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DAMAGE DETECTION AT VIBRATION PASSIVE ISOLATION DEVICES

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ABSTRACT

This paper deals with some theoretical aspects combined with experimental tests regarding early damage identification in vibroisolation devices. This study was a natural fall-back of an analysis regarding the behaviour of the passive isolation devices against vibration and seismic waves. On the exploitation time, all technical devices and systems acquire a different wearing out levels because of the dynamic charging. Hereby performance characteristics change and the system starts working improperly. Rubber based on elements is especially discussed. Numerical simulations were developed for simple spatial configurations of isolation devices. A Stochastic approach of essential results was briefly presented together with relevant results and discussions.

KEYWORDS: damage detection, vibration, passive isolation, rubber

1. INTRODUCTION

For vibroisolation devices, during the behaviour evaluation and measurements, both in the laboratory, and "*in situ*" tests, it was observed that the damages level growing up with the effective exploitation time, appears especially on the visco-elastic kernel. Taking into account the final influence of visco-elastic elements on the global isolation degree of the insulated ensemble, it results the basic idea of damage level evaluation based on the transfer characteristics of the dynamic system. The main advantages of this method are: non-destructive method, increased safety, reduced costs. Another advantage of this method is the possibility of evaluation as a continuous process, and the detection at the beginning of important failures before they reach a critical level and disturb the dynamics and the integrity of the entire isolation system.

This study continues a series of past theoretical and practical analysis regarding passive vibroisolation performances, methods, maintenance, monitoring, and damage detection [4-11]. The additional gain of this research is the estimation of primary sources for vibroisolation elements degrading and, based on this, a serviceable way for monitoring and damaged areas detecting in real time.

Like many other technical systems, the vibroisolation elements have a theoretical lifetime which, in practice, becomes more or less diminished. Intensive random dynamic loads can produce dangerous damages and a fast degrading. Aging of the base core material induces slow, but irremediable degrading of the element.

Aging of the rubber from the visco-elastic element core can have many causes. One of the most important is the internal energy dissipation during the working cycle. Internal heat leads to major changes of the material characteristics. A major decreasing of the performance level can occur. A part of these changes had only local and temporary effects and the other acquire permanent changes.

Note that this analysis procedure is framed into the *Structural Health Monitoring Concept*, which enables *Conditions - Based Maintenance* at structures through diagnosis of the status of current health during exploitation [4]. Parts of the theoretical approaches, that enable the method implementation, are based on *Reverse Engineering* concept and *Inverse Problems* theory [3].

2. BASICS AND HYPOTHESES

First of all, it had to show the linkage between the material characteristics changes and the natural frequency shifting. Supposing the inverse problems theory with applications in vibration analysis [3], and taking into consideration the initial hypothesis of beam structural composition of the vibratory isolated systems, it could be demonstrated the direct involvement of the rigidity variance in natural frequencies spectral degeneration.

Supposing the stiffness and the mass matrices denoted by K and M, the displacement by x, the natural frequency by Ω, and the changes of these parameters such as

$$\begin{aligned} &K+\Delta K; \quad M+\Delta M; \\ &\Omega+\Delta\Omega; \quad x+\Delta x; \end{aligned} , \qquad (1)$$

and the general discrete equation as

$$(K-\Omega M)x = 0, \qquad (2)$$

the replacement of changed main parameters (1) in (2) leads to an extended equation. Using the basic hypothesis that all the terms of second order and more will be ignored, supposing the null changes of masses, multiplying with the transposed solution x and making the computations, it results

$$\Delta\Omega = x^T \, \Delta K \, x \,. \qquad (3)$$

The Eqn. (3) shows that the shifting of natural frequencies can be found when the rigidity changes are known. Also, Eqn. (3) reveals the possibility of identification of which elements lead to the specified demotion in stiffness. Using this method it can be obtained also the linkage between damping changes and natural frequency shifting.

One of the sources for degrading of the rubber core of vibroisolation elements is damping energy [11]. Dissipated energy for each working time leads to internal heat emergence which is transmitted from inside to outside the active part of the vibroisolation element. This process includes the entire volume of the rubber element. The environment temperature on the working place is also an important factor for this process. The main characteristics of the material which acquires changes that can leaven the global performances are the rigidity and the damping. The intensive and various charges that actuate the isolators produce two basic types of effects, namely: temporary effects - which modify the characteristics only during the working cycle and the element recovers the initial state after that, and the permanent effects - which appear because of the cumulative process of degrading and the element partially recover the initial state after the external excitation stops.

3. RESULTS AND DISCUSSIONS

Experimental tests and numerical simulations [4-11], developed for a rubber element with 150x150x150mm loaded with 500N, showed that internal temperature, for a stabilized regime and common conditions, can get around 95°C into the core and 70°C on the external surfaces. The time interval for thermal and functional stabilization was 700...800s. In the case of dangerous evolutions, the temperature acquires over the 200°C in only 20...30s. Also, the amplitude of the motion was increasing very much (of 10...11 times). In this case, the element can be destroyed. It was used an exponential law for rigidity, respective damping, in respect with internal temperature

$$k = k_o\left[\alpha_k + \beta_k \, \exp\left(\delta_k\left(t_{ref} - t_i\right)\right)\right], \qquad (4)$$

$$c = c_o\left[\alpha_c + \beta_c \, \exp\left(\delta_c\left(t_{ref} - t_i\right)\right)\right], \qquad (5)$$

where α, β, δ denote thermal changes parameters depending on shape and material characteristics, k_o and c_o mean the rigidity and damping at reference temperature, t_{ref} is the reference temperature (20°C) and t_i is the instantaneous temperature on the evaluated point inside the vibroisolation element.

Hereby, in Figure 1 is depicted the evolution of transmisibility with respect to internal temperature and external excitation. It can be observed a relative stabilization of natural frequency for temperature values around 80°C, but a permanent increasing of magnitude for resonance area. From this diagram it results that post-resonance working regime can ensure a stable dynamic evolution because of the resonance frequency decreasing with increasing the temperature. For the same reason, a dangerous evolution can happen for the pre-resonant working state.

In Figure 2 are depicted three diagrams which show what happened during a long intensive exploitation. Hereby, cumulative thermal effects inside the rubber element lead to permanent changes of characteristics. This was simulated through rigidity increasing, with constant damping (see Fig.2.a) and both rigidity and damping growing up (see Fig.2.b). Comparatively, in Figure 1 is depicted the initial case, without any permanent changes.

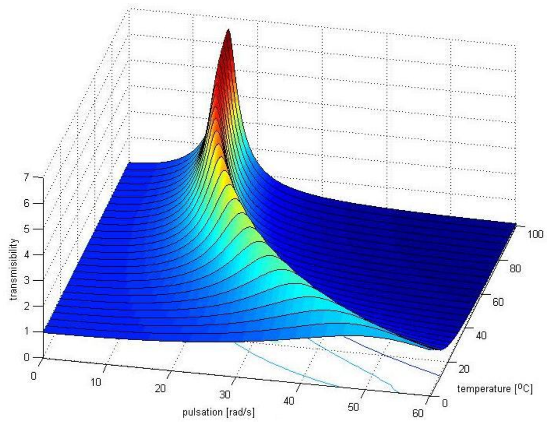
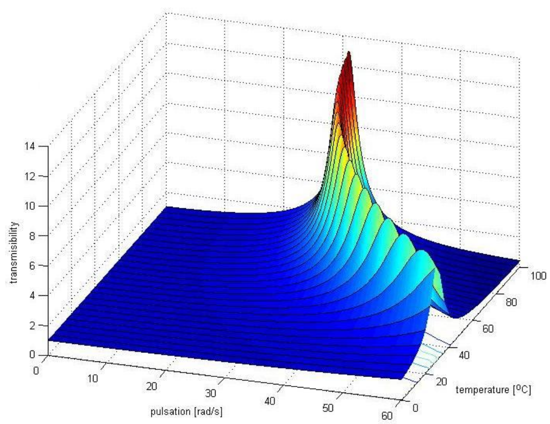
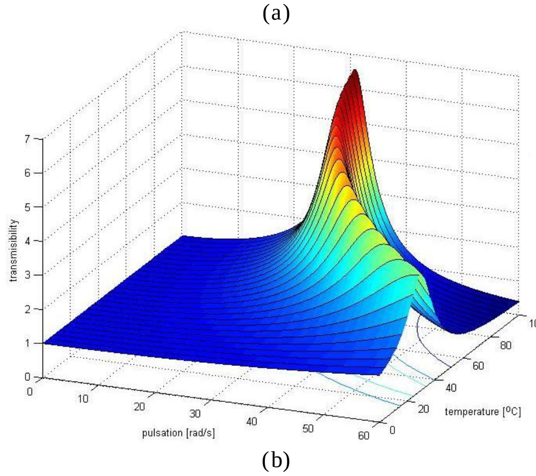


Fig. 1. Transmisibility evolution with pulsation and temperature changing

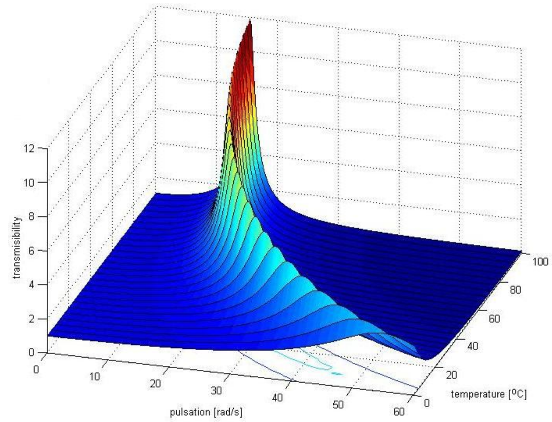


(a)

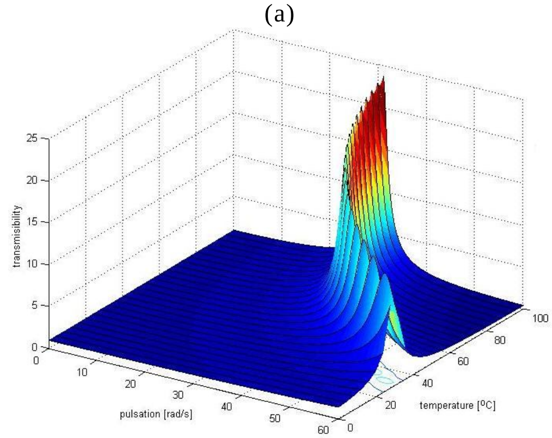


(b)

Fig. 2. Transmisibility evolution vs rigidity and damping permanent changes - first case; see text for details



(a)



(b)

Fig. 3. Transmisibility evolution vs rigidity and damping permanent changes - second case; see text for details

The comparative analysis of the three diagrams (see fig.1 and fig.2) reveals a consistent diminishing of post-resonant safety area. The lower limit of excitation pulsation for post-resonant non-dangerous working regime had to be increased. Quantitatively, the transmissibility has the maximum values as follows: (fig.1) 7; (fig.2.a) 13; (fig. 2.b) 6.5.

The diagrams in Figure 3 show the transmisibility evolution for increasing rigidity with aging, but decreasing damping. Hereby, in Fig.3.a the rigidity has the initial reference value and the damping decrease at half of the initial reference value. In Fig.3.b the rigidity grows up for four times and the damping remains at half of the reference value. Comparative with the diagrams in Fig.2 (when rigidity grows up for four times and damping for two times), the transmisibility reaches the maximum values as follows: (fig.3.a) 12; (fig.3.b) 24.

The case of rigidity decreasing was not presented in this paper. In this case, the low reference value of rigidity provides an initial shifting to the left of the natural frequency.

During the exploitation, due to the thermal additional shifting for the natural frequency (also to the left, at low values) it ensures post-resonant working conditions whatever the external excitation frequency.

4. CONCLUDING REMARKS

Even if the evolution under dynamic loads was evaluated for rubber vibroisolation elements, in case of aging, it is very difficult to estimate the reference value in each moment of time. Simulations on virtual model had shown the appropriate behaviour with the instrumental tests for each rubber element. But for aging of the rubber core of the isolator it was developed only virtual analysis. For this it was adopted also exponential laws, like the Eqn. (4) and (5). The evolution laws for aging have to take into account the hardening and/or softening both for stiffness, and for damping. The hardening law of rigidity is dangerous for the rubber element and for the entire insulated structure.

The future research will finalize the instrumental evaluation of rubber core degrading during the exploitation time and try to estimate a set of mathematical laws which can simulate the aging process.

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