New Structural Configurations for Vibroisolation Devices with High Isolation Performances

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Abstract: - This paper is a summary of the large study regarding the isolation performances improvement of the vibration isolation devices. The main area of this study was framed by the passive isolation, using different structural configurations, based on the compressing and torsion rubber elements. First, it is present the few theoretical aspects regarding the dynamic analysis of the passive elastic anti-vibrational devices and their isolation degree evaluation. It have to be mentioned that in this paper there are presented only the final structural configurations of passive isolation devices, obtained by a selection procedure based on the numerical simulation and instrumental tests of dynamic behaviour for each type. Taking into account the structure of the basic compressing and torsion elastic elements, their working principle, and their functional restraints, there was tested a lot of possible configurations, both from the structural, and from the functional points of view. Through the comparative analysis of the acquired results, it was fixed two final and operational structural configuration. All the theoretical suppositions, completed by the computer simulation on the numerical models, was entirety validated through the experimental tests on realistic models. Concluding the ensemble of numerical and instrumental tests, it could be mentioned that the major advantages of these special structural and functional configuration, with a view to the increasing of the isolation degree and to the passive anti-vibrational elastic devices performances incrementation, point at the high isolation performance, relative to a simple and robust structure. Using of these innovative anti-vibrational devices leads to high values of the isolation degree for a large area of technical and industrial applications, and also for vibration sensitive embedded equipments. As it could be see on the paper, the basic structural configuration could be easy modified, on call, as a function of a practical application service requirements, by changing a spatial distribution of the elastics components.

Key-Words: - isolation efficacy, passive elastic devices, rubber elements

1 Introduction

The necessity of this study is a natural result of a fact, that on exploitation time of a different technical systems, equipments, fixtures or structures, appears a lot of external and internal intrusions, which leading to the considerables over-loads, both qualitatives, and quantitatives, on its own working states. For diminishing of the effects of these over-loads it is necessary to use the elements or systems intended for reducing the intrusions transmissibility degree, from the source, to the receiver. In the frame of intrusions classes, one special category is designated by the vibration or the seismical type waves (e.g. challenge by tectonic motions, by controled or contingent explosions, a.s.o.).

The protection against vibration acquire a high dimension due to the next factors

- ⇨ the antivibration protection necessity for the vital equipments and for the inside buildings human being, because of the development and implementation of a new types of embedded equipments;
- ⇨ the intensive development of new industrial zones and the stringent necessity of the environment protection against the vibratory pollution generated by these;
- ⇨ the necessity of protection for a parts of systems or equipments against the vibration generated by the working state of the system/equipment itself.

Taking into account the previous ideas, this study treat only the case of anti-vibrational and anti-seismical protection and isolation of the embedded equipments. And, the main objective of this work consist of theoretical fundamentation and experimental validation of intensive and varied dynamic state behaviour, for special elastic systems - SES, with direct influences about growing of the isolation degree against vibration and seismical waves.

The concept of random dynamic actions protection was based on limits of demotions, of disables, as well as the avoidances of the structural and non-structural elements, equipments and fixtures collapses, for the next aims

- the human life losses or hurtings avoidance;
- the avoidance of disconnections of the activities and essential services for social an economical life continuity maintenances, both during the earthquake, and right away after;
- the destructions and demotions avoidance for a high level value cultural and artistic assets;
- the avoidance of dangerous substances (poisonous, explosive, a.s.o.);
- the corporeal damages avoidance.

The anti-vibrational isolation of the machines, fixtures and technological equipments, have the main purpose to minimum reducing of the vibration effects on environment.

Also, these special elastic systems could be used for vibration sensitive embedded equipments insulation.

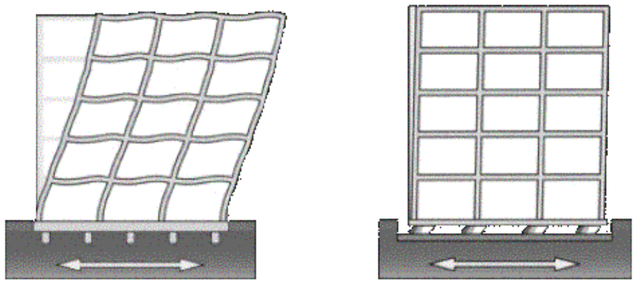
The antivibrational isolation analysis have the next major aims

- *to reveal* the structural measures, by means of, it could be reached the initial purpose,
- *to establish* the parameters set, by means of, it coud be survey the isolation efficiency,
- *to avoidance* the wrong technical solutions, and
- *to coach* the designer through the most economical methods for solving the initial problem.

For evaluation of the vibration effects on human being and on the environment, it used the usual kinematical parameters - displacement, velocity and acceleration - as a time or frequency relationship functions. For harmonic type movements it is enough to known one of the magnitudes - (x_o) for displacement, (ω x_o) for velocity or (ω^2 x_o) for acceleration - and the frequency (*f*). For another oscillating movements, either regular or irregular, it is disabled the previous presented simple situation. Because of this, for evaluation of the vibration effects on human being and on the environment, in practice, it used a lot of additional parameters, which, based on the effective analyzed case, could be supposed as a essential appreciation criterion about the vibration effects.

At this point of presentation, it is necessary to mentioned that the entire theory of the study are based on the classical base isolation principle.

In Figure 1 it is schematic presented the base isolation principle of a structure, against the strong vibration or seismic waves actions.



(a) (b)

Figure 1. The base isolation principle.
(a) classical rigid structure; (b) base isolation structure

2 Theoretical Formulations

The very simple model for a system with static linear behaviour is usual described by a single degree of freedom oscillator - see Figure 2.

The dynamic action (disuturbig action) on a mass m, it is attained through oscillator base displacement at one time with the terrain, during the external dynamic action (see Figure 2).

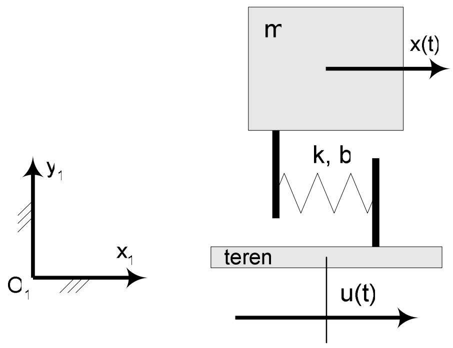


Figure 2. The single degree of freedom model
for the base isolation principle analysis

The analysis of the mass (named *m*) motion it could be realized either on relative coordinate *x(t)*, or on absolute coordinate $x_1(t)$, taking into account the relation between them

$$x_1(t) = x(t) + u(t). \quad (1)$$

The differential equation of motion is

$$m\ddot{x} + b\dot{x} + kx = -m\ddot{u}, \quad (2)$$

which means that the relative displacement $x = x(t)$ of a structure with mass *m*, simulated as in Figure 2, could be obtained through base fixing and actuate directly on a structure through an horizontal inertial force, with $-m\ddot{u}$ modulus.

Adopting as a main coordinate the absolute displacement $x_1 = x_1(t)$, then the motion equation of a mass relative to the inertial reference system $(O_1x_1y_1)$ is

$$m\ddot{x}_1 + b\dot{x}_1 + kx_1 = ku + b\dot{u}, \tag{3}$$

which indicate the fact that if the base translation motion become null, i.e. $u = 0$, $\dot{u} = 0$, then the absolute displacement also become null.

As such is defined in many bybliographic references, the isolation degree is defined as

$$I = 1 - T \tag{4}$$

or as a percentage

$$I = (1 - T)\cdot 100 \ \ [\%]. \tag{5}$$

It is necessary that the stable working state have been situated on superior area of the frequency domain, for high values of the isolation degree.

Analysing the diagram in Figure 3, where are presented the variation of the transmissibility function, for a SDOF system with low damping characteristic, it have been observed four major areas, from the isolation viewpoint. Thus, these areas are

- ⇨ the *forbidden area*
- ⇨ the *dangerous area*
- ⇨ the *allowed working area* - providing acceptable isolation performances level; used for common applications;
- ⇨ the *optimum working area* - providing high isolation performances level; used for special applications.

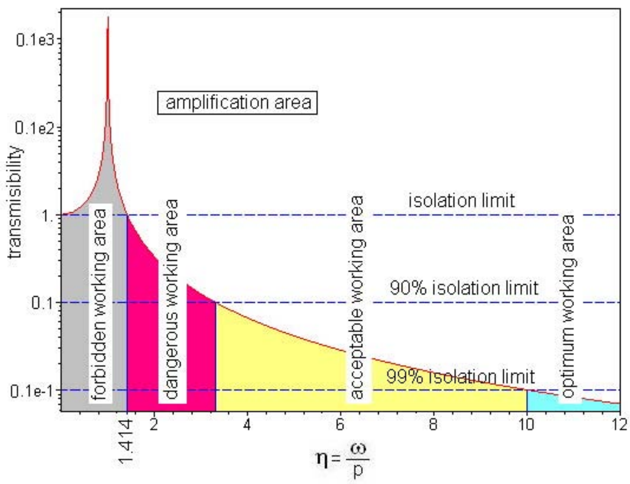


Figure 3. The operating areas classification

3 Concept Implementations

The proposed devices and systems for anti-vibrational protection of superstructures or embedded technical systems have modulated configuration, which included both the rubber elastic elements - with the main purpose that take over the deformation enery of the entire insulation system, and the rigid metallic elements - for take over and re-allocates the external loads, and for assures a certain rigidity and stability degrees of the entire ensemble framed by *superstructure - insulation and protection device - base structure*. The modulated configuration have the main advantage, namely: the basic structure of these insulation / isolation system could be conceived and modulated with minimum of manual labour and materials input, on practical service requirements of the real isolation configuration.

The breaking ground element of these special configuration elastic systems, that is common for all variants - proposed, presented and analysed on this study - is the way which the high levels of deformations of the entire insulation system, leads to the relative low levels of deformations on the elastic elements. The structural configuration of these innovative systems have the kinematics of the lever mechanisms, which could assure a high level of amplification of the linear or angular deformations.

The two main types of special elastic isolation systems are presented in the Figures 4 to 10, and these are *Special Elastic System with Stairs Configuration*, respectively, *Special Elastic System with Polygonal Configuration*.

The first main category (see Figure 4 for schematic diagram of basic working principle), noted as SES-SC that means *Special Elastic System with Stairs Configuration*, consist of a metallic structure framed by rigid rails, elastic insulated and hanged on rubber compressing elements. The basic working principle is that of the first order lever. Through the suiting mounting of the elastic elements on the base device configuration, and also, on the final isolation system, it could be assure a very high level of static and dynamic deformations, of the entire insulation system.

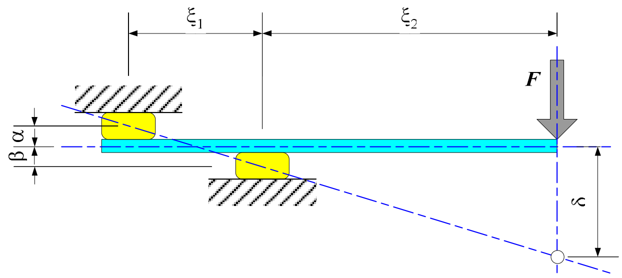


Figure 4. The special elastic systems with stair configuration - schematic diagram of basic montage

While in the Figure 4 have been presented a single level montage, in the Figure 5 have been presented a double level system. This was obtained by using of two identical basic systems, mounted on succession.

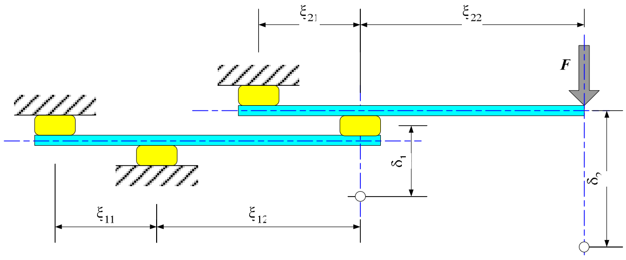


Figure 5. The special elastic systems with stairs configuration - schematic diagram of double level montage

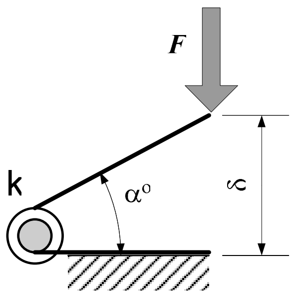
(a)

(b)

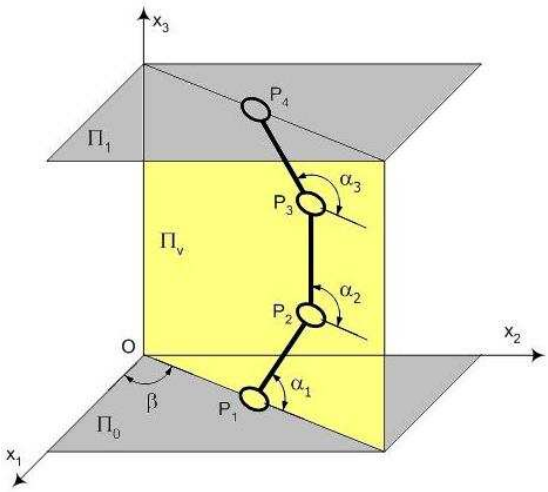
Figure 6. The special elastic systems with stairs configuration - singular (a) and complex (b) montages with double working levels

In the Figure 6 have been presented two experimental SES-SC, that is: (a) a single SES-SC with double configuration, with compact structure, for low and middle level loads; (b) a complex elastic isolation system composed by four SES-SC with double stair structure - such as the same presented in the Figure 6.a. The montage configurations was a result of a detailed study regarding the geometrical dimensions reducing, taking into account the fact that these ensembles will be used as a package configuration, with a large number of components, thus that will be assure the total required load capacity, to assume the static and dynamic external charges.

The second main category (see Figure 7 for schematic diagram of basic working principle), noted SES-PC, that is *Special Elastic System with Polygonal Configuration*, consist from an odd number of torsional rubber elements or working equivalent cassettes, on polygonal regular or irregular montage, and assembled between them through the rigid metallic elements (with the stability assurance, and linkages between superstructure - isolator - base structure provides aims).



(a)



(b)

Figure 7. The special elastic systems with polygonal configuration - schematic diagram of working principle; (a) a single elastic element; (b) a complete ensemble with four elastic elements

The schematic diagrams depicted in the Figure 7 presents a basic theoretical model for torsional rubber elements usage to assume a linear global deformations. For serviceable systems, it have to use at least two identical ensembles like the same presented in the Figure 7.b, mounted "*in the mirror*" in the same working plane. Because the stability of this system was very diminishing, in practice, it have to be used two or more identical systems, mounted on multiple layers, thus that the unit could assure the suiting distribution of external charges and the dynamic stability.

A schematic diagram of this kind of unit is depicted in Figure 8. In this figure is was presented a sigle layer mountage. For serviceable systems it have to be used at least two different layers of these units.

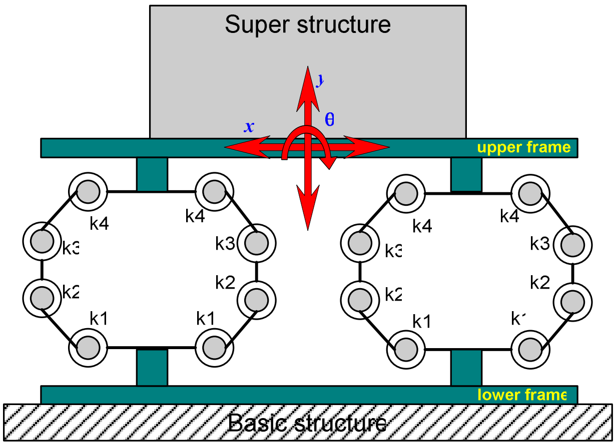
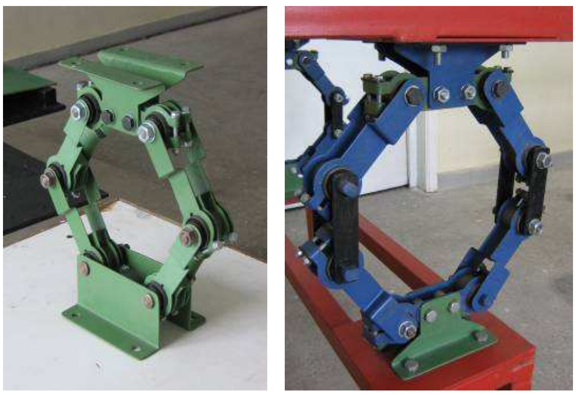


Figure 8. The special elastic systems with polygonal configuration - schematic diagram of a complex montage of SES-PC

In the Figure 9 have been presented two experimental types of the SES-PC, namely: (a)-SES-PC with six torsional elastic elements; (b)-SES-PC with eight torsional elastic elements, both with single layer configuration. All these devices have been designed for low values of external loads, within 100 ... 140 daN.



(a) (b)

Figure 9. The special elastic systems with polygonal configuration - single layer montages

A serviceable system, based on the SES-PC with eight elastic elements, have been presented in Figure 10. The four identical elastic units are identical with that presented in the Figure 9.b.

Figure 10. The special elastic systems with polygonal configuration - singular montages

4 Experimental Results

For instances of the proposed devices, the numerical analysis was maded for a (P+2) building, with cross section 15x20=300 m^2. The total weight of this construction was Q = 1,4 10^7 N. The analysis of the natural frequencies was maded for the next values of the stiffness (100, 140, 180, 220, 260, 300) 10^6 N/m. For a dependences between the isolators stiffness with expression $k_1 = k_2 = k_3 = k$, and for the values of the independent variable named $i = L/a$, within 2 and 6, the evolution of the equivalent stiffness of the isolatoris depicted in the Figure 11. If the expression of dependences between the included elements rigidities have the dependences of $k_1 = k_2/2 = k_3/2 = k$, with the k variable in the same domain as well as the previous analysis, the evolutiom of the equivalent stiffness is depicted in the Figure 12.

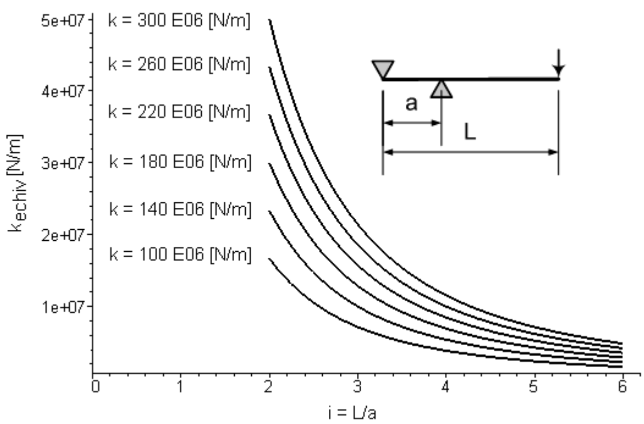


Figure 11. The variance of the equivalent rigidity with the ratio i=L/a, for $k_1 = k_2 = k_3 = k$

It have to mentioned that for both simulations it was supposed that beside the elastic elements on the lever supports, an additional elastic element on the free lever extremity being. This supposition was sustained by the multiple stairs utilization of the basic SES-SC.

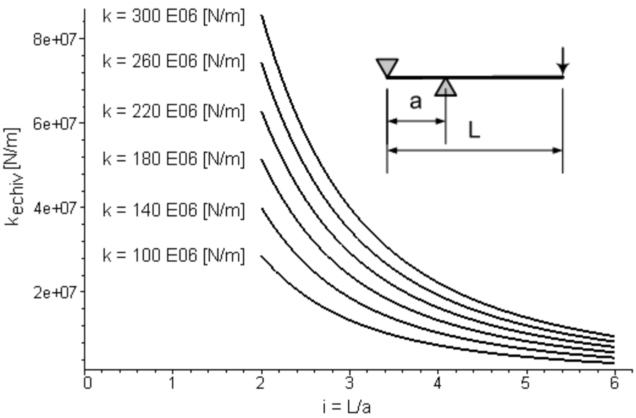


Figure 12. The variance of the equivalent rigidity with the ratio *i=L/a*, for $k_1 = k_2/2 = k_3/2 = k$

Taking into account the second type of SES, in Figure 13 is depicted the relationship between the structural parameters of the elastic rubber element - the ratio *n=D/d* between the inner and the outer diameters of the rubber elements, and the length of the lever *a* - on the equivalent rigidity, respectively on the natural frequency of the isolation device.

It have to be mentioned that for this analysis, presented in this paper, it was considered an isolation device with two active sides, on the same layer, and fully six elastic elements (with 40 mm length, and 50 mm innner diameter). This unit is the same like that presented in the Figure 9.a.

As a main characteristic of these systems, the isolation degree was analysed both on numerical simulations, and on instrumental tests.

For the entire set of S*pecial* E*lastic* S*ystems*, it was remarked (on experimental static and dynamic tests) that the SES depicted in the Figure 10 assure the most functional requirements and, because of this, the most dynamic performances was performed on this unit.

Regarding the transfer characteristics of the proposed S*pecial* E*lastic* S*ystems* for vibration isolation, it was performed a set of dynamic tests with quasi-harmonical excitation signal. The external excitation system consisted of the hydrostatic drive system, with the continuous adjustments of flowing rate. Thus that, the vibration generator could provide a frequency continuous range, between the 0.67 and 4.67 Hz. Taking into account both the excitation system, and the measurement instrumentation operating characteristics, it was adopted a frequency step value of 0.13 Hz - this value correspond to the 90^o rotational angle of the command element of the hydraulic unit flowing control.

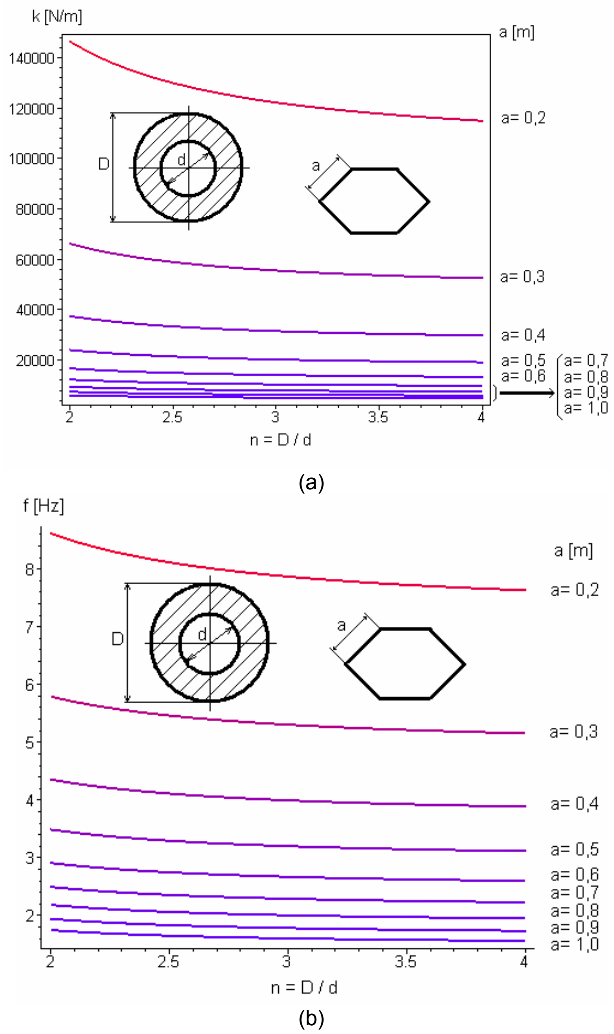


Figure 13. The relationship between the equivalent rigidity (a), respectively the natural frequency (b), and the ratio between the elastic element diameters, with the lever length parameter

The serviceable transfer characteristics evaluation, for the S*pecial* E*lastic* S*ystems*, was performed using the excitation vibratory source capability to supply a complete frequency domain between the two limits. Thus, taking into account the previous frequency step, the SES-CP unit was subjected to the discrete variable frequency excitation.

The movements of the two platforms - one for input, named as lower frame, and one for output, named as upper frame, both depicted on the schematic diagram in the Figure 8 - was continuous monitorized, for the entire time length. The acquired signals was post-processed after the event, using the frequency analysis principle with two synchronized measurement channels.

For the proposed antivibrational devices/ systems it was evaluated the transfer functions, both on the magnitude - phase coordinates, and on the real - imaginary parts coordinates. Also, it was performed the evaluation of the instantaneous absolute transmisibility - as a ratio between the magnitude gain on a disturbance transition through the system, and its value at the input.

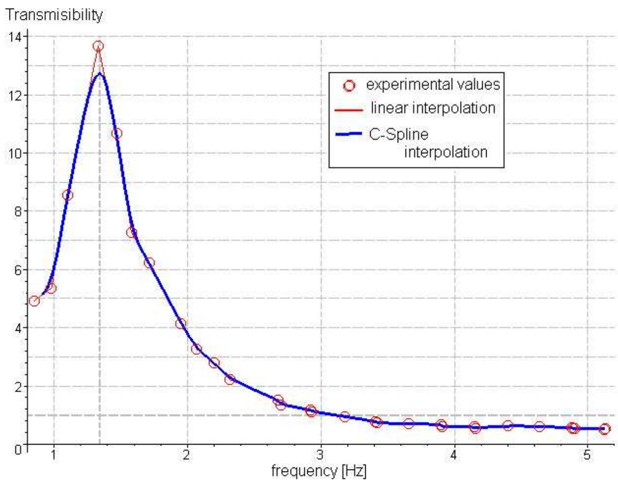


Figure 14. The experimental transmisibility function

Taking into account the fact that for the behaviour evaluation on dynamic permanently state, the elastic isolation devices was excited at different values of frequencies, and it was acquired and processed both the input, and the output signals, it could be evaluate the spectral transmisibility function. According this, for each frequency value of excitation, it is computed the ratio between the maximum values of the input and the output signals. In the Figure 14 it was depicted this series of acquired values. Because the fact that experimental values acquired and computed for the transmisibility framed a discrete function (see the points on the Figure 14) it was used a C-Spline interpolation procedure to obtaine a continuous characteristic of the transmisibility function (see the blacked curve on the Figure 14).

Taking into account the theoretical characteristic of transmisibility, evaluated for the SDOF (see Figure 2) for the critical damping ratio (0.1), with the experimental measured value, in the Figure 15 was comparative presented both diagrams - the theoretical vs. the experimental curves.

The dynamic behavioural tests, with transmisibility function computing, have the main purpose to find out if the proposed SES-CP unit framed into the right area of the serviceable limits for isolation degree presented in the Figure 16.

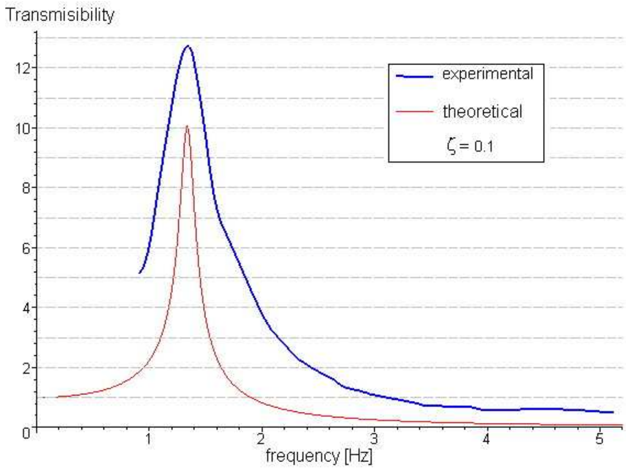


Figure 15. Theoretical vs. experimental transmisibility functions

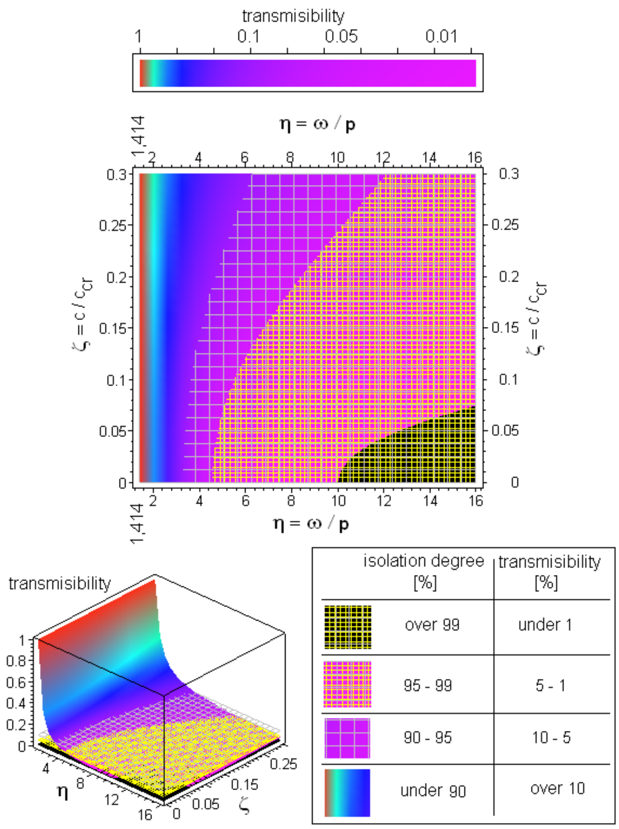


Figure 16. The relationship between transmisibility (respectively, isolation degree), pulsation ratio and dampings - serviceable limits for technical systems

The explanation for transmisibility utilization instead of isolation degree result from the practical way that was maded the instrumental tests, that suppose the resonance transitions, because the excitation pulsation growing up from 0 to maximum value, and contained the resonance value. The isolation degree is defined for greater values of pulsation ratio than 1.414, while the transmissibility is defined for the entire range of pulsation.

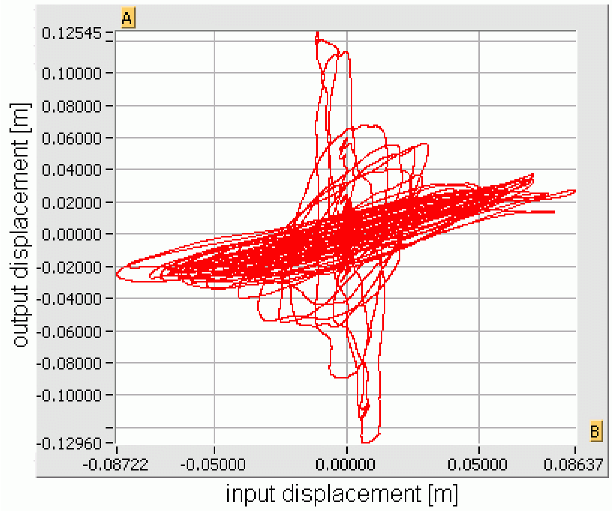


Figure 17. The output displacement vs. input displacement for complex SES-CP.
10 Hz Low Pass Filter processing of aquired signals

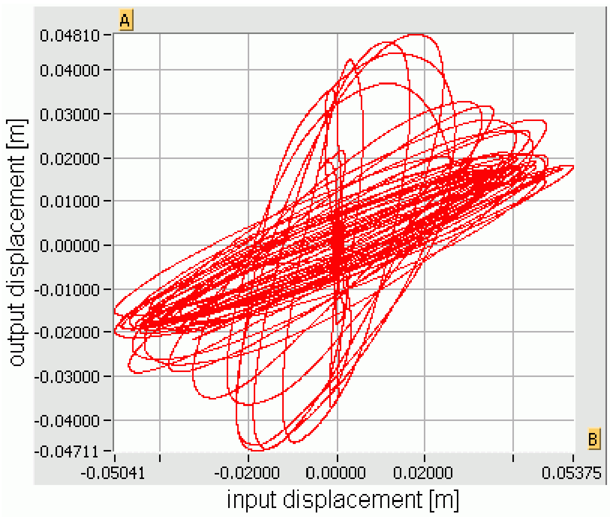


Figure 18. The output displacement vs. input displacement for complex SES-CP.
2...5 Hz Band Pass Filter processing of aquired signals

The diagram depicted in Figure 17 show the output displacement vs. input displacement for the proposed SES-CP unit. Because the original unprocessing signals was affected with undesirable noises, these was filtered before analysis. In the Figure 17 the signals was filtered with a Low Pass Filter with 10 Hz cut off frequency.

In the Figure 18 it is depicted the same situation as in the previous figure, but it was used a Band Pass Filter with 2...5 Hz cut off limits.

From the analysis of the last two diagrams results that this SES-CP unit provide an acceptable dynamic stability. This remark is also sustained by the full dynamic range of the instrumental tests - from the begining to the end the system working exclusive on transitory state and with resonance transition. The resonance passing through phenomenon is denoted by the vertical evolution of the displacements relationship curve.

The differences between these last two diagrams also denote that the resonances appers with priority at the low frequencies, under the value of 2 Hz (these frequencies was rejected by the Band Pass Filter, in the second case, comparative with the first case).

Also, from this comparison result that the dynamic working state become more stable after the resonances area (the curve evolution in the second diagram is more slick than the curve on the first diagram, especially in the vertical sector).

5 Concluding Remarks

The major conclusion of this study is that the proposed elastic systems with special configurations, have a decisive contribution to increasing the isolation degree of the base structure - isolator - super structure ensemble, up to the 85 ... 95%, these values being provided by actual laws.

The transmissibility diagrams (see Figures 14 and 15) denotes the next important aspect: the experimental curve of transmissibility bring closer to the theoretical, and the differences between them, regarding the frequency values corresponding to transmissibility decreasing under the unit (f_{exper} = 3 Hz; f_{theor} = 1,39 Hz) being a result of the internal components influences of the SES unit (the vibration upper modes, proper of the SES rigid components, has a considerable influences on the global transfer characteristic). Also, in this point, it have to be mentioned that it was compared the transmissibility absolute curve (depicted in the Figure 15) with the same, but continuously obtained through the special virtual instrumentation used on the acquire and processing activities. Thus, it was observed a similarity between the concordant frequencies of the unitary transmissibility, for the two cases, and this frequency is about 3 Hz.

While ensemble analysing the entire set of dynamic tests results, it was dignified the next partial concluding remarks regarding the capacity and capability of the proposed S*pecial* E*lastic* S*ystems* to accomplish the antivibrational function(s)

- ⇨ utilization of the special structural and functional configurations leads to the low values of the natural frequencies, with the direct implications on isolation performances increasing;
- ⇨ the dynamic analysis of the elastic devices concurs to the clear and evident prominences of the high performances of these S*pecial* E*lastic* S*ystems*, both by the dynamics values, and through the timed and frequency evolutions of these parameters;
- ⇨ corresponding with the depicted diagrams, and according to the valid legal stipulations, it is necessary to increase the isolation degree over the 20 %; thus that, for the proposed special configuration devices, this condition could be performed if the excitation frequency is over the 6 Hz value.

Finally, it have to enumerates some secondary objectives of this study

- ➢ the rubber elastic elements, on a stairs or polygonal mountages, assures the reduction of the natural frequency of the structure - terrain system, up to safety working state of the entire ensemble (on post-resonance regime);
- ➢ the damping of the rubber elements, while have reduced values, it concurs to the motion stabilization;
- ➢ the multi-stairs or polygonal configurations assures enough amplification of the global deformations, comparative with the singular elastic element;
- ➢ the utilization of these special systems are limited only by the technical suppositions (high charges, functional instabilities, a.s.o.), but even these disadvantages was passed off taking into account the mounting multiple configurations;
- ➢ the basic principle used on these special systems offer them an innovative, a breaking ground character.

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References:

[1] Ashwani Jain and D. K. Soni, Foundation Vibration Isolation Methods, *Proceedings of the 3rd WSEAS International Conference on APPLIED and THEORETICAL MECHANICS*, Spain, December 14-16, 2007, p.163-167.

[2] Bendat, J.S., Piersol, A.G., *Random Data: Analysis, Measurement, Procedures*, Wiley-Interscience, John Wiley & Sons, Inc., New York, 1971.

[3] Bratu P., *Mecanica teoretica*, Editura Impuls, Bucuresti, 2006.

[4] Bratu, P., *Vibratiile sistemelor elastice*, Ed. Tehnica, Bucuresti, 2000.

[5] Bratu, P., *Sisteme elastice de rezemare pentru masini si utilaje*, Ed. Tehnica, Bucuresti, 1990.

[6] Bratu P., Structural requirements imposed to vibration systems, *International Journal of Acoustics and Vibration*, Vol. 5, Nr. 2, 2001.

[7] Bratu, P., Dynamic response of nonlinear systems under stationary harmonic excitation, Non-linear acoustics and vibration, *Eleventh International Congress on Sound and Vibration*, pag. 2767-2770, St. Petersburg, Russia, 5 - 8 Iuly 2004.

[8] Debeleac, C., Vibratory Diagnosis of the Earthmoving Machines for the Additional Necessary Power Level Evaluation, *9th WSEAS International Conference on ACOUSTICS & MUSIC: THEORY & APPLICATIONS (AMTA '08),* Bucharest, Romania, June 24-26, 2008, pg. 83-88, ISBN 978-960-6766-74-9, ISSN 1790-5095.

[9] Harris, C.M. and Piersol, A.G., *Shock and Vibration Handbook - 5th Edition*, McGraw Hill, 2002.

[10] Leopa, A., Diagnosis of structural integrity using the non-linear vibration technique, *9th WSEAS International Conference on ACOUSTICS & MUSIC: THEORY & APPLICATIONS (AMTA '08),* Bucharest,

Romania, June 24-26, 2008, pg. 83-88, ISBN 978-960-6766-74-9, ISSN 1790-5095.

[11] Nastac S., On the Increase of the Isolation Efficacy for the Passive Elastic Devices by the Structural Configuration Optimization, *9th WSEAS International Conference on ACOUSTICS & MUSIC: THEORY & APPLICATIONS (AMTA '08),* Bucharest, Romania, June 24-26, 2008, pg. 83-88, ISBN 978-960-6766-74-9, ISSN 1790-5095.

[12] Nastac, S., The Functional Characteristics Influences of the Base Isolation Systems About the Global Dynamic Performances of the Structures, *The Proceedings of the VIII-th Symposium "Acustica si vibratiile structurilor mecanice"*, Academia Romana - filiala Timisoara, 26-27 mai 2005, Timisoara, ISBN 973-625-238-8, 273-7pg.

[13] Nastac, S., Analysis of the Antiseismic Passive Isolation System Based on the Virtual Prototyping, *The Annals of "Dunarea de Jos" University of Galati*, Fascicle XIV Mechanical Engineering, ISSN 1224 – 5615, 2004.

[14] Nastac, S., Considerations About the Technical Requirements for the Viscoelastic Elements from the Passive Antivibrating Devices, *The Annals of the Constanta Maritime University*, MECSOL 2006, Year VII, vol. 9, 2006.

[15] Nastac, S., The Virtual Prototyping Implementation for the Dynamic Analysis of the Isolation Elastic Systems with Complex Configuration, *The Proceedings of the International Symposium TMCR 2006*, Buletinul Institutului Politehnic din Iasi, Tomul LII (LVI), fasc. 5A, 2006.

[16] Nastac S., Dynamic Analysis of Vibration Isolation Systems for Construction Included Equipments, *A Dissertation submitted to the University "Dunarea de Jos" of Galati for the PhD Degree*, Romania, 2006.

[17] Ratier N. and Bruniaux M., A Symbolic-Numeric Method To Analyse Nonlinear Differential Equations in Fourier Domain, *4th Wseas int. conf. on Non-linear Analysis, Non-linear Systems and Chaos* (NOLASC '05), Sofia, Bulgaria, October 27-29, 2005, ISBN: 960-8457-36-x.

[18] Spacapan, I. and Premrov, M., Analysis of foundation-layered soil interaction using propagating wave-mode analysis, *2nd WSEAS Int. Conf. on Simulation, Modeling and Optimization (ICOSMO 2002)*, Skiathos, GREECE, September 25-28, 2002, ISBN: 960-8052-68-8.

[19] Wei Liao and Pu Han Wu Zhong Li, Detection and Localization of Power Quality Disturbances Based on Wavelet Network, *Proceedings of the 6th WSEAS International Conference on Signal Processing, Robotics and Automation*, Corfu Island, Greece, February 16-19, 2007, ISSN: 1790-5117, ISBN: 978-960-6766-01-5.