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Comparative Study of Ski Damping Technologies by Accelerance Maps †

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Abstract: The vibratory response of alpine skis plays a significant role in the overall skier's experience. This response is more important than ever as skiers now demand light and approachable (i.e., soft) skis. To improve the vibratory response, many companies now offer technologies to damp the ski's motion. Even if widely used, these technologies are still widely misunderstood. This paper presents a method based on accelerance maps to evaluate the vibratory response (i.e., bending and torsional modes up to 250 Hz) and the damping at all points on the ski forebody. A variety of commercial technologies are evaluated (i.e., tuned-mass damper, particle damper, constrained-layer and rod activated viscoelastic bushing) and compared to the more traditional effects brought by adjusting mass, bending/torsional stiffnesses and construction.

Keywords: vibration; damping; alpine skis; accelerance map; modal analysis; tuned-mass damper; particle damper; constrained-layer; stiffness

1. Introduction

The vibratory behavior of an alpine ski can play a significant role in its performance and in the skier's experience [1,2]. Indeed, as a ski glides on snow, it is excited by the slope's irregularities. These repeated impacts between the slope and the running surface can make the ski vibrate and break contact with the snow [2]. This results in reduced control and directional stability, which ultimately can result in undesired slippage, in a loss of speed or simply in an unpleasant experience.

Traditional ways to improve the vibration response, especially in ski racing, is to design heavy and stiff skis. However, these techniques are not always desirable. Indeed, even if a heavy and stiff ski feels precise and powerful for an expert skier, the same ski can be hard to handle and steer for beginning or intermediate skiers [3]. Similarly, it is desirable to have light backcountry skis to minimize uphill efforts [4], but lighter constructions often result in softer skis with unpleasant vibratory response. Ski designers can increase the stiffness of the skis to improve the vibratory response with materials like carbon fiber. That strategy however has its limits, as the stiffness affects a number of other on-snow feels (e.g., directional stability). Many companies are now claiming to reintroduce more weight and stiffness into their "light" skis in order to regain a more desirable dynamic behavior. Examples of this trend are DPS skis' perimeter weighted inserts [5] and the prevalence of skis with *Titanal* reinforcement, which adds both mass and stiffness. To obtain better dynamic performance, manufacturers are also attempting to increase damping within a ski (e.g., viscoelastic materials, tuned mass damper and particle damper). Few studies have evaluated the performance of damping devices [1,6,7] and, to our knowledge, no study has ever compared the various damping devices to each other and to increased mass/stiffness.

The aim of this study is thus to evaluate the performance of commercially available damping methods and devices. Section 2 presents the equipment and the method used to perform damping testing through accelerance maps. Section 3 presents and discusses the resulting accelerance maps for the damping devices tested.

2. Materials and Methods

Various methods have been proposed to evaluate the damping of a ski in a laboratory setting. The ISO6267 norm recommends to measure the half-time decay of the first bending mode for a clamped ski released from a bent position [8]. This method however neglects the higher bending modes, which have been shown to be important [9], does not excite the torsional modes of the ski as expected from the contact of the edge with the snow [1,10], and does not allow the transmission of vibrational energy through the foot section of the ski, contrary to most modern bindings [9,11]. Other improved methods have been developed to measure the vibrational behavior and damping of skis in the laboratory. Both Piziali [12] and Fanti [9] characterized the damping of each mode for a frequency response function (FRF) measured at a single location. Glenne explored the influence of support conditions on ski vibration and use two cylindrical contact points spaced by the length of a binding as appropriate boundary conditions to emulate the dynamic behavior recorded on-snow [11]. Using a shaker and 6 accelerometers on the forebody of the ski, he measured FRFs to compare different ski constructions with on-snow measurements [10]. Later, he used driving-point FRFs by impacting the ski with an instrumented hammer along the length of the ski edge to create accelerance maps including torsion modes that quickly illustrate the spatial distribution of the ski dynamic behavior [1]. In these maps, damping is calculated from the width of the resonant peaks with the 3 dB rule [13]. This paper implements the method proposed in [1] to evaluate the dynamic response of skis in more detail than the ISO6267 norm (e.g., mode frequencies, mode damping, position of nodes, mode proximity). However, a roving accelerometer is used to improve the measurement coherence [14] by reducing the chance of double impacts on a compliant ski. One driving point FRF is still included in the measurements to allow mode shape scaling in further studies [14]. The test bench used is shown in Figure 1.

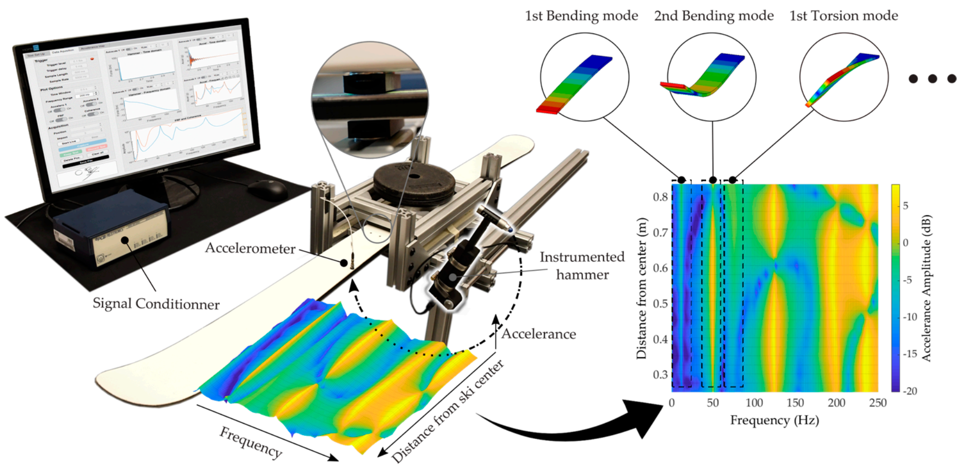

Figure 1. The developed test bench to measure accelerance maps on skis. Modes shapes are from [15].

The ski is held by 2 pairs of hard nylon cylindrical (Ø100 mm) supports that allow the propagation of vibrations from the front to the back of the ski through the foot section [11]. For skis with integrated rails, the rail was kept, and the contact with the cylindrical support was verified. For each measurement along the ski edge, the hammer impacts the ski base surface at the same location near the edge under the skis as shown in Figure 1. This chosen position of impact results in low coherence for the first bending mode but high coherence for all the higher order modes. This arrangement is acceptable in the present study, as the damping of the first mode typically shows no relevance to on-snow behavior [1,9]. The measurements are taken near the edge at every 2.5 cm for all skis except for the Rossignol Dualtec Generation (i.e., 5 cm) because of its long length. A pendulum is added to the hammer to make the impacts easily repeatable (i.e., position, orientation and energy). Because of the support, the foot section cannot be measured. Furthermore, because the on-snow vibration energy of the tail is only 20% of the vibration energy of the tip [11], this study only focuses on the front part of the ski. The range of the accelerometer and hammer used are of respectively ±500 g (recorded peak values up to 200 g) and 0 to 445 N. The program used to compute the FRFs with a H1 estimator was custom made using MATLAB. For all tests, the acquisition frequency was set to 5000 Hz and the sample length to 500 ms except for the Rossignol Dualtec Generation 210 (i.e., 8000 Hz, 250 ms). Results are presented up to 250 Hz to include all the modes up to the 4th bending mode in most cases [9], and the same color scale calculated in dB ($10\log_{10}$, ref: 1 g/N) is used on all the maps presented to facilitate their comparison. FRF coherence was above 0.95 for all the measurements considered.

The influence of the main test parameters was explored to evaluate the test sensitivity of the boundary conditions and excitation. Variation in the excitation force (133, 178 and 222 N) showed no change in the results as expected while variation in the clamping force (50, 110 and 200 N) showed differences in damping between 50 and 110 N. For this reason, a 110 N clamping force was kept for all tests as it was the minimum required force to prevent rattling at the supports. The spacing of the cylindrical supports affected the vibration response of the ski (20, 25 and 30 cm), and a shorter spacing allowed bigger amplitude of vibration in the 1st torsion mode (60 Hz) and in the mixed bending-torsion mode (190 Hz). Even though bindings and binding plates have an influence on the dynamic behavior of skis [10], this study limits itself to a 25 cm spacing of cylindrical supports for all tests because it best represents the spacing in binding plate screws and the on-snow dynamic behavior as shown in [10]. Detailed results for the influence of main test parameters are illustrated in the supplementary materials.

Three groups of tests were conducted. Firstly, two groups of three skis with different stiffness were tested to observe the effect of stiffness on the dynamic behavior. Secondly, identical skis (i.e., geometry and stiffnesses) constructed with different materials are tested to compare construction effect on damping. Thirdly, five commercially available devices are tested. Two of them, the FloShocks [16] and the Hero Helper [17] are sold to be installed on any ski and are thus evaluated on the same ski (i.e., a custom-built all-mountain ski 177 cm long, 94 mm waist, 1561 g, EI = 329 Nm^2 and GJ = 212 Nm^2). For all skis, stiffnesses are measured as in [18] and are expressed as the maximum values along the ski length. The three other devices, the Völkl UVO [6], the Rossignol VAS [19], and the Atomic Doubledeck [20] are evaluated directly on the ski onto which they are sold. Figure 2 shows the 5 ski damping devices tested in this study.

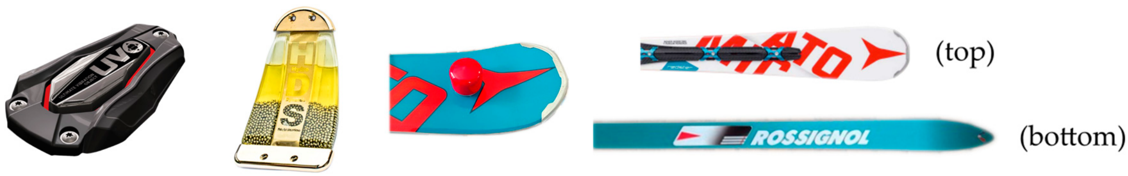

Figure 2. Ski damping devices from left to right: Völkl UVO [6], FloShocks [16], Hero Helper [17], Atomic Doubledeck [20] (**top**) and Rossignol VAS [19] (**bottom**).

3. Results and Discussion

3.1. Effect of Ski Stiffness and Mass on Damping

Figure 3 shows the mean of the forebody FRFs of three skis constructed with different bending stiffnesses but comparable torsional stiffnesses (235 ± 23 Nm^2) and of three skis with different torsional stiffnesses but comparable bending stiffnesses (323 ± 10 Nm^2). The test showed that increasing bending stiffness adds no damping but shifts the frequencies of the bending modes towards higher frequencies. It is important to note that increasing the bending stiffness also increases the tip pressure on snow. The tip would then require a higher force to break free and start vibrating.

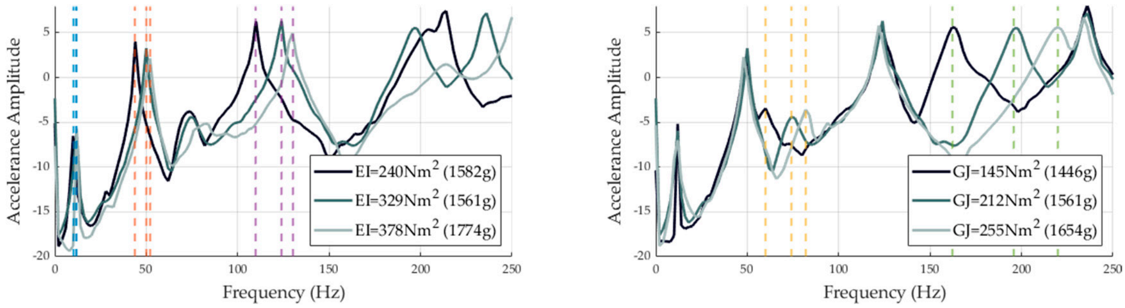

Figure 3. Mean accelerance frequency response function (FRF) of custom skis with varying: (**left**) bending stiffness; (**right**) torsional stiffness.

The test also showed that varying torsional stiffness does not affect the bending modes but shifted the 1st torsion mode and the mixed flexion-torsion mode towards higher frequencies with limited effect on the damping (see supplementary data for detailed results).

The effect of adding mass on a ski is demonstrated in Section 3.3 on the Völkl Racetiger.

3.2. Effect of Construction Materials on Damping

Two geometrically identical skis made with different materials but with comparable mass and stiffness were also compared. One ski was made with a laminate that includes only fiberglass (1654 g, EI = 313 Nm^2, GJ = 255 Nm^2) while the other had both *Titanal* and fiberglass (1710 g, EI = 306 Nm^2, GJ = 264 Nm^2). Both skis showed approximately the same damping in the 0 to 250 Hz spectrum (see supplementary data for detailed results).

3.3. Ski Damping Devices

Figure 4 shows the accelerance maps of a custom ski (1561 g, EI = 329 Nm^2 and GJ = 212 Nm^2) without any device added, with the Hero Helper and with the FloShocks. The Hero Helper weights 68 g and is installed 0.8 m in front of the ski boot center mark. This particle-damper filled will lead powder and steel marbles lightly damps the 3rd bending mode represented by a yellow vertical line with 2 nodes at 120 Hz. Damping is represented by the width of the yellow peak for each mode.

The FloShocks is a liquid filled particle-damper with steel marbles; it weights 281 g and damps bending and torsion modes at frequencies higher than 60 Hz. The 1st torsion mode at 70 Hz is damped to the point where it is difficult to identify on the accelerance map. The 3rd and the 4th bending modes at 120 Hz and 240 Hz, as well as the mixed bending-torsion mode around 200 Hz, are also damped. All modes are shifted to lower frequencies due to the significant added weight.

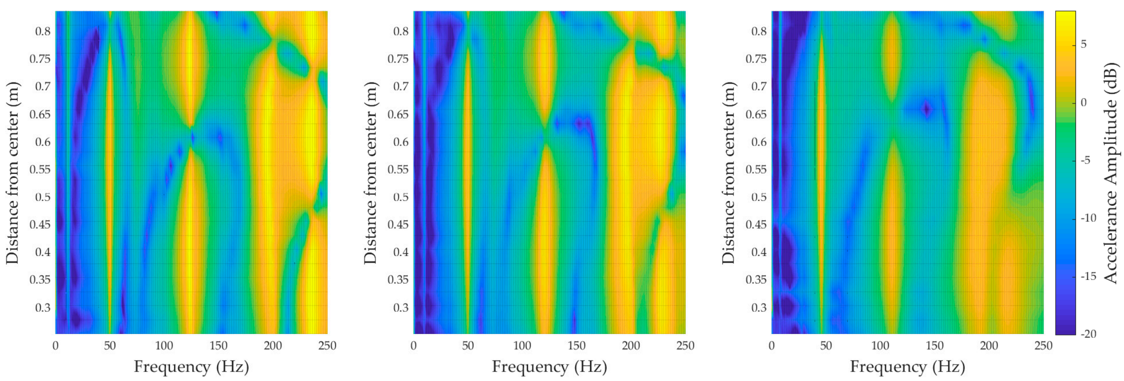

Figure 4. Accelerance maps of a custom ski: (**left**) without any device; (**center**) with the Hero Helper; (**right**) with the FloShocks.

Figure 5 shows the accelerance maps of a Völkl Racetiger 170 cm 2016 ski (2065 g, EI = 429 Nm², GJ = 225 Nm²) with the UVO (i.e., a tuned mass damper) removed from the ski, with the UVO deactivated by a piece of tape blocking its motion and with the UVO activated.

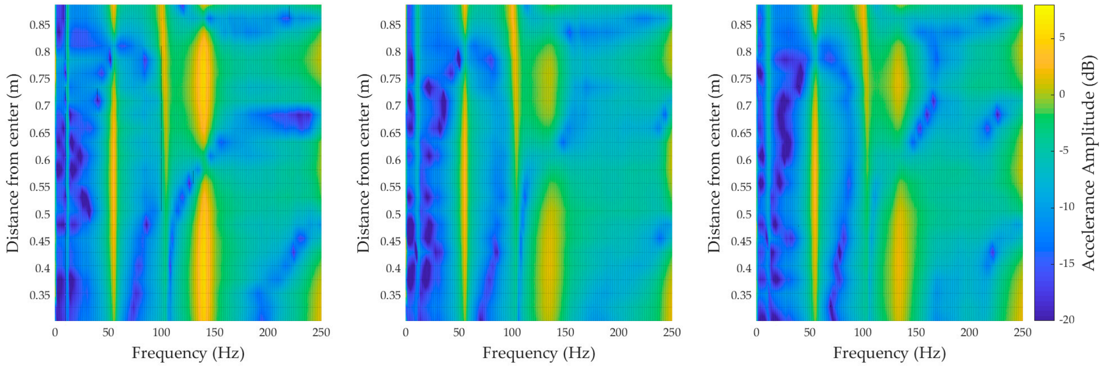

Figure 5. Accelerance maps of a Völkl Racetiger: (**left**) without; (**center**) deactivated; (**right**) UVO activated.

These results show little difference between the activated and deactivated devices but show a significant reduction in damping of the 3rd bending mode at 140 Hz when removed. This suggests that the UVO improves the dynamic response through its added mass (77 g) and not through the motion of the damper. The UVO has little effect on the 2nd bending mode (50 Hz) as it is installed at one of its nodes (i.e., 0.8 m).

Figure 6 shows the accelerance maps for a Rossignol Dualtec Generation 210 cm ski (3070 g, EI = 1320 Nm², GJ = 586 Nm²) with and without the VAS technology (i.e., constrained layer [21]). The two VAS devices totaling 53 g are placed at 0.46 m and 0.93 m from the ski center to align with the peaks of the 3rd bending mode (104 Hz). The first torsion mode (116 Hz) is superposed with the 3rd bending mode so we cannot clearly see the impact of the VAS on torsion modes. The effect of the VAS is negligible on the dynamic behavior of the ski.

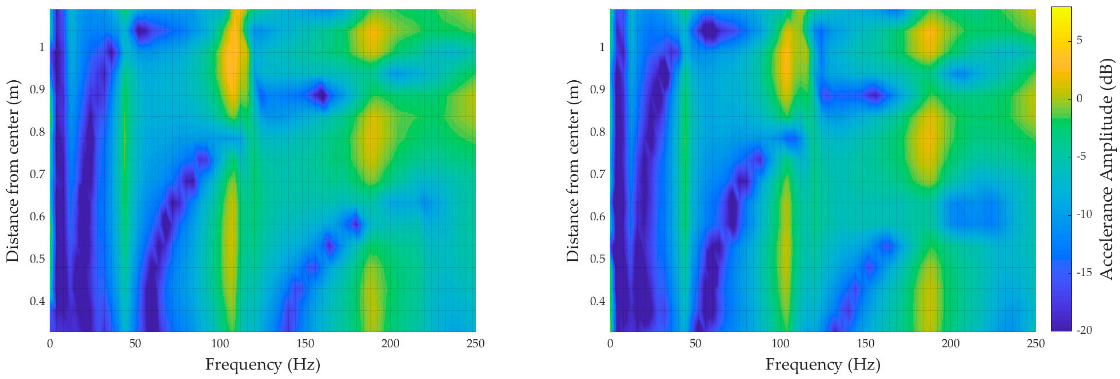

Figure 6. Accelerance maps of a Rossignol Dualtec Generation 210: (**left**) without VAS; (**right**) with VAS.

Figure 7 shows the accelerance maps for an Atomic Redster 193 cm ski (2285 g, EI = 941 Nm², GJ = 296 Nm²) with and without the Doubledeck. This 220 g device is made of 3 viscoelastic bushings compressed by a rail installed on the topsheet. It adds negligible rigidity (0.5% difference in bending (EI) and 3.5% in torsion (GJ), which is within the measurement machine's error). The bushings are located at 0.33 m, 0.53 m and 0.73 m from the ski center and align with peaks of the 3rd and 4th bending modes at 112 and 200 Hz respectively. The 3rd bending mode is the only mode damped by the device. The first torsion mode (104 Hz) is superposed with the 3rd bending mode so we cannot clearly see the impact of the Doubledeck on torsion modes.

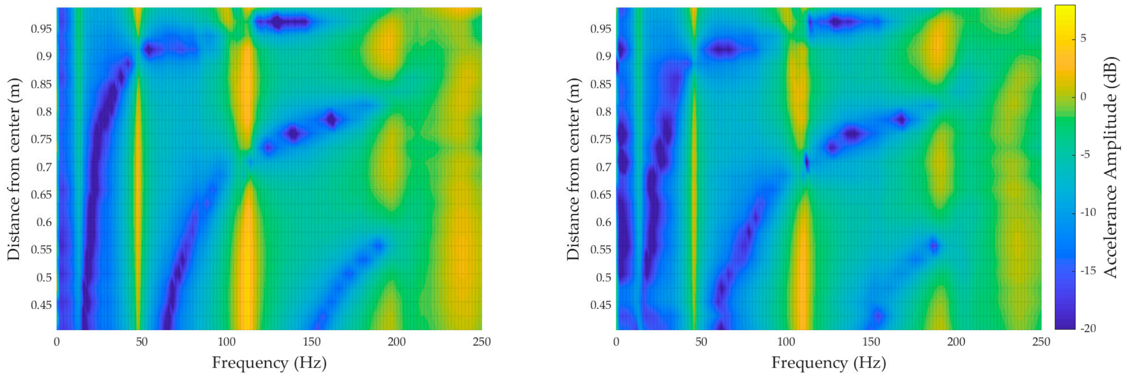

Figure 7. Accelerance maps of an Atomic Redster: (**left**) without the Doubledeck; (**right**) with the Doubledeck.

4. Conclusions

The aim of this study was to evaluate the performance of current commercially available damping technologies using accelerance maps. The effect of the variation of stiffness was explored. The results show that increase stiffness adds no damping but shifts the resonant frequencies of the modes towards higher frequencies. Moreover, the results showed that substituting fiberglass with *Titanal,* for the same mass and stiffnesses, has no effect on ski damping. Five commercially available ski damping devices were also evaluated. Most devices, beside the FloShocks, show limited damping when observing the accelerance maps. Even if changes in the vibratory response were measured, these changes seem to emanate solely from the added mass of each device. Further studies will focus on understanding the correlation between the accelerance maps obtained in the laboratory and the on-snow sensations felt by the skiers.

Supplementary Materials: The detailed results omitted in this work and the pictures of the skis and devices studied are available online at http://tiny.cc/4bq7fz.

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