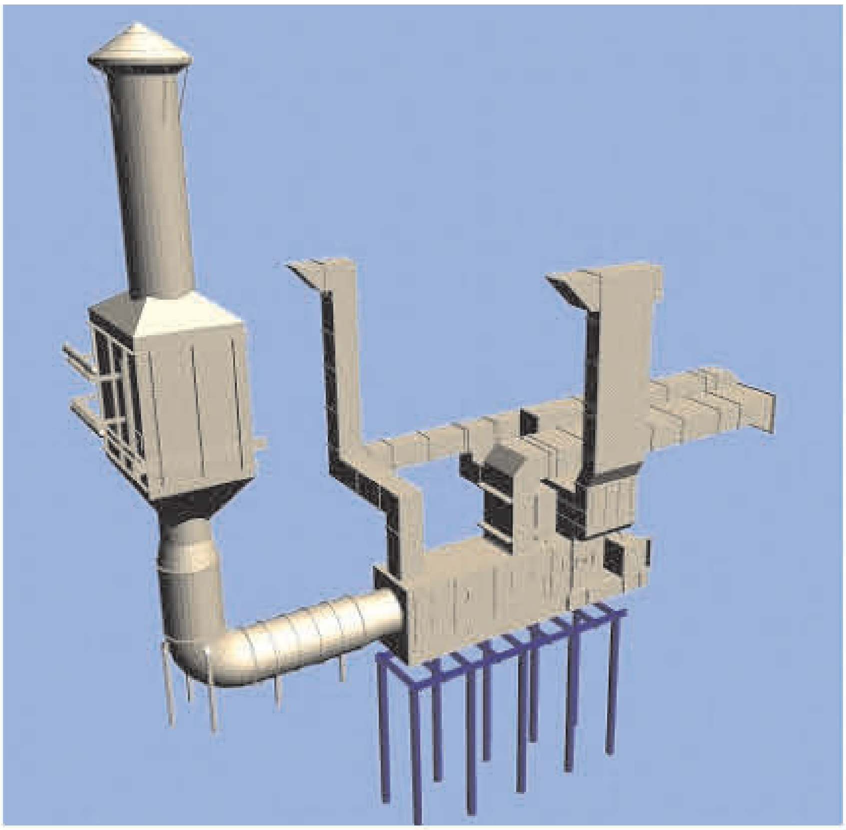

Fig. 4. Diagram of air ducts and flue ducts to GTU

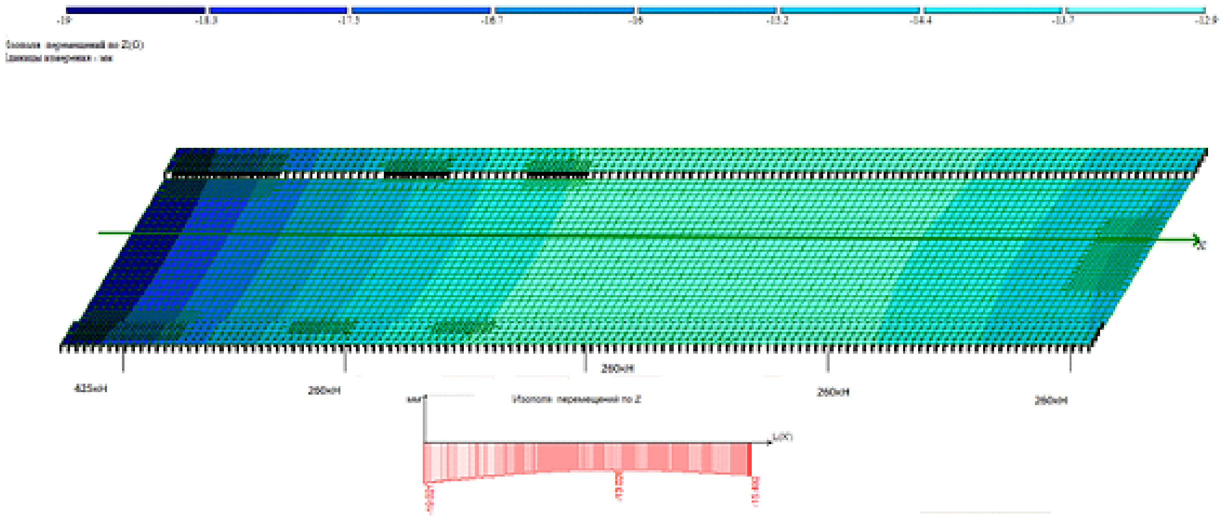

Fig. 5. Isofield of slab vertical displacements from static load

tain information about limit values of the deformations of GTU foundations (relative to deflection, inclination and displacement). Therefore, it is necessary to follow the requirements of the GTU manufacturers in the calculation of limit states. The limit values of the horizontal deformations of vibration isolators are specified by the manufacturer.

In general case vibro-isolation for the units with nominally balanced parts is selected in the following way:

1) Arrangement of vibration isolators based on limited transferred static loads (load nominal value is specified in technical specification for vibration isolator) from sprung weights, and also meeting the requirements for the limited deformations. In some cases there are limited capacities for selection of place for installation of vibration isolators in conditions of engineering equipment arrangement priority, so it is necessary to pay special attention on ensuring strength and rigidity of the foundation slab, which should be assured with required design calculations. In these cases selection of vibration isolators, design of vibro-isolated slab and arrangement of supporting structures is of iterative nature.

2) Accounting of transferred through compensators static loads from the pipelines, air ducts and flue duct. A repeated check of vibro-isolated slab deformation and probable correction of design diagram.

3) Determination of own frequencies of system fluctuations.

4) Analysis of frequency-response characteristics in the transient processes and working frequency ranges, taking into account concurrence and non-concurrence of initial phases of equipment, installed on the frame (frequency and spin phase of turbine and generator at presence of gear are mismatching). Received values are compared with limit values of vibration displacements, vibration speeds and accelerations.

5) Accounting of the rest dynamic loads on the lower structures.

In the absence of damping and when $\eta > \sqrt{2}$ vibro-isolation effect may be determined as follows:

$$I = \frac{\eta^2 - 2}{\eta^2 - 1} \cdot 100\%$$

where $\eta = f_m/f_n$; f_m — working frequency; f_n — own frequency.

The rest dynamic force F' may be determined as follows:

$$F' = F \cdot (1 - I/100).$$

German standards [2] when using spring vibro-isolation allow to neglect the dynamic effects on the supporting structure both in working and in emergency conditions.

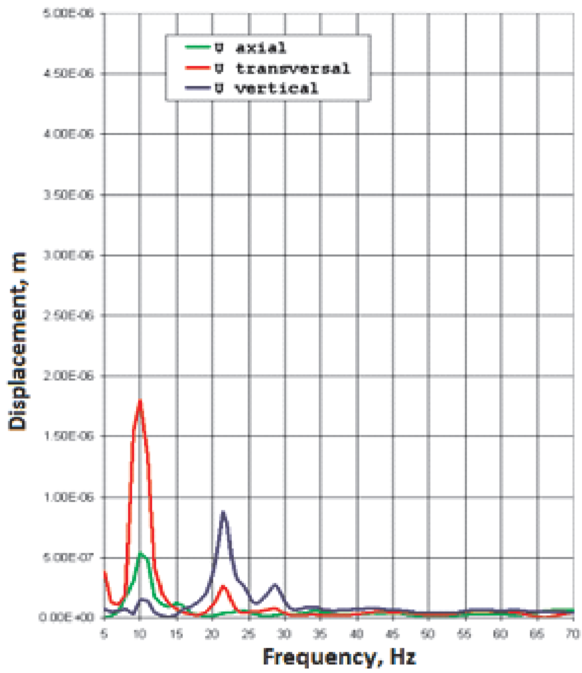

Fig. 6. Frequency-response characteristics

Conclusions

Thus, with a specific example rational area of vibro-isolation use, according to the author, is described that allows you to create a controlled system "machine — foundation — basement". The reasons causing the complexity of exact solution of this problem are considered. The features of the design analysis of the vibro-isolated foundations of rotating machines are specified and calculation algorithm is formulated.

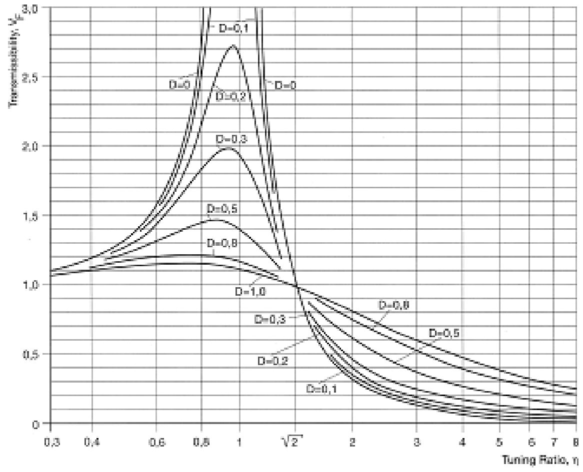

Fig. 7. Dependence diagram of the dynamic coefficient VF from tuning ratio η under various values of damping rate

In conclusion, it should be noted that in the process of designing the systems "machine — foundation — basement" an integrated approach to solving the problems is required, at that first-stage are structural solutions of engineering equipment (the value of any foundation is not more than 1–2 % of the cost of the equipment installed therein), but you should always keep in mind that its performance depends on the rational design of foundations on which equipment is located.

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