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# IMPACT OF JUNCTION PROPERTIES ON THE VIBROACOUSTIC BEHAVIOUR OF ASSEMBLED STRUCTURES

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## ABSTRACT

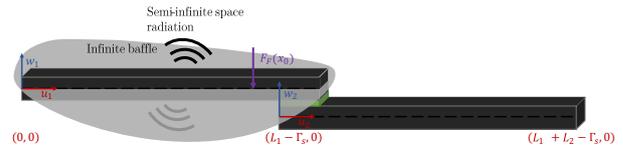
This communication is part of a study consisting in analyzing vibroacoustic behaviour of assembled structures. The study is focused on a system of two beams partly overlapped and whose junction is modelled by a distribution of linear stiffeners and dampers so that flexural and compressional motions are coupled. The model is constructed from a modal decomposition based on the uncoupled free/free beams and is solved in the frequency domain by a standard inversion method. The approach is validated by comparison with reference results from finite element simulations. The importance of modal coupling terms on the vibroacoustic behaviour of the assembly are then analyzed. The results obtained show the junction as a signature that can be linked to impact on vibroacoustic indicators of the assembled structure.

## 1. INTRODUCTION

Junction modelisation and their consequences on the assembled structure is an open scientific problem [1]. The junctions have different natures (bolted, glued, crimped, clipped,...) and get various mechanical properties on the assembled structure as induced damping and stiffness. With geometrical configuration, there is also wave conversion phenomenon when a movement turn to another movement.

To study these phenomena, the junction is defined as a linear viscoelastic pad and the substructures are beams in a non face-to-face configuration for studying wave conversion. Movement is a split between bending and compression wave as  $x(t) = (w^{(k)}(x) \ u^{(k)}(x))$  with  $(k)$ , a superscript which designed the studied substructure.

This paper focus on the study of the modal coupling of two beams and the phenomena of wave conversion into bending and compression and their incidence on beam radiation. This study is based on a modal approach by a modal synthesis method. First step is to study the uncoupled dynamic substructure. Then, the junction is fully defined. Finally, the steady-state response is studied and the radiation power is calculated. The system is a assembled of beams linked by a viscoelastic pad,



**Figure 1.** Assembled beams with double semi-infinite space radiation. Junction is defined with a Kelvin-Voigt model [2]

## 2. FROM UNCOUPLED DYNAMIC TO ASSEMBLED STRUCTURE RADIATION

### 2.1 Governing equations

In the physical space, with harmonic assumption, the Euler-Bernoulli is expressed as,

$$(E^* I \nabla^4 - \rho S \omega^2) w(x) + \int_{\Gamma_s} (f_\phi(x) + m_\phi(x)) dx = f_F(x_0), \quad (1)$$

and the wave equation is,

$$(E^* \nabla^2 - \rho \omega^2) u(x) + \int_{\Gamma_s} f_\psi(x) = f_L(x_0), \quad (2)$$

where  $\rho$  is the density of the material,  $L$  is the length of the assembly,  $S$ , is the cross-section (considered as constant according to  $x$ ),  $E^*$  is the complex Young's modulus and  $I$  is the quadratic moment. This is equal to  $I = \frac{bh^3}{12}$  where  $b$  is the base of the section and  $h$ , its height. With sharing beam length  $\Gamma_s$ , it is necessary to integrate these effort, moment.  $\nabla^4$  is a spatial operator. A field displacement can be approached by a infinite sum of modal solutions. It is called modal superposition. For bending movements,  $w(x) = \phi_S + \sum_i^\infty q_i \phi_i(x)$  with  $\phi_S$  are body modes shapes which are joined due to the boundary conditions, in free space. In flexion, there are a translation,  $\phi_{S1} = 1$  and a rotation mode  $\phi_{S2} = 1x$ . Dynamic modal shapes,  $\phi_i(x)$ , are obtained from homogeneous governing equation with free-free boundary condition, eq. 1, [3]. For compressive wave, this is the same mechanisms with  $u(x) = \psi_S + \sum_j^\infty q_j \psi_j(x)$  with only one translational body shape, [3].

## 2.2 Model for linear viscoelastic junction

The interaction of the sub-structures is modeled using a viscoelastic pad to model the linear induced stiffness and damping mechanisms. The Kelvin-Voigt model is a one-dimensional model describing the desired viscoelastic behaviour. The mechanisms on the normal axis are also considered to be close to those on the tangential axis. Thus, the viscoelastic pad is a combination of two Kelvin-Voigt models. Junction forces are linear as,  $f = k^* \delta$ , with  $k^*$  a complex stiffness where the damping is injected in a harmonic assumption. The relative displacement,  $\delta$ , is a difference of expansion series expressed before. The junction forces are not located on the neutral fiber. This is a cause of modal conversion. Moreover, due to the non face-to-face configuration of the beams, there is also a lever arm moment in the bending equation which depends on the relative displacement in the longitudinal direction. By expressing these junction forces and lever arm moment, it then come links between the bending and compression equations which are the modal conversion mechanisms.

## 2.3 Modal bases assembled

By a modal approach, the assembled structure is discretized into a set of mass-spring systems coupled by generalized modal forces. It is now proposed to solve the equations of motion by frequency methods. From the equations, by re-injecting the modal expansions and the definition of the forces at the junction with a mass-normalization, the final system becomes,

$$(\text{diag}(\Omega^2 - \omega^2) + \bar{\mathbf{K}}_{JCT}^*) \mathbf{Q} = \bar{\mathbf{F}}_e, \quad (3)$$

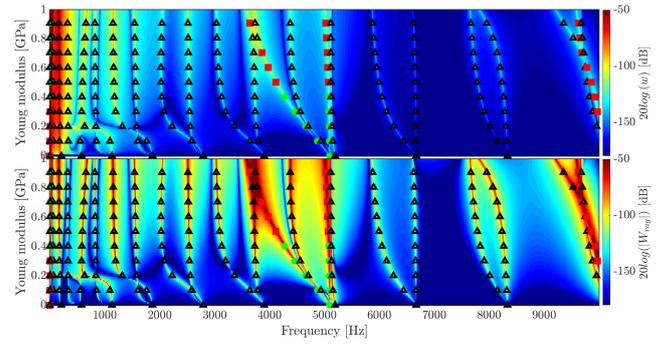
where  $\mathbf{Q}$  regrouped flexion and traction temporal terms for both beams. The global junction stiffness matrix,  $\bar{\mathbf{K}}_{JCT}^*$ , matrix which take into account the viscoelastic pad characteristics in term of induced stiffness and damping. This matrix is full. The steady state frequency response is obtained by inverting the dynamic rigidity from eq. 3.

## 2.4 Acoustic radiation from the beam

The beam assembly is placed in the air. The vibrations of each beam are coupled to the acoustic by a sum of parietal pressures,  $p_e(x, 0)$ , on the upper and lower surfaces of each beam and can be expressed on the bending expansion basis by using the continuity of speed principle. In addition, an infinite baffle is considered in the plane of each beam so that the acoustic radiation from the coupled system occurs in two semi-infinite spaces. One of the interesting outcomes is the radiated power which is obtained from bending velocity and the parietal pressure. By taking into account the modal approach consequence, radiation power is obtained as,

$$\Pi_{ray} = \frac{\omega^2}{2} \sum_n \sum_q q_n^2 N_n Z_{nq}, \quad (4)$$

where  $N_n$  is a modal normalization and  $Z_{nn}$  is the resistance matrix. With a light fluid assumption, there is no



**Figure 2.** Waterfall representation of field displacement responses (at the top) and of radiation power (at the bottom) from a parametric study where the pad Young modulus,  $E_p$  changes from 0 (no contact between beams) to 1 GPa (10 times stiffer than strong caoutchouc). Lines represent responses and are classified as bending bending response, (black triangle), pure compression response (green dot) or a combination of both movements, called hybrid responses (red square).

effect from a mode  $n$  to another  $q$  so it becomes diagonal,  $Z_{nn}$ .

## 2.5 Parametric study

The following figure, fig. 2, has been obtained from a parametric study where the pad Young modulus is variant from 0 to 1 GPa (10 times stiffer than strong caoutchouc). The structure is excited only in compression at the extremity on the first beam. Compression modes are non-radiant but, with the modal conversion mechanisms, there are pure bending response, (black triangle), pure compression response (green dot) or a combination of both movements, called hybrid responses (red square). The classification is obtained by calculating the ratio of kinetic energy between modal shapes.

As the parietal power is directly related to the displacement field, the results obtained between the vibration and acoustic data are close without considering the level. As the junction stiffens, the responses separate (demarcation of the response lines). This is a phenomenon of dynamic coupling of the two substructures. Although the structure is excited only in tension, there are also flexural responses due to the existing modal conversion. The level of these responses increases with the value of Young's modulus. One of the effects of the modal conversion is the hybridization of the resulting operational deformations. Indeed, as the Young's modulus value increases, the operational deformations, considered as pure traction, become a combination of the two movements. These results obtained for the displacement field are also reflected in the radiated power. Thus, the junction has a direct impact on the radiation of the assembled structure.

### 3. CONCLUSION

The work consists in studying a viscoelastic pad connection between two beams with a Kelvin-Voigt model in order to understand the induced dissipation, stiffness, the wave conversion mechanisms and their impact on the radiation behaviour of the assembled structure. By modifying the pad stiffness, the waterfall representations, fig. 2, show that the junction has a significant impact on the vibroacoustic behaviour on the assembled structure.

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