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EXPERIMENTAL ANALYSIS OF A MECHANICAL SYSTEM COMPOSED BY TWO IDENTICAL PARTS

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Abstract: *- The paper present an experimental analysis of a symmetric structure to validate some theoretically obtained properties of such mechanical systems. A real structure, used in the field of construction for fixing an industrial cooler, is studied. The structure is made of trusses, rigidly connected to each other. The vibrations of this system were determined and compared with the theoretical values. Thus, the experimental model has been validated, which then allows the determination of its eigenfrequencies and its eigenmodes of vibration considering the symmetry properties of the structure.*

Key words: *Vibration, Eigenvalue, Eigenmode, Bar, Symmetry, Truss.*

1. INTRODUCTION

In engineering practice, there are many times encountered situations in which identical components or parts are used within a structure. The use of identical parts may be useful for several reasons: less information will be required to describe the system, to make a project faster and easier, to make components easier and, finally, the time to achieve the mechanical structure and the cost of manufacturing falls.

For such systems, some interesting properties have been established in the literature concerning the vibrations, eigenvalues and eigenmodes. For discrete systems these properties are presented in [7], [20]-[23]. For continuous systems, analyzed with the finite element method, the analysis of some systems with symmetries led to the determination of these properties [1], [2], [6], [8], [9], [24],[25].

In the paper we make a study, on a structure, made of trusses, rigidly linked, these properties. The structure is made up of two identical parts, symmetrical in the mirror, linked together by common elements. In the paper is verified the validity of the finite element model used to study the mentioned properties.

2. FINITE ELEMENT MODEL

The structure on which the present study was made consists of a series of trusses which are rigidly connected (usually by welding, Fig. 1). The mechanical model of this structure is shown in Fig. 2. Based on this model, the meshing is done using the finite element method. The dimensions of the structure are shown in Figs. 3,4. The structure consists of 48 trusses connected by 20 knots. In the paper [27] are presented the theoretical properties that such a structure should have. The calculated eigenvalues are presented in Tab. 1. The structural damping of the system is neglected in the following. The structure is supported on the ground on some rubber mats. In order to model these links in the finite element model, we consider a grip of each leg through a cross-shaped structure with mechanical properties that satisfactorily shapes the structure's connection with the fixed space through rubber mats.

Figure 1

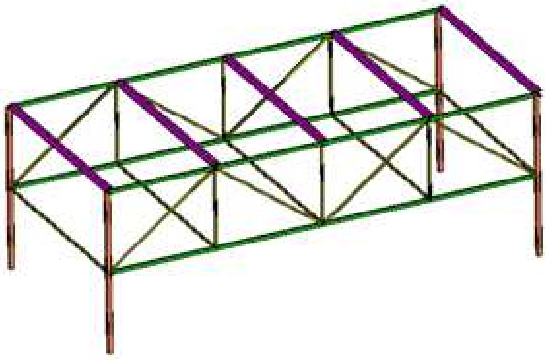

Figure 2

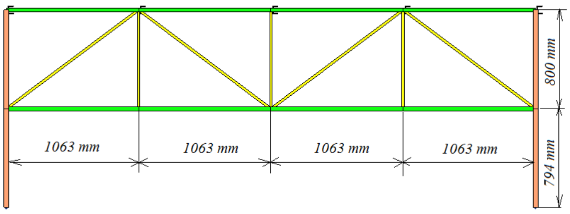

Figure 3

The motion equations of the free vibration are ([3]- [5], [10]-[19]):

$$\begin{bmatrix} M_{11} & 0 & M_{12} \\ 0 & M_{11} & M_{12} \\ M_{12}^T & M_{12}^T & M_{22} \end{bmatrix} \begin{Bmatrix} \ddot{\Delta}_{1s} \\ \ddot{\Delta}_{1d} \\ \ddot{\Delta}_{2} \end{Bmatrix} + \begin{bmatrix} K_{11} & 0 & K_{12} \\ 0 & K_{11} & K_{12} \\ K_{12}^T & K_{12}^T & K_{22} \end{bmatrix} \begin{Bmatrix} \Delta_{1s} \\ \Delta_{1d} \\ \Delta_{2} \end{Bmatrix} = \{0\} \tag{1}$$

where:

M_{11} - the inertial matrix for the structure presented in Fig.5;

M_{12} - the inertial coupling matrix between the two identical parts and the liaisons elements;

M_{22} - the inertial matrix for the liaisons elements;

K_{11} - the rigidity matrix for the structure presented in Fig.5;

K_{12} - the rigidity matrix between the two identical parts and the liaisons elements;

K_{22} - the inertial matrix for the liaisons elements;

Δ_{1s} - the vector of the independent coordinates of the left part of the structure;

Δ_{1d} - the vector of the independent coordinates of the right part of the structure;

Δ_{2} - the vector of the independent coordinates of the liaisons elements.

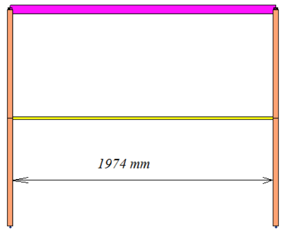

Figure 4

The equations (1) can be written, in a short form, as:

$$[M]\{\ddot{\Delta}\}+[K]\{\Delta\}=\{0\} \tag{2}$$

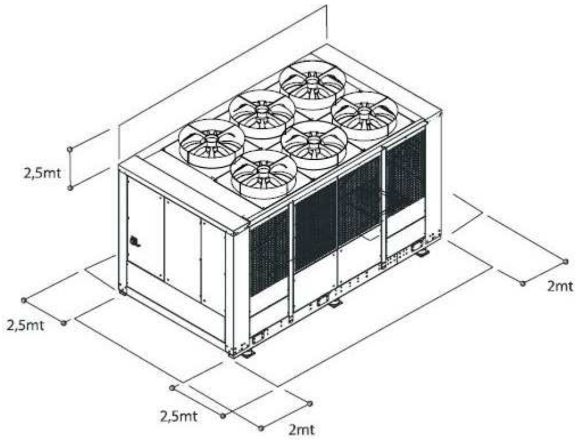

Figure 5

3. EIGENVALUES AND EIGENMODES OF VIBRATION

To solve the eigenvalues problem for the described structure returns to solve the characteristic equation [14],[16],[20]:

$$\begin{vmatrix} K_{11} - p^2 M_{11} & 0 & K_{12} - p^2 M_{12} \\ 0 & K_{11} - p^2 M_{11} & K_{12} - p^2 M_{12} \\ K_{12}^T - p^2 M_{12}^T & K_{12}^T - p^2 M_{12}^T & K_{22} - p^2 M_{22} \end{vmatrix} = 0 \quad (3)$$

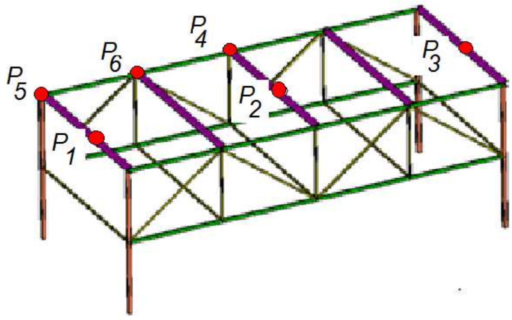

Figure 6. The measurement points

Table 1. Eigenfrequencies

Computed aigenfrequencies		Measured eigenfrequencies	
Mode No.	Frequency (Hz)	Mode No.	Frequency (Hz)
1	3,71	1	3,65
2	6,39	2	6,46
3	7,04	3	7,42
4	11,95	4	11,96
5	12,52	5	13,18
6	15,37	6	undetected
7	15,51	7	undetected
8	18,47	8	17,92
9	19,74	9	19,07
10	21,92	10	21,91
11	22,63	11	22,60
12	24,90	12	24,77
13	26,98	13	26,97
14	35,82	14	36,66

In Table 1 are presented the computed and experimental obtained eigenfrequencies for the structures from Fig.1. Generally, there are a good accordance between the experimental and computed values. In Figs. 7-10 are shown, for example, several modes of vibration. For two mode of vibration we have obtain not results (in the limits of errors).

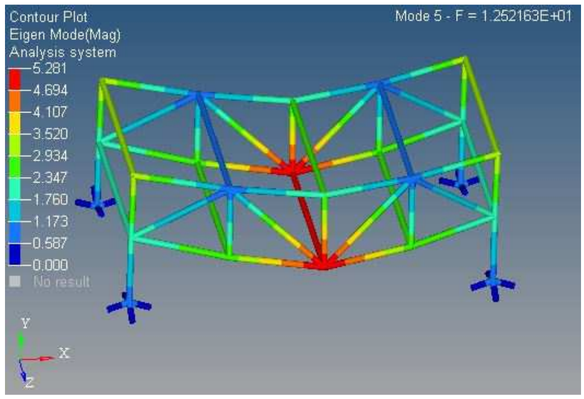

Figure 7. Eigenmode 5 (symmetric)

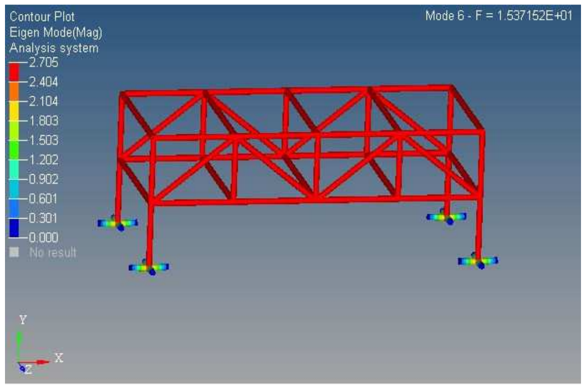

Figure 8. Eigenmode 6 (vibration as a rigid)

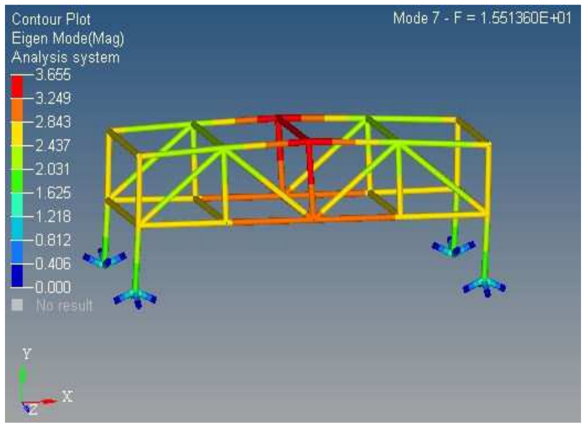

Figure 9. Eigenmode 7 (symmetric)

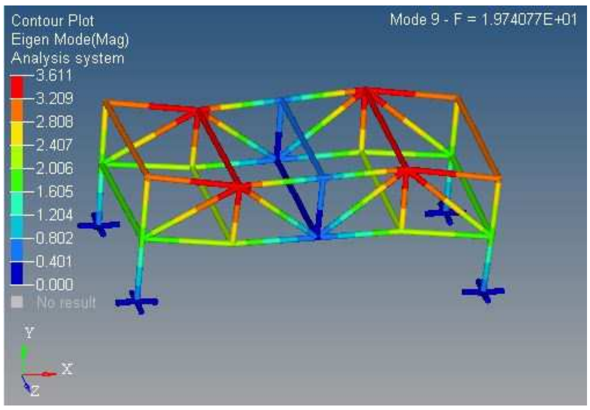

Figure 10. Eigenmode 9 (skewsymmetric)

This problem happens for the eigenmodes 6 and 7. For the eigenmode 6 there is a possible explanation. All the structure has a rigid vibration on the rubber support. The excitation being in a perpendicular direction, it is possible that the amplitude of the vibration to be small. But we can see, in the Fig.17 two small frequencies around the value of 15 Hz. For this reason we consider that a new experiment can confirm these two missing values.

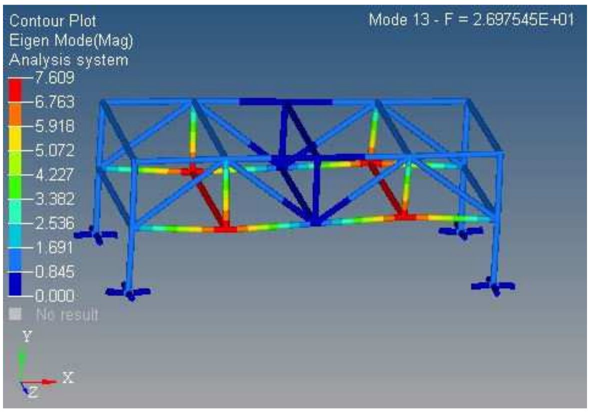

Figure 11. Eigenmode 13 (skewsymmetric)

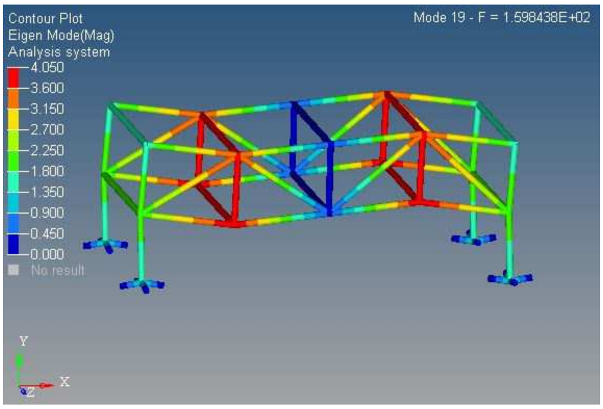

Figure 12. Eigenmode 19 (skewsymmetric)

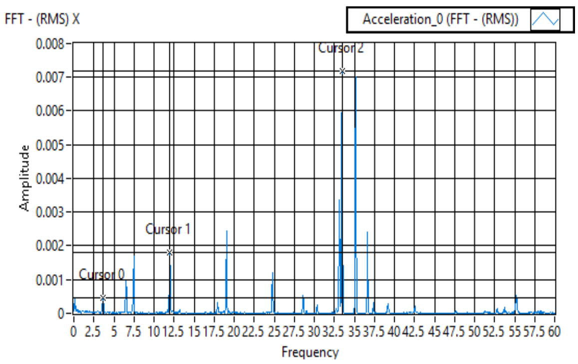

Figure 13. Frequencies chart for accelerations

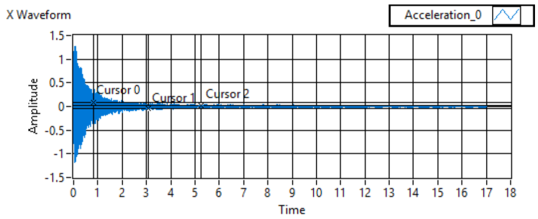

Figure 14. Amplitude of acceleration [m/s^2]

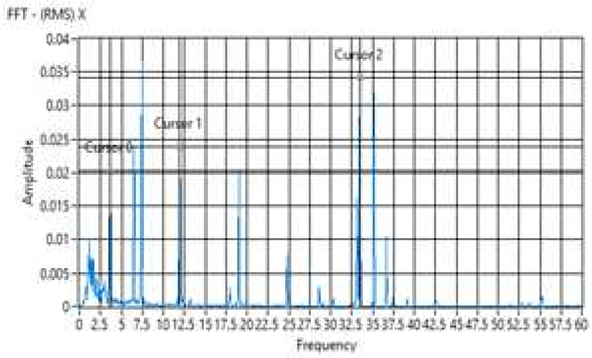

Figure 15. Frequencies chart for velocity

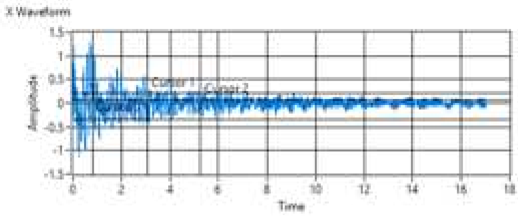

Figure 16. Amplitude of velocity [m/s^2]

Table 2. Eigenfrequencies.Measured values

Frequency [Hz]	**Eigen-value** [rad/s]	**Acceleration** [m/s^2]	**Velocity** [mm/s]
3.67	23.08	0.0005	0.0201
6.50	40.87	0.0010	0.0236
7.46	46.93	0.0017	0.0367
11.98	75.31	0.0018	0.0239
17.95	112.78	0.0003	0.0028
19.03	119.59	0.0024	0.0204
24.75	155.55	0.0012	0.0076
33.12	208.15	0.0034	0.0162
33.49	210.42	**0.0072**	**0.0342**
35.17	221.02	0.0070	0.0318
36.62	230.10	0.0024	0.0105

4. CONCLUSIONS

In the case of the mechanical systems presenting certain symmetries, the theoretical model shows the existence of some properties concerning the eigenvalues and eigenmodes of vibration.

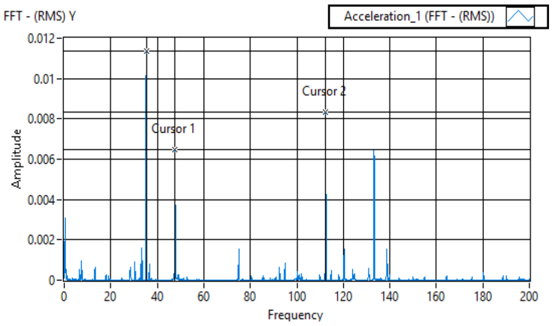

Figure 17. Eigenfrequency spectrum for the point P4

The literature provides for such properties for different type of mechanical systems. The paper presents an experimental validation of the theoretic finite element model [27]. To achieve this, a real structure has been studied that can be used in practice to provide a support for an industrial cooler. The structure is made of rigid trusses. Experimental determinations of the structure's eigenvalues were made. These results were presented in section 3. A good accordance can be observed between the theoretical values and the measured values.

5. REFERENCES

[1] Bratu, P., Stuparu, A., Popa, S., Iacob, N., Voicu, O., The assessment of the dynamic response to seismic excitation for constructions equipped with base isolation systems according to the Newton-Voigt-Kelvin model. *Acta Technical Napocensis, Series: Applied Mathematics, Mechanics*, and Engineering Vol. 60, Issue IV, November, 2017,pp.459.

[2] Ciuncanu, M., Chiroiu, V., On the post-earthquake damage detection of structures. *Ro. J. Techn. Sci. −Appl. Mechanics*, Vol. 61, N° 3, pp. 189–205, Bucharest, 2016.

[3] Cristea, A.F., Farcaş, A.E., Arghir, M., Study regarding the vibration transmission of the autovehicle about human body. *Acta Technical Napocensis,* Series: Applied Mathematics, Mechanics, and Engineering, Nr. 59, Vol. IV, pp.379-382, 2016.

[4] Douglas, Th., *Structural Dynamics and Vibrations in Practice: An Engineering Handbook*, CRC Press, 2012.

[5] Gillich,G.-R., Praisach,Z.-I., Iavornic,C.M., Reliable method to detect and assess damages in beams based on frequency changes. *ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. pp. 129-137, 2012.

[6] Ioan, R., Munteanu, L., Dumitru, D., Determination of dynamic Young's modulus for steel alloys. *Romanian Journal of Mechanics*, [S.l.], V. 1, N. 1, pp. 3-12, 2016. ISSN 2537-5229.

[7] Mangeron, D., Goia, I., Vlase, S., Symmetrical Branched Systems Vibrations. *Scientific Memoirs of the Romanian Academy*, Bucharest, Serie IV, Tom XII, Nr.1, 1991,pp.232-236.

[8] M. Marin, On weak solutions in elasticity of dipolar bodies with voids, *J. Comp. Appl. Math.*, vol. 82 (1-2), pp.291-297, 1997.

[9] M. Marin, D. Baleanu, On vibrations in thermoelasticity without energy dissipation for micropolar bodies, *Bound Value Probl*, vol. 2016, Art. No. 111, pp. 1-19, 2016.

[10] M. Marin, An approach of a heat-flux dependent theory for micropolar porous media, *Meccanica*, vol.51, No.5, pp.1127-1133, 2016.

[11] Meirovitch, L., *Principles and Techniques of Vibrations*. Pearson (1996).

[12] Negrean, I., Advanced notions in analytical dynamics of systems. *Acta Technical Napocensis,* Series: Applied Mathematics, Mechanics, and Engineering Vol. 60, Issue IV, November, 2017,pp.491.

[13] Negrean, I., Mass distribution in analytical dynamics of systems. *Acta Technical Napocensis*, Series: Applied Mathematics, Mechanics, and Engineering Vol. 60, Issue II, June, 2017, pp.175.

[14] Rades, M., *Mechanical Vibrations*, II. Ed. PRINTECH, 2010

[15] Shi, C.Z., Parker, R.G., Modal structure of centrifugal pendulum vibration absorber systems with multiple cyclically symmetric groups of absorbers. *Journal of Sound and Vibration*. DI 10.1016/j.jsv.2013.03.009.

[16] Timoshenko, P.S., M. Gere, J.M., *Theory of Elastic Stability*, McGraw-Hill,New York, London, 2nd Edition, 2009.

[17]. Tyn Myint-U, *Ordinary Differential Equations*. Elsevier, 1977.

[18] Vlase, S., Finite element analysis of a linear elastic body in a centrifugal field. *Romanian Journal of Mechanics*, V. 2, N. 1, pp. 51-62, 2017. ISSN 2537-5229.

[19] Vlase, S., A method of eliminating Lagrangian-multipliers from the equation of motion of interconnected mechanical systems. *Journal of Applied Mecanics-Transactions of The ASME*, Vol: 54 Issue: 1, pp.235-237 DOI: 10.1115/ 1.3172969.

[20] Vlase, S., Some properties of the Eigenvalues and Eigenvectors of the Elastic Systems with Three Identical Parts. *Proceeding of the ASVM Conference*, ISBN 973-625-238-8, Timişoara, pp.227-231, 2005.

[21] Vlase, S., Cândea,I., Mihălcică,V., Ambruş, C., Vibration of the transmission of a truck with two identical engines. *Proceedings of the 3rd International Conference EpsMsO*, Athens, Greece, 8-11 July, 2009.

[22] Vlase, S., Chiru, A., Symmetry in the study of the vibration of some engineering mechanical systems. *Proceedings of the 3rd International Conference 3rd International Conference EpsMsO*, Athens, Greece, 8-11 July, 2009.

[23] Vlase, S., Paun, M., Vibration Analysis of a Mechanical System consisting of Two Identical Parts. *Ro. J. Techn. Sci. - Appl. Mechanics*, Vol. 60, No 3, pp. 216-230, Bucharest, 2015.

[24] Vlase, S., Năstac, C., Marin, M., Mihălcică, M., A method for the study of the vibration of mechanical bars systems with symmetries. *Acta Technical Napocensis*, Series: Applied Mathematics, Mechanics and Engineering Vol. 60, Issue IV, November, pp.539, 2017.

[25] Vlase, S., Mihălcică,M., Scutaru, M.L., Năstac, C., Coupled transversal and longitudinal vibrations of a plane mechanical system with two identical beams, *Ro. J. Techn. Sci. −Appl. Mechanics*, Vol. 61, N° 3, pp. 276–289, Bucharest, 2016.

[26] Vlase, S., Danasel, C, Scutaru, M.L., Mihalcica, M., Finite element analysis of a two-dimensional linear elastic systems with a plane "rigid motion". *Romanian Journal of Physics*, Vol: 59 Issue: 5-6, pp.476-487, 2014.

[27]. Vlase, S., Itu, C., Vasile, O., Năstac, C., Stanciu, M.D., Scutaru, M.L., Vibration Analysis of a Mechanical System Composed by Two Identical parts. Romanian Journal of Accoustic and Vibration. Vol. XV, Issue 1, 2018.

Analiza experimentală a unui sistem mecanic alcătuit din două părți identice

Lucrarea prezintă o analiză experimentală a unei structuri simetrice, realizată pentru validarea modelului cu elemente finite utilizat pentru evidențierea unor proprietăți obținute teoretic ale unor astfel de sisteme mecanice. Se studiază o structură reală, utilizată în domeniul construcțiilor utilizată pentru fixarea unui răcitor industrial. Structura este realizată din ferme, rigid conectate una cu alta. Vibrațiile acestui sistem au fost determinate și comparate cu valorile teoretice. Astfel, modelul experimental a fost validat, ceea ce permite apoi determinarea frecvențe propii și a modurilor proprii de vibrație, având în vedere proprietățile de simetrie ale structurii.

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