Chapter 11
Vibration Mitigation of Bladed Structures Using Piezoelectric Digital Vibration Absorbers

J. Dietrich, G. Raze, A. Paknejad, A. Deraemaeker, C. Collette, and G. Kerschen

Abstract This work presents a novel vibration damping approach for bladed structures. Piezoelectric transducers bonded to a structure can be used simultaneously as actuators and sensors to mitigate the vibrations of their host. This can be achieved by connecting a transducer to a digital vibration absorber composed of a voltage sensor, a digital processing unit and a current injector. The digital vibration absorber thereby emulates a piezoelectric shunt. In this study, this technique is applied to bladed structures featuring small modal damping and closely spaced resonance frequencies grouped in mode families. A strategy exploiting the high modal density is presented. Effective vibration mitigation is experimentally demonstrated on multiple mode families simultaneously.

Keywords Piezoelectric shunt · Digital vibration absorber · Vibration mitigation · Multimodal damping · Bladed structures

11.1 Introduction

Attenuating structural vibrations is a well-known challenge for different engineering applications. In the field of mechanical engineering, a suitable damping solution can be piezoelectric shunt damping: piezoelectric transducers convert mechanical energy into electrical energy that is dissipated in an electrical circuit [1]. Often, these circuits are designed with so-called *RL* branches that consist of a resistance *R* and an inductance *L* that are connected in series or in parallel. These branches are tuned to resonate at the targeted resonance frequency of the mechanical structure. To realize high inductance values that are usually needed in these types of applications, synthetic inductors are commonly used [2]. Alternatively, a full digitalization of the desired electrical shunt circuit can be realized with so-called digital vibration absorbers (DVA). With this application, large inductance values are easily implemented, and the shunt parameters can be adapted in case the structural parameters change [3]. The effectiveness of a DVA operating on a beam structure has already been proved experimentally [4]. In this work, multiple DVAs are used to attenuate the vibrations of a bladed structure, namely a bladed rail. These structures have particular dynamics because the blade resonance frequencies occur in closely spaced groups of modes, so-called mode families [5]. Tuning a shunt toward closely spaced modes can be challenging and asks for adapted tuning strategies. This work provides the results of an experimental campaign in which the structural vibrations of a support structure (rail) with five blades are attenuated by five DVAs. Although the bladed rail is not rotationally symmetric, this structure exhibits similar dynamic properties as other bladed assemblies from real-life applications. A tuning procedure and a design for a multimodal shunt is presented in the following and validated experimentally.

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11.2 Background

Five DVAs with the same circuit design were used in this work. One DVA is connected to one patch glued under the root of a blade. Each DVA consists of an analog circuit and a microcontroller unit (MCU) connected to a controller board. The piezoelectric voltage is measured by the DVA and given as input to the MCU. A current is finally injected into the patch by a current source driven by the output voltage of the MCU. This current follows an input/output relation programmed in the MCU, thereby realizing the electrical admittance of one or multiple RL shunt branches.

The experimental setup is presented in Fig. 11.1. The structure was excited acoustically by a sine-sweep excitation in the frequency range of the first two mode families of the bladed rail. A mode family consists of five resonance modes that are grouped in a narrow frequency range. The velocity at the tip of the first blade was measured with a laser vibrometer. The open-circuit frequency response function (FRF) under acoustic excitation is presented in Fig. 11.2. Two mode families are clearly visible. These are the first bending (0.31–0.33) and torsion modes (0.80–0.83). Due to the setup configuration, only four resonance peaks were visible in the measured FRF for mode family one.

To tune the digital shunt properly, the undamped structural resonance frequencies need to be known for both short-circuit and open-circuit conditions. They can be determined by evaluating the transfer function between the voltage and the charge,

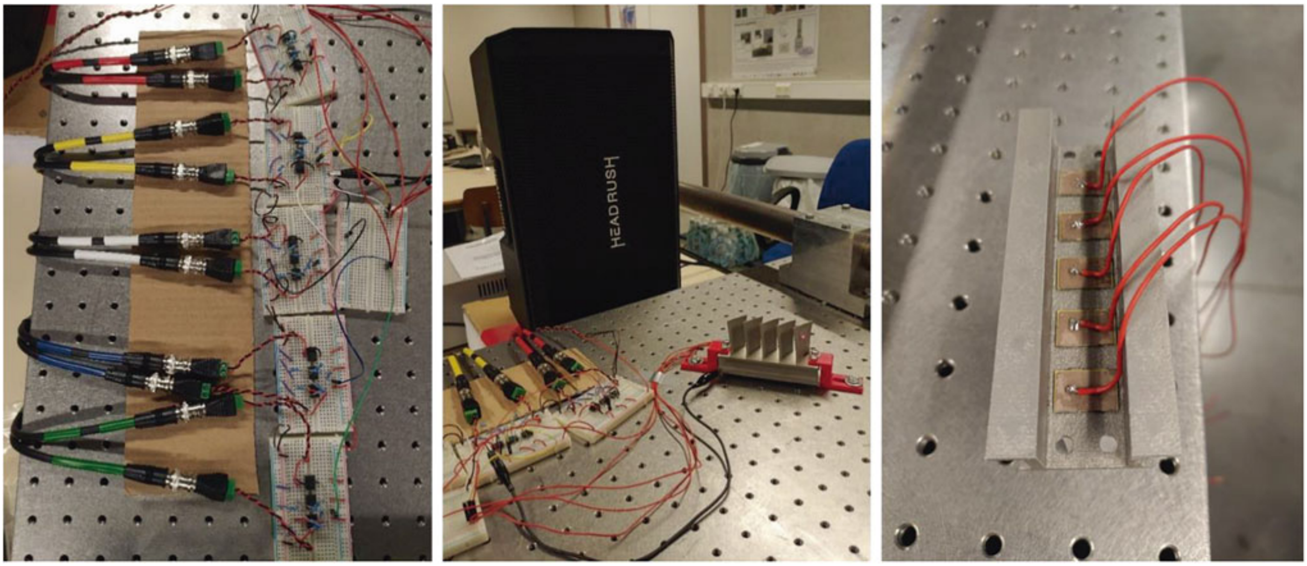

Fig. 11.1 Experimental setup of the bladed rail

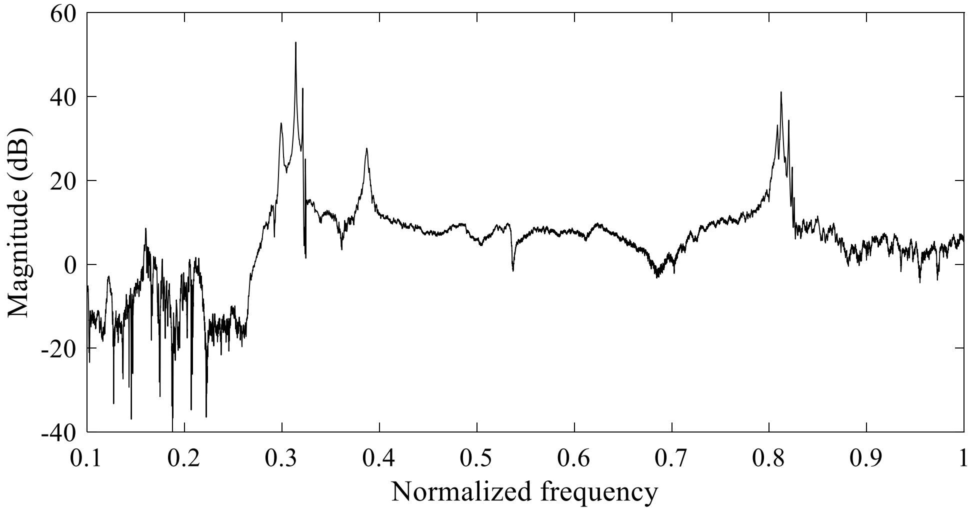

Fig. 11.2 Open-circuit FRF at the first blade tip under an acoustic sine-sweep excitation

also called the dynamic elastance. It was extracted by exciting the structure via a multisine excitation over the full frequency range of the first two mode families which is realized via the patches themselves. Thus, the piezoelectric patches function both as an actuator and a sensor. The measurements of the dynamic elastances are used for the modal parameter estimation method PolyMAX [6]. This method delivers a state space model with the characteristics of the mechanical-electrical coupling. The knowledge about this coupling with each mode is important when deciding which patch should target which mode. It can be assessed by setting the relation between the open- and short-circuit resonance frequencies of the structure. They are the resonances and antiresonances of the measured dynamic elastances and thus provided by the identified state space model. Five modes per family were identified with the PolyMAX method. Typically, there is more than one patch with a good mechanical-electrical coupling at a mode. Finally, the patch with the strongest coupling is chosen to be the respective shunt to attenuate this mode.

Two cases have been regarded in this work: the monomodal and the multimodal case. In the monomodal case, only mode family one is targeted by the five DVAs. Since only four modes were visible in the measurements for mode family one, one mode was chosen to be targeted by two patches. Each shunt consisted of a simple *RL* shunt that is tuned to the targeted resonance frequency. Each transfer function of this *RL* shunt is injected via one DVA, respectively. The second case is the multimodal case where two mode families were targeted. Thus, one DVA attenuates one mode from each mode family at the same time. In the multimodal case, a current blocking shunt circuit is exploited [7]. It consists of multiple shunt branches with each branch tuned toward one mode. A branch has an *RL* connection and a notch filter tuned toward a specific resonance frequency, in ascending order. The notch filters ensure that the current flows through the respective shunt branch by providing an infinite impedance at the targeted resonance frequency. Thus, the current is not able to flow to further branches and its way is forced through the shunt branch tuned toward it. To consider the influence of each previous stage, they are tuned successively. In this way, an equivalent piezoelectric structure that consists of the actual piezoelectric patch and the previous branches is identified. It is the basis for the tuning of the shunt parameters of the current shunt branch. With this approach, well known tuning rules for single *RL* branches can be used. In this work, the H_∞-tuning rules that were introduced by, inter alia, Soltani et al. have been exploited to tune the branches [8]. Finally, the overall admittance of the shunt circuit is injected as the transfer function via the DVA.

11.3 Results

The results of a monomodal and a multimodal shunt acting on the bladed rail are presented in Fig. 11.3. Mode family one is presented in Fig. 11.3(a). A better performance on mode two and three is visible in comparison to the multimodal shunt. This can be explained by the fact that the branches in the multimodal approach might slightly interact with each other, and an ideal current flow is not always guaranteed. However, in both cases, a clear reduction of the resonance peak amplitudes of up to 19 dB could be achieved. For the second mode family presented in Fig. 11.3(b), all resonance peaks could be successfully

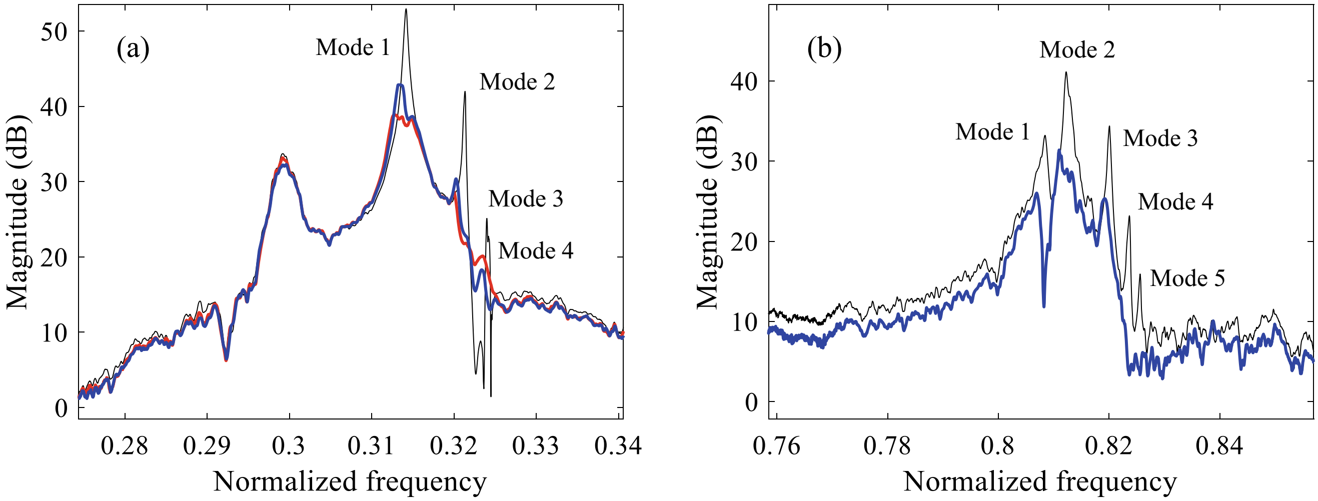

Fig. 11.3 FRF at the first blade tip in the range of the first (**a**) and the second (**a**) mode families of the system in open-circuit (—) and the shunted systems are displayed with the monomodal approach on mode family one (—) and the multimodal approach on both families (—)

attenuated up to 10 dB. Thus, the multimodal approach enabled a reduction and the control of the resonance amplitudes of two modes. With the use of five properly tuned DVAs, the two mode families of closely spaced modes can be damped at the same time.

11.4 Conclusion

This work presented a tuning strategy for monomodal and multimodal damping of structures with complex dynamics using piezoelectric shunts that are realized with DVAs. The strategies have been demonstrated experimentally on a bladed structure that has dynamic features similar to real-life bladed structures such as closely spaced modes that occur in mode families. Resonance amplitudes could be successfully reduced for two mode families while using multiple DVAs at the same time. The results of this experimental campaign pave the way for demonstrations of the DVA and the suggested tuning strategies on real-life industrial applications such as bladed disks.

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