Vibroimpact induced damping in an architected sandwich composite

Emeline Sadoulet-Reboul[1], Gaël Chevallier[1], Pierre-Henri Cornuault[1], Théo Citerne[1] and Guilhem Michon[2]

[1] Univ. Bourgogne Franche-Comté, Institut FEMTO-ST

Department of Applied Mechanics
24 rue de l'épitaphe F-25000 Besançon- France

[2] Institut Supérieur de l'Aéronautique et de l'Espace – Institut Clément Ader
School of Technology

3, rue Caroline Aigle F-31400 Toulouse CEDEX 04, France

ABSTRACT

Sandwich composites are widely used in design especially in transport because they combine bending rigidity and lightness. On the other hand, their attenuation properties are not always as good as expected, and it is necessary to overcome this limitation in order to improve the vibratory comfort and the durability of the structures in which they are integrated. Several strategies exist such as the introduction into the core of the sandwich of passive materials with viscoelastic properties for example to allow energy dissipation, or the use of electronic circuits for active control strategies. The approach presented in this paper is based in the introduction of vibro-impact zones to generate damping. The local interactions occurring during the impacts allow to dissipate the vibratory energy: it is about nonlinear phenomena which have the advantage to be effective over a wide range of frequencies, and to be few sensitive to environmental conditions such as temperature. A sandwich composite prototype has been designed for the purpose of the study, and small ceramic balls have been inserted in the sandwich core to generate impacts phenomena. Experiments have been performed to evaluate the damping performances obtained depending on the number of balls, on the amplitude on excitation and on the frequency band. Analytical and numerical models of the structure have also been developed to perform parametric studies and evaluate the impact of parameters such as the ball added mass or the positions of the masses for instance : numerical results have been confronted to experimental ones. It has thus been observed that good damping performances could be obtained on a large frequency band.

Keywords: Damping, vibroimpact, functionalization

INTRODUCTION

Vibroimpact systems are nonlinear systems for which oscillations of a small structure as a mass generate collisions with other masses or with a structure or a barrier. Following the impact, exchange of momentum occurs and it leads to energy dissipation. This phenomena has led to the development of passive control device as impact dampers that are used for instance to improve the damping capability of boring tools and suppress chatter vibration [Satoshi, 2000], to control the vibrations of turbomachinery blades [Duffy, 2004], or to suppress wind vibrations on tall buildings [Masri, 1976]. The main advantages of such devices is that their behavior does not depend or temperature, they do not need power requirement and they are quite cheap, so they could be interesting solutions for vibratory control where other solutions fail. Impact dampers can have different configurations, they can consist in single units [Duncan, 2005], multi-units [Iwata, 2016], or granular impacts [Djemal, 2017].

One limitation of the vibroimpact systems for vibration mitigation is that the collision can lead to large contact forces and high noise levels, in particular when collisions occur between metallic elements. The principle of using multiple masses instead than one like in multi-units or granular configurations is to reduce the impact forces and so the impact noise. The association of multiple particles in one chamber has shown good efficiency for vibration suppression but the obtained damping is such a case is due to a combination of impact with other phenomena as shear friction, and so it is difficult to identify the exact effect of impact in the attenuation [Xu, 2005].

The purpose of this work is to investigate analytically and numerically the damping capability of a multi-unit vibroimpact system integrated in a composite structure. The collisions are generated by individual masses inserted in small cylinder where they can move vertically without and friction not contact between them. The question addressed in the research is: “ is-it possible to obtain good performances in terms of vibration mitigation with such a device, on a large frequency band and for any environmental conditions ? The paper summarizes the first results obtained on a prototype developed to answer this question.

BACKGROUND

The prototype developed for the study is a sandwich composite composed of two skins as the one presented in Figure 1. The lower and the upper skins present a lot of small holes where ball masses can be inserted and move vertically when the two skins are associated together. The master structure is done with aluminium while the masses are in ceramic to improve the impact conditions. The total length of the beam is 300 mm, the thickness is 1 mm, the hole diameter is 1.2 mm and the ball diameter is 1 mm.

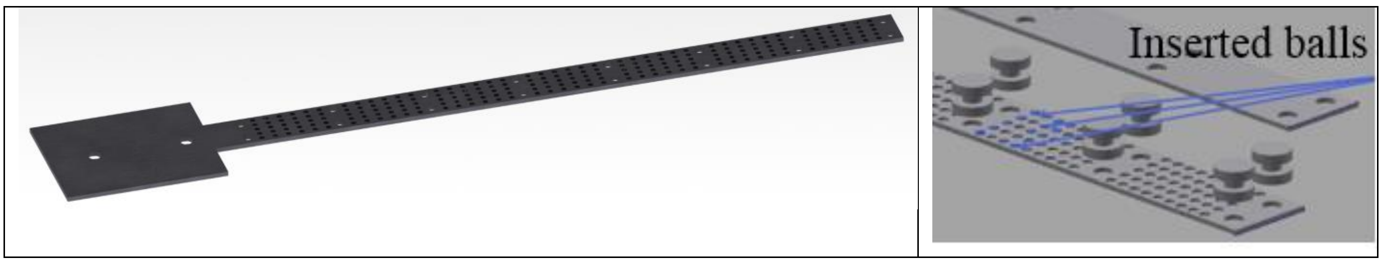

Figure 1 : Lower skin of the sandwich composite

The structure has been prototyped to evaluate the damping performances, and numerical tools have been developed in a purpose of topology design.

ANALYSIS

NUMERICAL INVESTIGATION

The structure is modeled as a beam and a Hertz model is used for the contact between each ball and the structure. The transversal displacement w of the beam is written by superposing the normal modes $\emptyset_k$,

$$w(x,t) = \sum_{k=1}^{n_{\text{mode}}} \Phi_k(x)\, q_k(t) \qquad (1°)$$

The equations governing the time behavior of the structure are written as

$$\begin{aligned} 1 \le k \le n_{\text{mode}} \quad &: \quad \ddot{q}_k + 2\xi_k\omega_k\dot{q}_k + \omega_k^2 q_k + \sum_{j=1}^{n_{\text{masse}}} \frac{c_{m_j}}{m_k}\left(\dot{w}_p(x_{m_j}) - \dot{w}_{m_j}\right)\phi_k\left(x_{m_j}\right) + \sum_{j=1}^{n_{\text{masse}}} \frac{k_{m_j}}{m_k}\left(w_p(x_{m_j}) - w_{m_j}\right)^{3/2}\phi_k\left(x_{m_j}\right) = \frac{F_0}{m_k}\phi_k\left(x_F\right)\cos(\omega t) \\ 1 \le j \le n_{\text{masse}} \quad &: \quad \ddot{w}_{m_j} + \frac{c_{m_j}}{m_{m_j}}\left(\dot{w}_{m_j} - \dot{w}_p(x_{m_j})\right) + \frac{k_{m_j}}{m_{m_j}}\left(w_{m_j} - w_p(x_{m_j})\right)^{3/2} = 0 \end{aligned} \qquad (2°)$$

Where m_k, ξ_k denote the modal mass and damping, $m_{mj,}c_{mj}$ are the mass and the damping of each ball placed at x_{mj}. The Hertz stiffness contact between each ball and the master structure is k_{mj}. These equations are solved in the time domain and transferred in the Fourier domain to evaluate the Frequency Response Functions.

EXPERIMENTAL INVESTIGATION

The structure has been excited with an harmonic excitation for different number of balls, from 0 to 90 to observe the influence of this parameter on the damping. Figure 2 presents the frequency response function obtained for the different configurations and the damping factor variates from 0.006 to 0.01

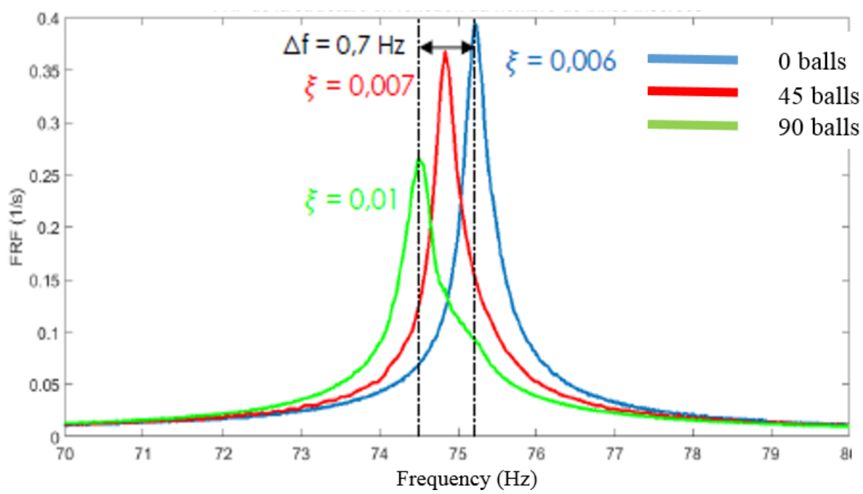

Figure 2 : Experimental frequency response functions on the prototype for different sets of balls

CONCLUSION

This work is the beginning of a project to evaluate the performances that could be obtained with a multi-unit configuration of impact dampers. Numerical tools have been developed and will be used to design a new configuration with optimized properties. First experimental results confirm the damping efficiency of the impact strategy, the nonlinear behavior of the structure, and the variations of performances with the level of excitation. Ongoing work aims at improving the model behavior of the contact, understand the different oscillations regimes occurring in the composite structure, and optimize the repartition of the contact areas.

ACKNOWLEDGEMENTS

This work has been supported by the EIPHI Graduate School (contract "ANR-17-EURE-0002").

REFERENCES

[Satoshi, 2000] Ema, Satoshi & Marui, Etsuo. (2000). Suppression of chatter vibration of boring tools using impact dampers. International Journal of Machine Tools & Manufacture - INT J MACH TOOL MANUF.

[Duffy, 2004] Duffy, K. P., Brown, G. V., & Bagley, R. L. (2004). U.S. Patent No. 6,827,551. Washington, DC: U.S. Patent and Trademark Office

[Bapat, 1985] Bapat, C. N., & Sankar, S. (1985). Single unit impact damper in free and forced vibration. Journal of Sound and Vibration, 99(1), 85-94.

[Duncan, 2005] Duncan, M. R., Wassgren, C. R., & Krousgrill, C. M. (2005). The damping performance of a single particle impact damper. Journal of Sound and Vibration, 286(1-2), 123-144.

[Djemal, 2017] Djemal, F., Chaari, R., Gafsi, W., Chaari, F., & Haddar, M. (2017). Passive vibration suppression using ball impact damper absorber. Applied Acoustics.

[Xu, 2005] Xu, Z., Wang, M. Y., & Chen, T. (2005). Particle damping for passive vibration suppression: numerical modelling and experimental investigation. Journal of Sound and Vibration, 279(3-5), 1097-1120.

[Iwata, 2016] Iwata, Y., Komatsuzaki, T., Kitayama, S., & Takasaki, T. (2016). Study on optimal impact damper using collision of vibrators. *Journal of Sound and Vibration*, *361*, 66-77.

[Masri, 1976] Masri, S. F. (1973). Steady-state response of a multidegree system with an impact damper. *Journal of Applied Mechanics*, *40*(1), 127-132.