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Numerical design and test on an assembled structure of a bolted joint with viscoelastic damping

Chaima Hammami [a], Etienne Balmes [a,b,*], Mikhail Guskov [a]

[a] Arts et Métiers Paritech, PIMM, 151 boulevard de l'hôpital, 75013 Paris, France
[b] SDTools, 44 Rue Vergniaud, 75013 Paris, France

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ABSTRACT

Mechanical assemblies are subjected to many dynamic loads and modifications are often needed to achieve acceptable vibration levels. While modifications on mass and stiffness are well mastered, damping modifications are still considered difficult to design. The paper presents a case study on the design of a bolted connection containing a viscoelastic damping layer. The notion of junction coupling level is introduced to ensure that sufficient energy is present in the joints to allow damping. Static performance is then addressed and it is shown that localization of metallic contact can be used to meet objectives, while allowing the presence of viscoelastic materials. Numerical prediction of damping then illustrates difficulties in optimizing for robustness. Modal test results of three configurations of an assembled structure, inspired by aeronautic fuselages, are then compared to analyze the performance of the design. While validity of the approach is confirmed, the effect of geometric imperfections is shown and stresses the need for robust design.

1. Introduction

Vibrations in mechanical assemblies often cause damage, noise and discomfort. The introduction of additional dissipation limits vibration levels and can thus significantly improve performance. This work will focus on the damping generated by joints incorporated in a structure typical of aeronautic construction. Since materials used in these structures are typically lightly damped, junctions clearly appear as areas where additional damping can be introduced. Nevertheless, a trade-off between the relative motion of the connected surfaces enabling for dissipation and the stiffness of the junction is to be found. The main physical dissipation mechanisms found in junctions are contact/friction, e.g. [1–3], and viscoelastic behavior of materials, such as [4–6].

Vibration damping has been the object of many studies [7–10]. However, treating damping design in assemblies has, in the last decade, been a significant interest for the aerospace and automotive sectors as illustrated in [11–13]. The treatment of the whole structures, as in [4,14], has not been the object of much literature. The most common joint geometries are flat lap joints with bolts, rivets or weld spots working in shear, and bracketed joints with folded plates and connectors working in traction [7]. The present paper will illustrate a design process for the latter.

The work is focused on the viscoelastic behavior of materials and illustrates how a numerical approach can be used to guide the design of dissipative assemblies. Taking a global dynamics of two fuselage segments, the objective is to redesign the joints

* Corresponding author.
E-mail address: etienne.balmes@ensam.eu (E. Balmes).

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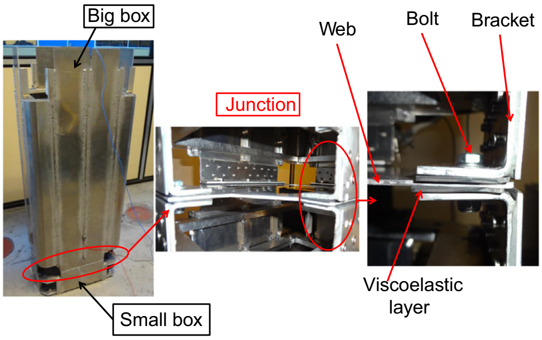

Fig. 1. Fuselage testbed 1155 × 409 × 259 mm.

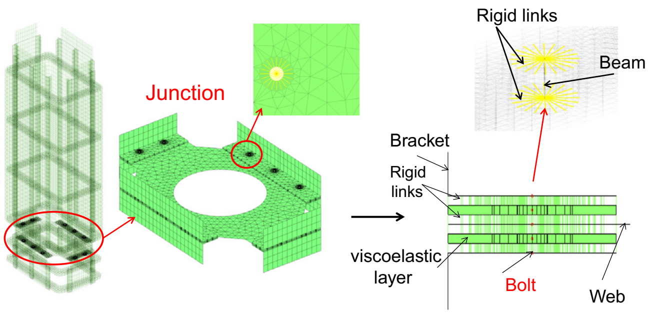

Fig. 2. Testbed model (42,615 nodes, 46,924 elements mixing shells, volumes and rigid links).

to maximize dissipation while preserving the base function of a bolted junction. More specifically, this work presents a new approach to use the dissipative effect of viscoelastic materials, while preserving the functional state of junctions. The first notion introduced is a level of coupling, which measures the influence of a junction on the overall dynamics and is strongly correlated with the ability of the junctions to dissipate.

The study is carried out on a testbed shown in Fig. 1. The structure is typical of aeronautic fuselage construction with frames and longerons providing a base structure and skins enclosing the whole. The testbed objective being to focus on the damping added by junctions between fuselage segments, one considers a main component "big box" connected to a "small box" that is clamped to the ground. This design limits the testbed size while generating significant loads in the connection between the two parts. Each box is welded to minimize internal damping and ensure that the overall damping will be mostly due to the junction shown in Fig. 1.

The configuration considered here uses bolted brackets with a web (thin plate) for additional stiffness. The brackets are riveted and glued to the skin in order to minimize dissipation sources. Partial tests have shown that dissipation induced by riveted and glued parts is extremely low and can be neglected for the rest of the work.

This paper is divided into two parts. The first part is about the finite element analysis done with bolted junctions incorporating viscoelastic materials. The coupling level in the junction is first investigated in Section 2 since dissipation is its direct issue. Once this criterion is highlighted, a suggestion of a new design for dissipative bolted joints is detailed in Section 3. The approach is based on reaching a compromise between the dissipative effect of viscoelastic materials and the functional static state of bolted joints. The addition of viscoelastic material can certainly increase the dissipation, while optimization is always desirable. Therefore, optimization strategies are then proposed in Section 4. In the second part, an experimental investigation for normal modes is described and results are compared to numerical ones after identification process in Section 5.1. Actually, mechanical structures have shape defects of variable importance due to machining or mounting processes. The impact of these defects on the damping design is thus discussed in Section 5.2.

2. Coupling: a measure of joint influence

When designing a damping treatment, the first step is to evaluate the amount of energy present in the structural elements under consideration. This is similar to the notion of electromechanical coupling in designing active systems so that the term **joint coupling level** will be used here. This is easily seen in the well-known formulation of the modal strain energy method [15] where the global loss factor η_s in a structure is approximated by a strain energy weighted loss in various components

$$\eta_s = \sum \eta_c E_c / \sum E_c \qquad (1)$$