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Equivalent vibration tests

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Abstract

The requirements for test results on vibration authenticity and reproducibility are discussed. Experimental results of longevity and vibration loading (fatigue curves and curves of the "vibration loading") of a 10 deterministic and random modes of vibration, done by a special technique with new sensors and the test equipment, were obtained. The deterministic and random modes equivalence coefficient much increases with the time before the destruction of the sample. It is shown that the "equivalent" replacement of a deterministic model of a random loading when tested on vibration loading is unacceptable. The model replacement when tested on durability is allowed only for polyharmonic mode but is incorrect.

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Keywords: broadband casual vibration; equivalent vibration tests; stresses; deformation; vibration speed; sensor; durability;

1. Introduction

The last decade has been characterized by a sharp increase in power and speed of transport equipment. This causes an increase in vibration loading on constructions because of the occurrence of turbulent flow, pressure fluctuations in the engines and the forces of interaction with the environment. These factors cause the deterministic and random vibrations. More than 70% of failures are caused by vibration in engineering, because of which fatigue destruction of construction elements transported goods, failures and malfunctions of electronic equipment occur.

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The operating conditions of some objects (missiles, space vehicles, submarines, aircraft, etc.) and the growing shortage of metal in the world require a reduction of weight of the metal in constructions. Finding a reasonable compromise of the maximum reliability with minimum weight is laid in the development of methods for determining the adequate behavior of materials in the construction with a specified service life and reliability.

In testing for the vibration there are two major problems.

- Obtaining the reliable fatigue curves of the material at loads**,** close to any operational conditions, the study of the construction vibration loading and the prediction based on their durability test.
- Evaluation of reliability and strength of the vibration test facility for a specified time under specified loads. At the same time for completion of the tests there is no reliable data on the remaining resource of the object, and to bring a construction to the destruction, many of which are unique, is too expensive.

But there is a general tendency - the desire to simulate the operational condition of the random vibration loading. During the operation of transport vehicles the most common type of load is the broadband random vibration.

The International Electrotechnical Commission (IEC) imposes on the vibration test two basic requirements: reliability of the results and their reproducibility in different laboratories, which is especially important during the acceptance testing [1]. The reproducibility of test results is not realistic at a low reliability of the results.

In the development of methodology of the vibration test, there were new problems [2], including equivalent tests, by these we mean the actual replacement of the random vibration by the deterministic test condition. The research in this direction was made in order to reduce the cost of testing, because energy consumption under random vibration increase in an order of magnitude or more compared with the deterministic vibrations. The tests conducted in some cases many days.

The problem of replacing the random vibration by the deterministic process is considered in the theoretical aspect [3, 4], and in terms of hardware reproduction [2, 5] and standardization of tests [6, 7]. There have been made a huge number of experimental studies [8, 9, 10, 11 etc]**,** however, a universal solution to this problem was not found. However, in industry deterministic modes are used until now. And if the equirements of the IEC to the reproducibility of test results for harmonic loads are not difficult to satisfy, the degree of reliability of the results of such tests has caused some doubt [12]. In works [8-11 etc.] strain sensors were used earlier and are used now for strain measuring. These sensors accumulate damage as the measuring object at prolonged vibration loading [13,14]. Therefore, strain sensors change their metrological characteristics.

However, these methods of tests are applied till now [15, 16, 17 etc].

To establish the reliability of the results of equivalent tests is possible with the results of fatigue tests on similar modes, because the reliable criterion of equivalence is just time before destruction. The reliability of the results of fatigue tests can be improved by perfecting test and measurement equipment and test procedures, using the test conditions close to real life.

Let us consider the experimental results in the destruction of cantilevered fixed beams of alloy AMg6 according to method [18], which contains requirements for testing the vibration loading, and the longevity on the deterministic resonant modes (Fig. 1, № 1, 9 and № 2, 10), on the narrowband (№ 3 and № 4) and on the broadband random mode with a continuous spectrum (№ 5 ... 8). № 9 and № 10 in figures show for the first time in practice of research presents the results of fatigue tests on the harmonic and polyharmonic modes. These modes are formed by the device that supports the given value of deformation during the test [19]. The results of these modes differ significantly from traditional modes results in № 1 and № 2 constant value of the vibration velocity, obtained by statistical processing of measurements of deformation.

The deformation was measured with a non-contact capacitive deformation sensor [20], which, unlike the resistive-strain sensor is not deformed along with the object of testing and does not change its metrological characteristics in the long process of loading. Test method [18], unlike most others, does not contain any schematization of random processes.

On the basis of this material representing all kinds of operational loading, let us analyze the reliability of the results of equivalent tests of vibration loading and durability.

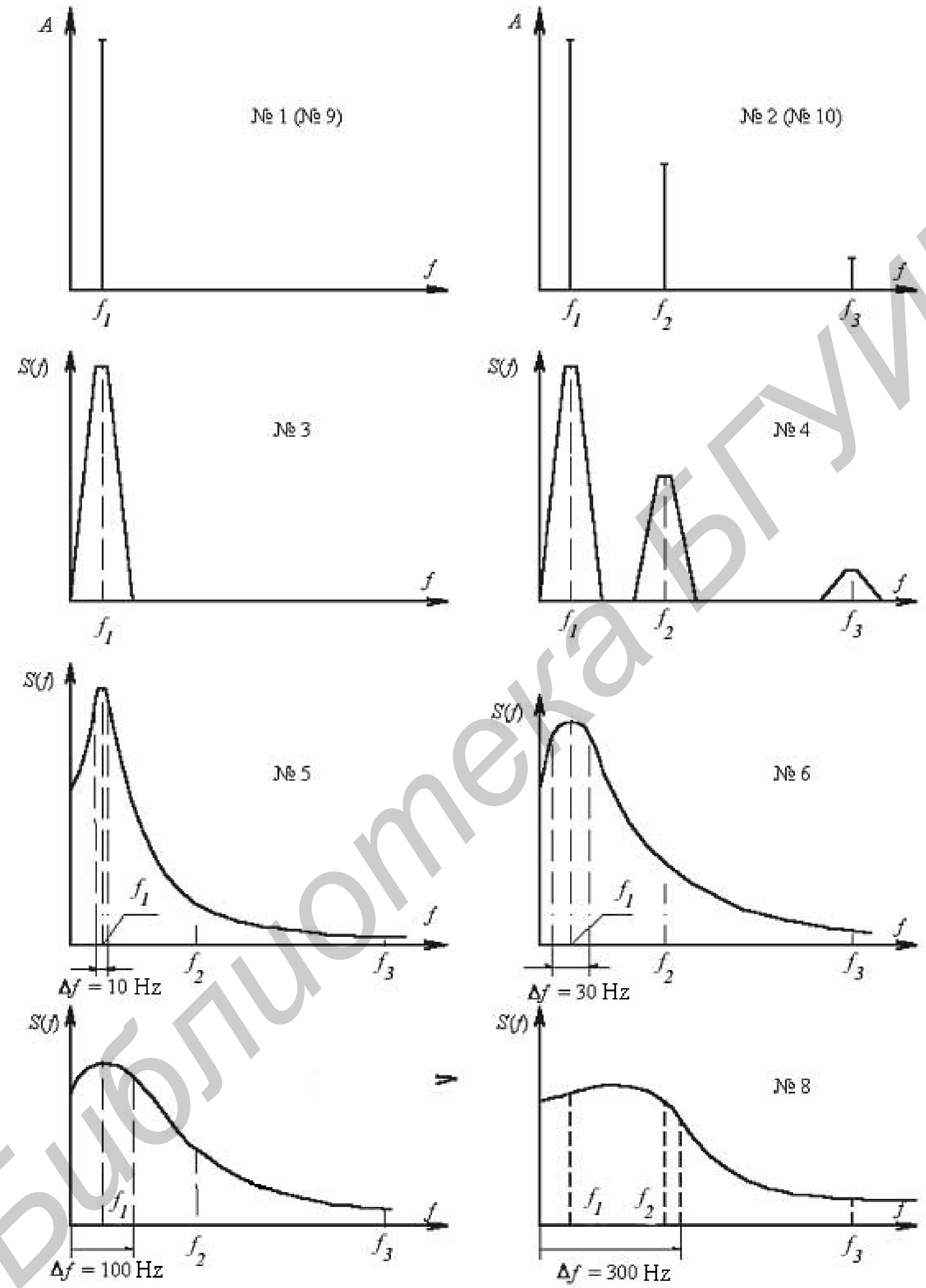

Fig. 1. The amplitude-frequency spectra of the test modes: A – the amplitude of the spectrum of vibration; f_1, f_2, f_3 – the own frequencies of the test samples; S(f) – power spectral density of vibration exposure; Δf – width of the spectrum of the shaping filter.

2. Test on vibration loading

Specifically for the vibration loading test analysis for the first time in technical literature the analogues of the fatigue curves are shown - «vibration loading curves» - dependence on the time till destruction t_d of the average vibration speed V_{avg} ina dangerous cross section of the test sample (Fig. 2). The use of vibration speed, instead of the acceleration, like a parameter characterizing the vibration due to the greater information content [21]. Whichever of the random modes № 3...8 (Fig. 1) is considered to be "operational condition", none of the deterministic modes for close values of durability does not give the values of vibration speed, commensurate with the vibration in the random loading (difference to 3 for 10 times, Fig. 2).

Fig. 2. Depending t_d of the samples of V_{avg} in a dangerous cross section of the beam (curves of the "vibration loading").

The vibration speed on the deterministic modes № 1, 2, 9 and 10 is almost the same, and at random and deterministic regimes will be at the only one level at a much greater durability of the material samples tested on random modes (if the curves №3...8 Fig. 2 extrapolate down). But in this case, the deterministic regime will destroy the object of testing much faster, than in the "operational" mode (at 5...20 times).

When operating in a mode tension control in the object we get the opposite result. That is, for close values of the stresses on deterministic and random modes the failures in random mode will be much greater. Here we are again faced with the problem when niether separate power nor vibration speed uniquely characterizes the degree of danger of loading modes.

If the random vibration loading mode is replaced by a deterministic mode, the ratio of the vibration speed decreases with increasing time to destruction t_d (Table 1), because the vibration loading curves for various modes in the right hand side diverge.

Table 1. The ratio of vibration speed V_{avg} with increasing time to distruction of samples t_d for comparing regimes.

Comparable modes numbers	t_d = 15 min	t_d = 30 min	t_d = 60 min
	V^m_{avg}/V^n_{avg}	V^m_{avg}/V^n_{avg}	V^m_{avg}/V^n_{avg}
№ 9 and .№ 7	0,279	0,142	0,116
№ 9 and № 4	0,362	0,216	0,189
№ 4 and № 7	0,772	0,659	0,616

Therefore, the coefficient of equivalence of the two modes of vibration speed is not constant:

$$k^e_{m,n}(V) = t^m_d(V)/\ t^n_d(V) = var \qquad (1)$$

where m and n - compared modes numbers; $t^m_d(V)$ and $t^n_d(V)$ – time before destruction of samples of the material in the appropriate mode for a given value of the vibration speed V, depending on the load.

The significant difference in the vibration speed modes of the random and deterministic spectra is explained by the fact that in random spectrum incomparably more "components" at different frequencies contain than in deterministic. Each frequency component of the random spectrum has a kinetic energy that is transferred to the object, that is why its vibration speed, which characterizes the kinetic energy is so high.

This material shows that the deterministic simulation of random vibration exposure makes it impossible to make a authentic conclusion about the reliability of the objects in the vibration test.

3. Durability test

In the studies [4,5,6 etc], on the equivalent replacement of one regime by another there were received two fatigue curves for the two modes in a narrow range of loading, making it possible to find a specific conversion factor from random to harmonic mode. Analysis of ten fatigue curves (Fig. 3), allows us to consider this issue more objectively. The presented fatigue curves are equidistant and at time to destruction are close to zero, they will seek to a temporary resistance of the material σ_y. With decreasing load differences in durability increase, as illustrated by the data in Table 2, which shows the ratio of time to destruction t_d on the modes № 1 and № 8 at equal values of the tension.

There is a similar trend in all other modes. Therefore, the coefficient of equivalence of the two modes of the tension

$$k^e_{m,n}(\sigma) = t^m_d(\sigma)/\ t^n_d(\sigma) = var \qquad (2)$$

where m and n - compared modes numbers; $t^m_d(\sigma)$ and $t^n_d(\sigma)$ – time before destruction of samples of the material in the appropriate mode for a given value of the tension σ, depending on the load or the tension.

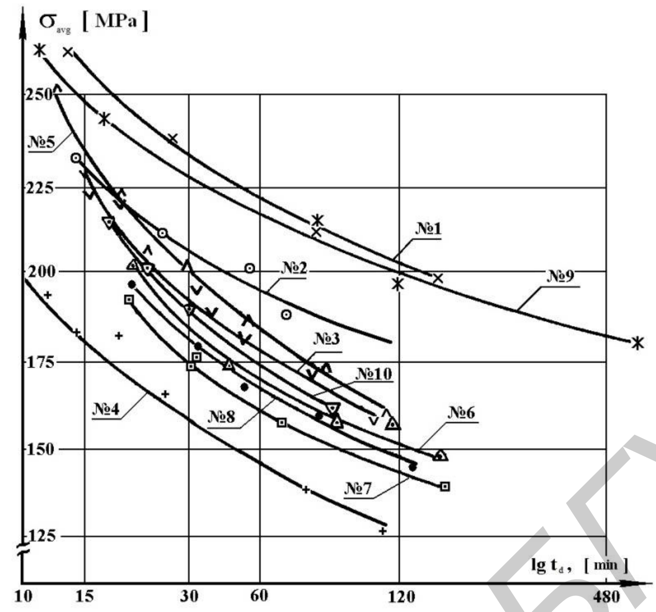

Fig. 3. Fatigue curves of ten test modes.

Table 2. The ratio of time to destruction t_d on the modes № 1 and № 8 at equal values of the tension.

σ_{avg} [MPa]	196	188	181
t^1_d / t^8_d	9,4	12,6	19

The modes with the different types of spectra at equal tensions can produce even greater differences in longevity. Because for $\sigma_{avg} = 158$ MPa ratio is $t^1_d / t^4_d = 90$.

Since the coefficients of equivalence of the mode for the vibration speed $k^e_{m,n}(V)$ (1), and for tension $k^e_{m,n}(\sigma)$ (2) are not constant for different values of the parameters and time to destruction of samples, we can assume that a single equivalent of the transition from one mode to another does not exist. Equivalent transition from mode to mode when they are of equal durability can be carried out only for a specific level of the load. It should be noted that the value of tension, adopted at a measure of resonant stresses, is uniquely characterized the longevity only in a single mode of loading. While the tests were performed only with harmonic mode, a description of the load by the tension is sufficient. In a random process for greater information content it is necessary to use the vibration speed.

Durability and vibration loading (Fig. 3 and Fig. 2) at random and deterministic modes differ in ten times. At that time the physical process of damage accumulation may change.

For different types of random vibration exposure spectra results are also different, although not to this extent. At the time of destruction of samples t_d=30 min vibration speed on the mode № 4 for 33,5% is smaller than the mode № 7 (accordingly 0,575 m/sec and 0,865 m/sec). On the mode № 4 to achieve vibration speed 0,865 m/sec is possible by increasing the level of loading.

In this case in the mode №4 $t_d^{\ 4}$ =14 min, is 2 times less than in the mode № 7. It follows that in the modes with the spectra of various forms for close values of vibration speed, the durability of the samples are significantly different.

Basic requirements for the testing mode consist of the largest accordance to any real life operational condition:

- In the frequency range (the number of the excited own frequencies of the object is to be the same);
- By the character of the exposure (deterministic or random);
- By the shape of the spectrum (the spectrum of the test object should be identical in the area of own frequencies).

Thus, at the modes of satisfying these requirements (№ 3 and № 5, № 6 and № 7, № 7 and № 8) parameters in the investigated range of loading differ by 1.2 ... 1.8 times, that can be considered acceptable when simulating vibration exposure.

The analysis showed that the "equivalent" replacement of a deterministic model of a random loading when tested on vibration loading is unacceptable, and when tested for durability is admissible but is incorrect; the validity of the results when using the polyharmonic modes above. The coefficient of equivalence should be determined from the experimental results.

The high degree of reliability of the results of the experiment confirmation is its close match with the simulation results presented in author report to Congress ICAS 2014.

Unfortunately, the vibration tests are still held by the "brute force" [2]. As was already shown that it is necessary to take into account the "own spectrum bands" – a new property of mechanical systems [23].

4. Conclusion

- The "equivalent" replacement of a deterministic model of a random loading when tested on vibration loading is unacceptable, and when tested for durability is admissible but is incorrect.
- The most significant results of fatigue tests are obtained by the using of the non-contact capacitive deformation sensor.

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