ELIMINATION OF UNDESIRABLES MOVEMENTS IN DYNAMIC RESPONSES OF A DRIVER

Paulo César M. Doval, doval@fem.unicamp.br
Departament of Mechanical and Material, Federal Institute of Maranhão, Av. Getúlio Vargas,04, São Luís, Maranhão, Brazil, CEP 65.030-005

Alain Girard, alaingirard@intespace.fr
Société INTESPACE, Complexe Scientifique du Rangueil, 18, avenue Edouard-Belin, B.P 4356, 31029, Toulouse, France

Abstract. *The structure of a satellite must be designed to withstand loads induced during launch vehicle flight phases. This is mainly to thrust force, on which is superimposed a low frequency vibration environment (up to hundreds of hertz), which excites the launch vehicle and the satellite during flight phases. In order to qualify the satellite on this environmental load, ground tests are performed based on standard rates.*
The interface between the shaker and the satellite is not perfectly rigid, thus, during the qualification tests, when the satellite is excited about at its base with a force following a direction given, it appears in the center of the interface between the shaker and the satellite one nominal motion and five other parasites motions (two translations and three rotations). On the other hand, the guidance system of the interface by the exciter along the axis roll is not perfect, it allows small transverse displacements and small rotations.
This paper propose to determine the responses due to the nominal single movement (rigid interface and perfect guidance) by eliminating the effects of non-rigid interface and imperfect guidance to the structure.

Keywords: *Qualification test, undesirables movements, dynamic structural analysis, dynamics characteristics, modal analysis.*

1. INTRODUCTION

The experimental study of structural vibration has always provided a major contribution to the efforts to understand and to control the vibration phenomena encountered in pratice. However, there are two distincts types of tests: vibration tests and controled tests. In the vibration tests the structure is submited to vibration forces under normal or specified conditions and the responses are measured during operation of the structure under study. Controled tests, the structure is vibrated with a known excitation (functionnal tests). The test is made under much more cosely-controled conditions an consequently yields more accurate and detailed informations (sine and random tests, modal tests).

The structure of a satellite must be designed to withstand loads induced during launch vehicle flight phases. This is mainly to thrust force, on which is superimposed a low frequency vibration environment (up to hundreds of hertz), which excites the launch vehicle and the satellite during flight phases. In order to qualify the satellite on this environmental load, ground tests are performed based on standard rates (Girard, 1985).

The interface between the shaker and the satellite is not perfectly rigid, thus, during the qualification tests, when the satellite is excited about at its base with a force following a direction given, it appears in the center of the interface between the shaker and the satellite one nominal movement and five other parasites movements (two translations and three rotations). On the other hand, the guidance system of the interface by the exciter along the axis roll is not perfect, it allows small transverse displacements and small rotations.

This paper propose to determine the responses due to the nominal single movement (rigid interface and perfect guidance) by eliminating the effects of non-rigid interface and imperfect guidance to the structure.

2. THEORETICAL DEVELOPMENT

2.1 General Case

In this case it was considered a simple model of a structure, as shown in figure 1, which is excited about at its base with a force following a direction given, X direction for example. The interface between the shaker and the satellite is not perfectly rigid, thus appears in the center O of the interface between the shaker and the satellite one nominal motion of translation , in X axis, and five other parasites motions (two translations in Y and Z axis, and three rotations, in X, Y and Z axis).

The aim of this paper is to determine these parasites motions from a number of sensors j (junction), placed on the interface, and then eliminate their effects on the sensors i (internal) placed in the structure, to find the responses due to a single nominal motion.

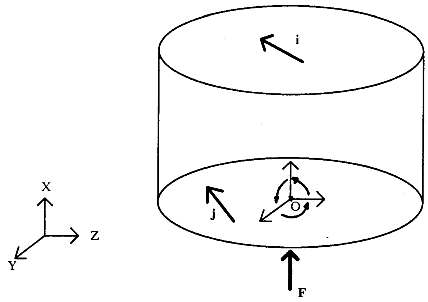

Figure 1. Simplified model of the structure object of study

2.1.1 Equations of the interface motion

The acceleration vector γ_o of six components $(\ddot{u}, \ddot{v}, \ddot{w}, \ddot{\theta_x}, \ddot{\theta_y}, \ddot{\theta_z})$ of the center O is linked to the acceleration vector γ_j by the following equation:

$$\gamma_j = T_{jo}\gamma_o, \tag{1}$$

where T_{jo} is the transformation matrix that provide kinematic relations between points j and o.

For a given sensor located at a point M in the direction of unit vector x_j, the relation can be written as:

$$\gamma_j = \vec{x_j}\left[\left\{\begin{array}{c}\ddot{u}\\ \ddot{v}\\ \ddot{w}\end{array}\right\} + \left\{\begin{array}{c}\ddot{\theta_x}\\ \ddot{\theta_y}\\ \ddot{\theta_z}\end{array}\right\} \times O\vec{M}_j\right], \tag{2}$$

If the matrix $T_{oj}T_{jo}$ is not singular (sensors j sufficient to determine γ_o), the equation 1 give by the square minimum method (pseudo-invertion of T_{jo}):

$$\gamma_o = \left(T_{oj}T_{jo}\right)^{-1} T_{oj}\gamma_j, \tag{3}$$

The difference

$$\gamma_j - T_{jo}\gamma_o = \left[I_{jj} - T_{jo}\left(T_{oj}T_{jo}\right)^{-1} T_{oj}\right]\gamma_j, \tag{4}$$

represents the interface deformation around the medium motion, null if the interface is rigid.

2.1.2 Elimination of the parasites motions

It is assumed known the responses $\gamma_{(i+j)}$ to excitation F_n, as a function of $\omega = 2\pi f$.

The identification of eigenvector from the transfer function $\gamma_{(i+j)}/F_n$, is given by:

$$\gamma_{(i+j)}/F_n(\omega) = -\omega^2 G_{(i+j)n}(\omega), \tag{5}$$

with

$$G_{(i+j)n}(\omega) = \sum_k \frac{1}{\left[1 - \left(\frac{\omega}{\omega_k}\right)^2 + i\eta_k\right]} \frac{\phi_{(i+j)k}\phi_{kn}}{\omega_k^2 m_k} + G_{(i+j)n,res}\ , \tag{6}$$

where, G is the dynamic flexibility matrix, ϕ is the eigenmode matrix, η_k is the modal damping and i is the imaginary unit.

Now, let us reconstitute the transfer function $\gamma_{(i+j)}/F_j$, with only the residual terms:

$$\gamma_{(i+j)}/F_j(\omega) = -\omega^2 G_{(i+j)j}(\omega), \tag{7}$$

with

$$G_{(i+j)j}(\omega) = \sum_k \frac{1}{\left[1 - \left(\frac{\omega}{\omega_k}\right)^2 + \eta_k\right]} \frac{\phi_{(i+j)k}\phi_{kj}}{\omega_k^2 m_k} + G_{(i+j)j,res}. \tag{8}$$

The relation 7, between forces and accelerations, is valid whatever the forces F_j and displacements $\gamma_{(i+j)}$.

At the first moment we will go to examine the implication of a rigid interface and after, that of a rigid interface with perfect guidance.

A rigid interface, characterized by the 6 movements γ_o of its center O, implies that the acceleration γ_j are expressed strictly in terms of γ_o, as we can see in equation 1:

$$\gamma_j = T_{jo}\gamma_o$$

Correspondingly, the forces F_o can be deduced by the forces F_j:

$$F_o = T_{oj}F_j, \tag{9}$$

and from equations 7 and 1, we can obtain:

$$F_j = \left[-\omega^2 G_{jj}\right]^{-1} \gamma_j = \left[-\omega^2 G_{jj}\right]^{-1} T_{jo}\gamma_o. \tag{10}$$

Substitution of equation 10 into equation 9 yields

$$F_o = T_{oj}\left[-\omega^2 G_{jj}\right]^{-1} T_{jo}\gamma_o, \tag{11}$$

or

$$\gamma_o = \left[T_{oj}\left[-\omega^2 G_{jj}\right]^{-1} T_{jo}\right]^{-1} F_o. \tag{12}$$

If among the six components of the excitation force F_o there is only the electrodynamic force F_n, the other F_p components being zero, the movement at the interface is given by:

$$\gamma_o = \left[T_{oj}\left[-\omega^2 G_{jj}\right]^{-1} T_{jo}\right]^{-1} I_{on}F_n. \tag{13}$$

with $I_{on} = [1\ 0\ 0\ 0\ 0\ 0]$ for a nominal motion along X axis. However, if one driver on the nominal motion $\gamma_n = I_{on}\gamma_o$, the excitation force necessary is given by:

$$F_n = \left[I_{no}\left[T_{oj}\left[-\omega^2 G_{jj}\right]^{-1} T_{jo}\right]^{-1} I_{on}\right]^{-1} \gamma_n. \tag{14}$$

We found all the responses by exploiting equations 1, 7, 10 and 13.

If now we consider a perfect guidance, situation identified in what follows by (*), it implies that the movements of O other than the nominal movement γ_n are zero and the relations 1 and 10 become:

$$\gamma_j^* = T_{jn}\gamma_n^*, \tag{15}$$

$$F_j^* = \left[-\omega^2 G_{jj}\right]^{-1} T_{jn}\gamma_n^*. \tag{16}$$

Equation 10 provides the necessary electrodynamics force F_n^* as well as F_p^* forces which allows a perfect guidance:

$$F_n^* = T_{nj}\left[-\omega^2 G_{jj}\right]^{-1} T_{jn}\gamma_n^*, \tag{17}$$

$$F_p^* = T_{pj}\left[-\omega^2 G_{jj}\right]^{-1} T_{jn}\gamma_n^*. \tag{18}$$

Finally, by using equations 7 and 16, the accelerations γ_i^* are given by:

$$\gamma_i^* = \left[-\omega^2 G_{ij}\right] F_j^* = G_{ij}G_{jj}^{-1}T_{jn}\gamma_n^*. \tag{19}$$

Relations from 15 to 19 reflecting the behavior of the perfectly clamped structure and guided as a function of the nominal movement specified γ_n^*. A new identification from transfer function $\gamma_{(i+j)}/F_n$ allows to determine the eigenvectors:

$$\left(\frac{\gamma_{(i+j)}}{F_j}\right)^*(\omega) = -\omega^2\left[\begin{array}{c} G_{ij}\ G_{jj}^{-1} \\ I_{jj} \end{array}\right] T_{jn}\left[T_{nj}\ G_{jj}^{-1}\ T_{jn}\right]^{-1}. \tag{20}$$

2.2 Test Case

The characteristics of the test case treated were chosen in a representative manner of the problem. According to the model we used the finites elements program (NASTRAN) to generate a database PROTO. This software, developed by the INTESPACE Society, implement the modal superposition technique based on the results from NASTRAN by calculating the cross admittances of de modes. For test case we have been found cross admittances from 10 to 200 Hz in 500 points linearly spaced (Girard, 1977). The force that generates an acceleration of $1g$ was applied to node 10 along the X axis.

From these results, we used the software MATLAB to generate 26 files (frequency, strength, acc_{ix}, acc_{iy}, acc_{iz}, with i = 1, 2, ..., 8); to determine the average motion of the interface (equation 3); the deformation around the average motion (equation 4) and transfers functions (equation 5), placed on appropriate pattern for identification of the eigenvector by using the software TDAS. From the results of the identification was reconstituted the flexibilities $G_{(i+j)}$, equation 7 and transfers functions $\left(\gamma_{(i+j)}/F_n\right)^*$, equation 20 (Hurty, 1965).

A new identification from these transfers functions can determine the eigenvector of the structure in the absence of perturbatios introduced by the non-rigid interface and imperfect guide.

2.2.1 Characteristics of the model test case

In this work it was considered a finite element model with different types of beam elements and concentrated masses in the nodes, as we can see in figure 2. The concentrated mass from node 1 to node 6 (M_1 to M_6) is equal to $500kg$; node 7 (M_7) is equal to $550kg$; node 8 (M_8) is equal to $450kg$. The Characteristics of the beam elements are:
low beams: $S_l = 10^{-2}m^2$; $I_{plan} = 10^{-2}m^4$; $I_l = 10^{-4}m^4$; $J_l = 10^{-4}m^4$;
vertical beams: $S_v = 10^{-3}m^2$; $I_{xy} = 10^{-2}m^4$; $I_{xz} = 2.10^{-4}m^4$; $J_v = 10^{-4}m^4$;
upper beams: $S_u = 10^{-2}m^2$; $I_{plan} = 10^{-2}m^4$; $I_l = 10^{-4}m^4$; $J_u = 10^{-4}m^4$.

Where, S, I and J are, respectively, area, area moment of inertia and polar moment of inertia.

The guide excitation at nodes are: $K_{TX} = 10^6 N/m$ and K_{TY} to $R_z = 10^9 N(m)/m$.

The shape and modal frequency from the first to fourteenth modes are representeds in table 1 bellow.

Table 1. Shape and modal frequency of the test case

Modes	Frequency (Hz)	Shape	Modes	Frequency (Hz)	Shape
1	2.515	TX	2	32.45	RZ
3	34.86	RY	4	43.38	RX
5	63.04	Saddle	6	67.40	RZ
7	73.64	RY	8	84.40	TX
9	98.92	TX	10	121.59	few excitation
11	123.78	few excitation	12	124.60	few excitation
13	175.23	few excitation	14	176.93	few excitation

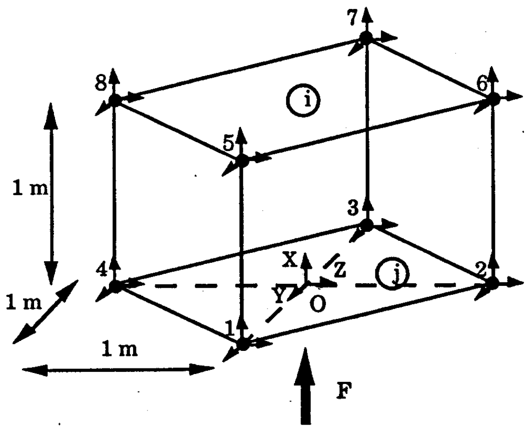

Figure 2. Finite element model of the test case studied

3. RESULTS

It's shown in figures 3 and 4, respectively, the curves of the transfers functions $\gamma_{1(x,y,z)}/F_{10x}$ and $\gamma_{5(x,y,z)}/F_{10x}$ in the junction and interne, with parasite motion. Figures 5 and 6 shows the curves of the transfers functions $\gamma_{1(x,y,z)}/F_{10x}$ and $\gamma_{5(x,y,z)}/F_{10x}$ in the junction and interne, of the structure perfectly clamped and guided (with no parasites motions).

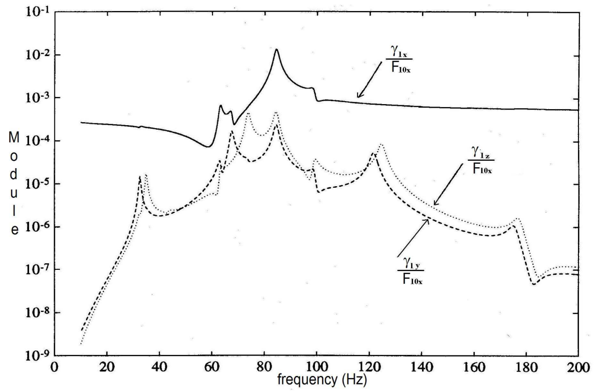

Figure 3. *Transfer function at node 1 - Junction (with residual terms)*

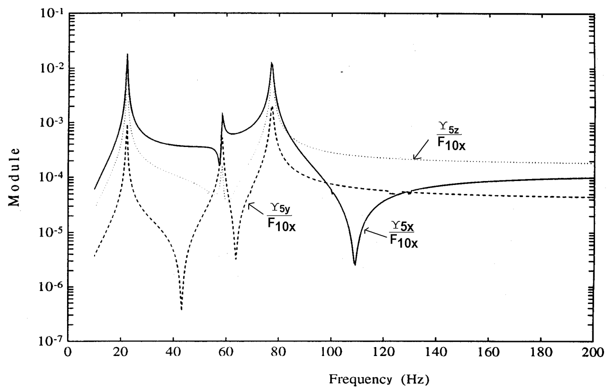

Figure 4. *Transfer function at node 5 - Interne (with residual terms)*

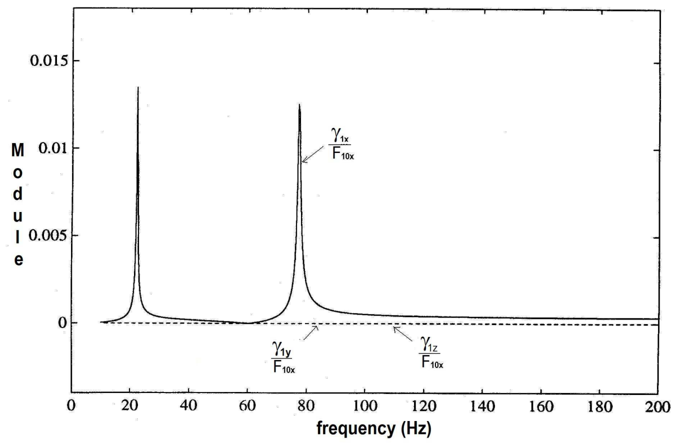

Figure 5. *Transfer function at node 1 - Junction (without parasite motion)*

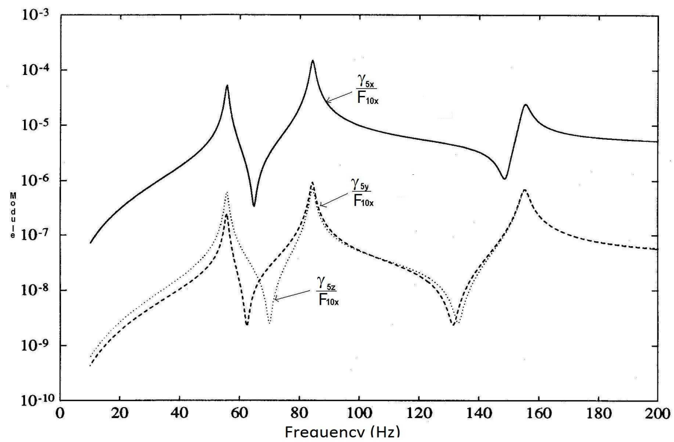

Figure 6. *Transfer function at node 5 - Interne (without parasite motion)*

4. CONCLUSIONS

This paper presented a method to determine the dynamics responses in qualification tests of satellites, due to the nominal single movement (rigid interface and perfect guidance) by eliminating the effects of non-rigid interface and imperfect guidance to the structure.

From the analysis of curves obtained by calculations, we can see that about 20 Hz the responses founded are different of the nominal responses .

The same calculations were made by researchers of the INTESPACE whose answers were the same, despite some differences can be attributed to machine error.

A study must be performed on a model that allows a relatively simple resolution, 2-DOF with a hundred points, for example, to solve this problem.

5. REFERENCES

Girard, A., 1977. *Identification dynamique des structures: les essais d analyses modale*. Centre National d Etudes Spatiales, 18, Edouard Belin, Toulouse, France.

Girard, A., 1985. *Response des structures a un environnement de basse frequence*. Centre National d Etudes Spatiales, 18, Edouard Belin, Toulouse, France.

Hurty, W.C., 1965. "Dynamic analysis of structural systems using component modes". *AIAA*, Vol. 3, No. 4, pp. 678–685.

6. Responsibility notice

The authors are the only responsibles for the printed material included in this paper