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EXPERIMENTAL RESEARCH OF ENGINE FOUNDATIONS

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This paper tries a compact presentation of the experimental research of engine-foundations. The dynamic phenomena are so complex, that the vibrations cannot be estimated in the design stage. The design engineer of an engine foundation must foresee through a dynamic analysis of the vibrations, those measures that lead to the avoidance or limiting of the bad effects caused by the vibrations.

1. Introduction

Even with all the recent progresses in the theory and analysis of the vibrations of the engine foundations, there are vibration problems that come up during their practical carrying out and that cannot be solved only from the theoretical point of view. In some situations, the dynamic phenomena are so complex that the vibrations cannot be estimated in the designing stage. Therefore, the design engineer of an engine foundation must foresee through a dynamic analysis of the vibrations, those measures that lead to the avoidance or limiting of the bad effects caused by the vibrations. We can see that the theoretical research methods must be associated with the instrumental ones so as together to provide useful technical information that would lead to a rational design of a structural assembly made up of *engine–foundation–setting soil.*

2. Purpose and Importance of the Experimental Researches

The experimental researches that were carried out on the engine foundations provide information about their actual condition.

We are going to present synthetically the most important aspects that can be explained through the experimental researches:

a) Verifying their elastic and dynamic characteristics that were first assessed by means of numerical analysis based on some computation models.

b) Verifying the functioning parameters in the insertion process or stabilized conditions, as well as the technical and technological performances (inclusively, during the technological tests).

c) Verifying the potential modifications in time of the parameters specific to the interaction between *engine–foundation–setting soil*, and implicitly of the influence of the physical-mechanical characteristics of the setting medium.

d) Verifying, during the exploitation, the preservation of the elastic and inertial characteristics and the excited (disturbed) sources.

e) Verifying the diagrams (strategy) for the equipment operation (by stages of lubrication and relaxation) according to the number of rotations prescribed by the supplier and their possible field calibration.

f) Identifying some possible disturbances due to some causes such as: modelling and designing of the foundations, dynamic adjustment between source and system, specific functioning parameters of the equipment, degradation of the materials specific to the strength structure and of the (fixed and unfixed) components of the vibration generating plants.

g) Permanent or periodical monitoring of the functioning, within the limits of the acceptable parameters, of the assembly *engine–foundation* in order to avoid some interruptions in the technological processes or causing some damages.

3. Using the Experimental Researches in Order to Verify the Modelling Criteria in Dynamic Concept of the Engine–Foundations Assembly

The experimental researches are carried out after the practical achievement of an engine foundation and, as a result, if the dynamic model specific to the instrumental research stage is not validated, it is too late to resume the modelling, analysis and designing process. Therefore, the *recording of the vibrations of a foundation represents a means of verifying the modelling criteria and the performances in exploitation.* The vibrations that were studied experimentally can be generated by: a) artificial fires; b) disturbance forces that result from the functioning of the engines or equipment; c) micro-seismic agitation.

The *artificial fires* generate free vibrations and their analysis enables us to *identify entirely the defining characteristics* of the dynamic system (their fundamental characteristic values and the degree of damping through the logarithmic decrement). Under certain conditions, we can verify instrumentally the *type of damping* (viscous, structural hysterical, voltaic) and *the dependence of the damping versus the frequency.*

In the case of the measurements of the *forced vibrations*, we can obtain information regarding the level of vibrations, as well as the characteristic frequencies of the system, if the *beating phenomenon* appears (amplitude modulation). We can draw the following conclusions:

a) The frequencies of the vibration can be precisely identified experimentally; the elected dynamic model is confirmed or invalidated by comparing them with those determined through the theoretical analysis.

b) If we identify the beating phenomenon, the frequency of the source, as well as the characteristic frequency of the dynamic system results with an exceptional accuracy.

c) The damping degree can be determined through the response curve obtained experimentally. This way of determining the damping power is called *frequency range method.*

d) If in the case of the foundations from the block category, the influence of the soil on the dynamic characteristics is underlined, we can establish through experimental studies that this influence upon the engine foundations in spatial frames can also be founded.

If we analyse the dynamic response to the *micro-seismic agitation*, we realize that the engine foundation functions as a narrow band filter that diminishes the components of the oscillatory motion situated outside the defined fundamental frequency zone characteristic of the vibration.

4. The Use of the Experimental Researches for the "Correction" of the Dynamic Assembly Made up of Engines and Foundation

By carrying out the experimental researches in different stages from the setting up of the dynamic assembly, that is:

a) after the foundations are made, but before the aggregate set-up,

b) after the aggregate set-up, but before rendering them operative,

c) during rendering them operative for the technological tests,

d) during placing them out of operation,

we can draw useful conclusions that allow us to carry out several interventions in order to *correct* the assembly for a normal, even the best functioning.

5. Using the Instrumental Researches for Identifying the Excitation Source

In the case when we know the physical and dynamic characteristics for the defining the system and its response, the dynamic system becomes an instrument that allows us to identify the excitation source (input quantities). This issue is situated at the basis of the construction, calibration and use of the measurement equipment of the movements generated by different excitation sources, such as: unbalanced engines, explosions, seismic action, etc. We can identify the actual excitation that the instrument undergoes by processing the obtained experimental data. Thus, we can design the *active isolation* of the disturbance forces generated by an engine if we know their characteristics. If we measure the vibrations where the engines are placed, we can estimate *the passive isolation* system of an apparatus.

6. The Experimental Identification of Some Cracks or Segregations in the Mass Foundation

If we measure certain *relative kinematic values*, we can notice:

a) the existence and the influence of some cracks (presumed);

b) the existence of some "segregations";

c) the misfit attachment of the engine to the foundation.

In order to identify these situations, it is enough to place two sensing devices on both sides of the crack or on the foundation and the bearing. If the two recordings are identical (especially in the phase), then the supposed crack (segregation) is not "working" or the attachment of the engine to the foundation is correct.

We can establish through complex, theoretical and experimental analysis:

a) the causes of an incorrect functioning of the assembly: *engine–foundation–setting soil*;

b) "the degree of degradation" of a foundation;

c) the recovery index of the structural rigidity of an engine foundation through a possible "remediation".

7. Stages of an Experimental Research Specific to the Engine Foundations

In order to obtain the characteristics of the dynamic phenomena generated by the functioning of some engines or industrial equipment, we need to go through the following stages:

1. Carrying out a preliminary analysis (visual), on the spot, in order to define and explain the phenomena that led to the decision related to taking instrumental measurements. During this stage we choose the values that must be measured (shifting, speeds, accelerations) and we estimate the limits within which these values vary.
2. Selecting the adequate and necessary apparatus for the aspects that are going to be explained.
3. Establishing the dynamic co-ordinates (recording points and directions).
4. Connecting the dynamic co-ordinates in order to achieve some simultaneous recordings of the vibrations for the identification of possible phase changes.
5. Carrying out the instrumental recordings in the established points and directions.
6. Analogical and numerical processing of the signs recorded on magnetic base.
7. Analysis and interpretation of the results from the dynamic point of view.
8. Diagnostic of the functioning of the analysed assemblies.
9. Drawing some conclusions, taking some decisions and recommendations.

8. Measured Mechanical Values

The response of a dynamic system (the assembly *engine–foundation* that vibrates) is expressed by the known fundamental kinematic values (instantaneous/maxim):

1. Shifting.
2. Speeds.

3. Accelerations.

Basically, all three values have the same content of information because they can be inferred one from the other by derivation or integration in point of time. The election of the sensing device compatible with the kinematic value is determined by the characteristics of the vibration that is going to be studied, as well as by the value that is important for the study. It is important first to know the movement because it conditions the election of the sensing device for shifting, speed or acceleration.

1. Measurement of the shifting is done in the following cases:

a) For the study of low frequency vibrations, that correspond generally to the number of rotations in the case of some engines (the measurement of the speed and acceleration leads to output signals with low amplitudes). The component with high frequencies, that are important for the safety of the functioning and the preventive maintenance of the engine, correlated with the noise produced by the engines and its wear, are not taken into account, which may lead to incorrect conclusions related to the quality of the engine.

b) When the amplitude of the shifting is highly important (in the case of the sub-assemblies made up of mechanical components that vibrate independently and therefore they must not enter into contact).

c) In the case in which the value of the measured shifting represents an indication for the stress and deformation states.

2. Measurement of the speed can be useful:

a) For the study of medium frequency vibrations, when the amplitude of the shifting is too low so as to be measured.

b) For the acoustical measurements, correlated with the vibration measurements, because the vibrating membrane can generate acoustic waves whose pressure is proportional to the speed.

3. Measurement of the acceleration:

a) For the study of high frequency vibrations, when the maximum output signal can be obtained through such measurements.

b) When the forces must be assessed, if we take into account the fact that the inertia is proportional to the acceleration.

c) In the case in which the shifting or speed sensing devices do not fit into the space used for the assembling, because the acceleration sensing devices are small.

The measurement of the acceleration in the area of low frequencies is especially used for the shocks that consist in spectral components up to zero frequency. We suggest the measurement with shifting sensing devices with frequencies between 0...1,000 Hz, with speed sensing devices with frequencies between 10...2,500 Hz and acceleration sensing devices between 20...20,000 Hz.

The gathering of the instrumental data in the case of engine foundations that are subjected to *harmonic excitations*, intends to explain the following fundamental aspects:

a) determination of the amplitudes of the vibration represented by shifting/ /speeds/accelerations;

b) analysis of the vibrations in the stage of the phases;

c) identification of the frequencies (of the spectral structure).

If we refer to the acquiring of some information experimentally, in the *case of the engines with mechanical components that generate shocks*, we must take into account that the charging is characterized in the impact stage, by the following parameters: duration of the impact, configuration of the impulse, duration of the increase of the force and the maximum value of the impact force. The combination of these parameters determines the shape of the function of the dynamic action proportional to time. In most of the cases, the followings are important:

a) determination of the instantaneous and maximum values of the amplitudes;

b) duration and configuration of the impact.

Most of the time, besides the recording of the variation of the instantaneous amplitude in time, it is better to carry out some analysis in the complex area of the frequency.

In the case of the *aleatory excitations*, a long duration recording of the response of the foundation is absolutely imperious. The practical interpretation of the recorded signals is difficult and inconclusive in this case and, therefore, we had to perfect the experimental techniques and, implicitly, the apparatus used for the acquiring of the signals. We developed the *signal correlation method*, that is, the determination of the *self-correlating function* of a signal with itself and/or the *inter-correlating function* of two signals. The mathematical definition of these functions is represented by the expressions:

$$(1) \qquad R_{xx} = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t)x(t-\tau)\,\mathrm{d}t,$$

respectively

$$(2) \qquad R_{xy} = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t)y(t-\tau)\,\mathrm{d}t.$$

R_{xx} is the self-correlating function for a signal, $x(t)$, and R_{xy} – the inter-correlating function for the signals $x(t)$ and $y(t)$.

The values $R_{xx}(\tau)$ and $R_{xy}(\tau)$ graphic representations makes the vibration process correlogramm.

In the case of the experimental determination of the correlating functions, the duration, T, from the expressions (1) and (2), becomes a finite value that, depending on the nature of the signals, must fulfill the following conditions:

a) in the case of the correlation of a periodical signal, the duration T is equal to the period of the signal or to an integer number of periods, so as not to introduce errors in the estimation;

b) in the case of the correlation of the aleatory signals, the duration of the achievements that we have in view is imposed by the accepted estimation error.

If the gathering of data refers to *transient signals*, the self-correlating function has the following shape:

$$R_{xx} = \int_0^T x(t)x(t-\tau)\,\mathrm{d}t \tag{3}$$

and it can be obtained without dividing it with the integration duration. due to the fact that the average in time would tend to zero if the observation time increased. *The inter-correlating function* of two transient signals is:

$$R_{xy} = \int_0^T x(t)y(t-\tau)\,\mathrm{d}t. \tag{4}$$

The correlating functions of the periodical signals maintain the periodicity of the correlated signals. In the case when two signals, $x(t)$ and $y(t)$, are periodical, with a period equal to that of the "beatings" obtained through the mixture of the two signals. The characteristics presented above are extremely useful for the measurement of the periodical signals or the measurement of the aleatory signals "superposed" to the periodical ones.

In the case of these signals, the measurement of some spectral characteristics is useful, such as: spectral density of the mean square value, interspectral densities together with the values of the distributing functions of the amplitudes and the probability density.

If the instrumental research is meant to establish the "vibration level", the *absolute* values of the response shall be determined, because we need to determine a precise *standardization and calibration* of the apparatuses.

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INVESTIGAREA EXPERIMENTALĂ A FUNDAŢIILOR DE MAŞINI

(Rezumat)

In teoria şi analiza vibraţiilor fundaţiilor de maşini apar probleme de vibraţii în realizarea practică, care nu pot fi rezolvate integral. Inginerul proiectant al unei fundaţii de maşină, printr-o analiză

dinamică adecvată, trebuie să prevadă acele măsuri care să ducă la evitarea sau limitarea efectelor vibraţiilor şi şocurilor asupra persoanelor, maşinilor, vecinătăţilor sau clădirilor care le adăpostesc. Se poate constata că metodele de investigare teoretice trebuie asociate cu cele instrumentale astfel încât, împreună, să poată furniza informaţii tehnice utile, care să conducă la o proiectare raţională a unui ansamblu structural *maşină – fundaţie – teren de fundare*.