

Effect of Bass Bar Tension on Modal Parameters of a Violin's Top Plate

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Experimental modal analysis of a violin with three different tensions of a bass bar has been performed. The bass bar tension is the only intentionally introduced modification of the instrument. The aim of the study was to find differences and similarities between top plate modal parameters determined by a bass bar perfectly fitting the shape of the top plate, the bass bar with a tension usually applied by luthiers (normal), and the tension higher than the normal value. In the modal analysis four signature modes are taken into account. Bass bar tension does not change the sequence of mode shapes. Changes in modal damping are insignificant. An increase in bass bar tension causes an increase in modal frequencies A0 and B(1+) and does not change the frequencies of modes CBR and B(1–).

Keywords: violins, modal analysis, bass bar tension.

1. Introduction

A bass bar and a soundpost are two “hidden” elements of a violin, making it an asymmetric construction. The bass bar is a wooden reinforcing bow, usually made of spruce, parallel to the long axis of symmetry of the violin's body and mounted near the left foot of the bridge (as seen from the position of the player). Near the right foot the soundpost leads from the top plate to the back plate. The bass bar and the soundpost serve structural and acoustical purposes (CREMER, 1984). Their structural function is to support the top plate against the downward pressure of the strings and bridge and to spread out this load by the bass bar over the top plate and by the soundpost to the back plate. Without the bar, the top plate would eventually sag and collapse. Acoustically, the bass bar leads to in-phase excitation of the largest possible area of the top plate. The soundpost, along with ribs and the air volume, transmits vibration of the bridge to the back plate (CREMER, 1984). Over time the bass bar loses its tension, the instrument no longer responds correctly to lower notes and the top plate becomes de-

formed. The bass bar, as well as the soundpost and the bridge, are parts which should be periodically replaced in the playing instrument.

The dynamic behaviour of violins can be investigated by experimental and computational methods. Among those former very popular is modal testing. A first detailed modal analysis of a violin has been performed by Marshall (MARSHALL, 1985). Then, many other researchers applied the experimental modal technique to string instruments (BISSINGER, KEIFER, 2003; BISSINGER, 2003; 2008; SKRODZKA *et al.*, 2009; 2013). A few reports have been published on the effect of structural modifications on vibrational behaviour of violins (SKRODZKA *et al.*, 2009; 2013; WEINREICH *et al.*, 2000; MEINEL, 1937). There are many papers on the modal analysis of violins, two on the action of the soundpost (SALDNER *et al.*, 1996; BISSINGER, 1995) and none about the effect of bass bar tension on modal behaviour of the top plate.

The aim of the present work is to show differences (if any) in natural vibrations of the top plate of the violin with intentionally introduced differences in bass bar tension. To the best of the authors' knowledge, this

paper is the first attempt to describe changes in the top plate natural vibrations caused by applying bass bar of different tensions.

2. Experiment

2.1. Violin

A copy of the “Dickson-Poynder” violin of Antonio Stradivari (1703) is made by a professional luthier. The top plate is made of spruce and consists of two glued parts. The back plate is made of maple and is also glued of two parts. The violin’s sizes are listed in Table 1. The only intentionally introduced difference is the tension of the bass bar. The term “tension”, expressed in millimetres, is used in the paper in the meaning popular among luthiers, i.e. as the tension necessary to adjoin the ends of the free bass bar to the top plate when the gap between the bass bar ends and the plate is non-zero for the non-tension condition. Three configurations of the bass bar tension are investigated: with no tension (the free ends bass bar perfectly fitting the shape of the top plate), with the “normal” tension of 1.5 mm (the space between the ends of the bass bar and top plate is 1.5 mm when no force is applied to the bass bar), and with the “high” tension of 3 mm. The “normal” tension is chosen as a standard in violin making. Sometimes luthiers decide to apply a tension differing from the standard one, and so do we. The theory of the bass bar action can be found in handbooks (CREMER, 1984; FLETCHER, ROSSING, 2010). Bass bars with a different tension are applied to one violin, which means that the instrument is opened for the bass bar mounting and then reassembled. This procedure may have some influence on the results. However, the procedure introduces a smaller error than constructing

three separate instruments for three bass bars investigated.

The instrument is equipped with the Thomastik Dominant set of strings and tuned to the playing condition. Their strings are damped during the modal testing.

2.2. Modal analysis experiment

Modal analysis is an experimental method of studying the dynamic behaviour of structures (EWINS, 1995). The method describes the dynamics of any vibrating system in terms of modal parameters: natural frequencies, natural damping, and mode shapes. As the measurement setup and measuring technique are similar to that described in our previous works (SKRODZKA *et al.*, 2005; 2011; 2013; SKRODZKA, SĘK, 1998), only the most crucial details are given below. The instrument is excited by an impact hammer to provide a broad-band excitation (PCB Impact Hammer 086C05). The response signal is measured at a fixed measuring point marked as a black dot in Fig. 1. An ONO SOKKI NP-2910 accelerometer with a mass of 2 g is used to record the response signal. Both the excitation and the response signals are measured perpendicularly to the top plate, i.e. in the most important direction with regard to the vibration of the instrument. The accelerometer is mounted on beeswax. On the basis of these signals, the frequency response functions (FRFs) are calculated between all excitation points and the fixed response point. Modal parameters extracted from FRFs are calculated by means of the SMS STAR-Modal® package. The FRFs are measured at 244 points on the front plate. Geometry of the measuring mesh is shown in Fig. 1. All FRFs are measured in the frequency range of 0–2000 Hz with 2 Hz spectral resolution, and their quality is controlled by

Table 1. Violin sizes (mm).

	Front plate	Back plate
Body length	356	356
Maximum width in the upper bout	167	167
Width at the waist (arch)	113	113
Maximum width in the lower bout	206	206
Maximum height of the arch	16	15.5
Thickness in the centre	3.3	4.5
Thickness in the upper bout	2.6	2.6
Thickness in the lower bout	2.7	2.7
Ribs height	29.5–30.5	
Bass bar length	270	
Maximum bass bar height	13.5	
Bass bar width	3–6	

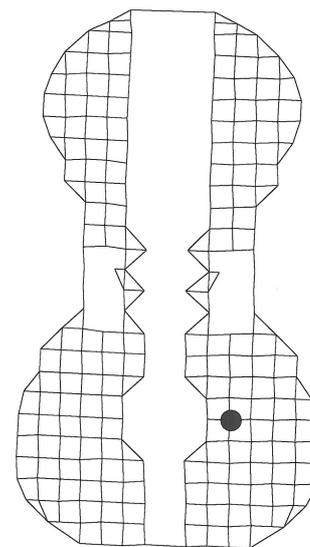


Fig. 1. Geometry of the modal analysis measuring mesh. The black dot denotes the position of the accelerometer.

the coherence function. Ten spectral averages are used to improve signal-to-noise ratio in FRFs.

2.3. Force vs. deflection for the bass bar

To describe the tension of the bass bar, additional measurements are performed to establish a relation between the force necessary to close the gap between the bass bar ends and the top plate. The measurements are performed using a digital force gauge Sauter FH 500 with the 0.1 N resolution, mounted in the tripod Sauter TVL with a digital length meter of 0.01 mm accuracy. Force is changed with a step of 1 N. The results are shown in Fig. 2. For the deflection of 0 mm, the force value is 0 N. For the deflection of 1.5 mm, the force value of 10.5 N is necessary. For the deflection of 3 mm, the force value is 21.3 N. The mentioned above three deflection-force results are marked as black dots in Fig. 2. As resolutions of deflection and force measurements are very small, standard deviations are not visible in Fig. 2. The relation between the force value and the bass bar deflection is proportional, in the measured force range.

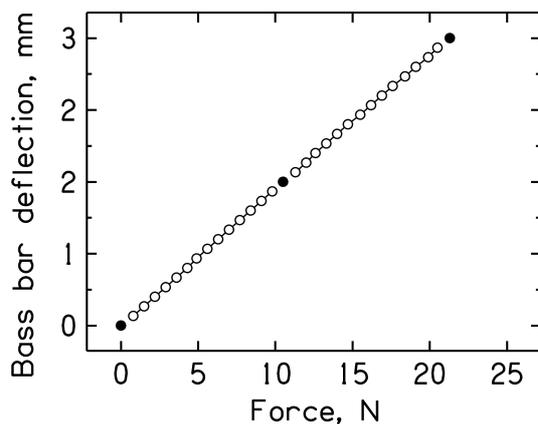


Fig. 2. Relation between the bass bar deflection and applied force.

3. Modal analysis results

The frequency range of the analysis is limited to 700 Hz, as in this range the most important signature modes A0, CBR, B(1−) and B(1+) of the top plate occur (BISSINGER, 2008). The frequencies of these modes fall into the first Dünwald frequency band (190–650 Hz) and are responsible for the sound “richness” (DÜNWALD, 1999; FRITZ *et al.*, 2007). A0 is the Helmholtz resonance (“air mode”). The CBR mode is the lowest frequency corpus mode with a single nodal line along the instrument and two nodal lines perpendicular to the longitudinal one, crossing the upper and the lower bout. Two subsequent modes, B(1−) and B(1+) are “plate modes” which arise from the bending and stretching of the front plate or, in other words,

they are a superposition of the breathing and body bending modes (ROSSING, 2007). For the top plate, the mode shape B(1−) has two longitudinal nodal curves placed almost symmetrically on both sides of the main axis of symmetry. Mode B(1+) on the top plate has two nodal curves crossing the upper and the lower bouts. Modes A0, B(1−), and B(1+) are the so-called out-of-plane modes, with vibrations mainly perpendicular to the hypothetical plane of the violin (SKRODZKA *et al.*, 2013). They are strongly radiating modes and they are crucial for the violin sound (BISSINGER, 2008). Table 2 gives the mode shapes, modal frequencies (f) and percentage of the critical damping (d) for the above modes for three bass bar tensions under investigation. The main assumption of the modal analysis is linearity of the system under investigation. Strictly speaking, no violin is a linear system but it can be treated as such when critical damping is smaller than 10% (EWINS, 1995; SKRODZKA *et al.*, 2009; 2013). All modes shown in Table 2 have the damping lower than 10%.

4. Discussion

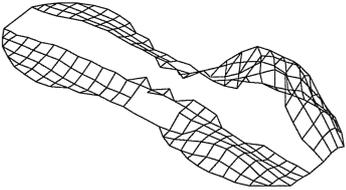
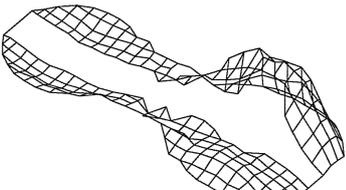
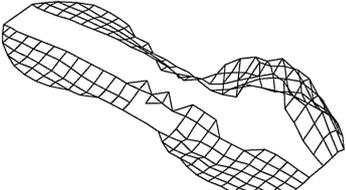
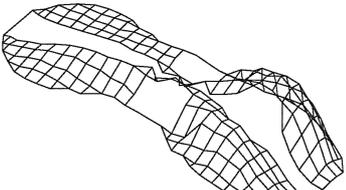
For all three bass bar tensions the mode shapes, their sequence and modal damping of the modes under consideration are similar to those described in earlier papers (MARSHALL, 1985; BISSINGER, 2008; SKRODZKA *et al.*, 2009; 2013). Some differences in the modal frequencies are found for modes A0 and B(1+), Table 2 and Fig. 3.

The frequencies of modes A0 and B(1+) systematically increase with increasing the bass bar tension, as the bass bar experiences bending in these modes. For mode A0 the modal frequency is 297 Hz for the bass bar without tension, 310 Hz for the bass bar tension of 1.5 mm, and 337 Hz for the bass bar tension of 3 mm. For mode B(1+) the frequency growth is from 671 Hz for the bass bar without tension to 681 Hz and 687 Hz for the tensions of 1.5 mm and 3 mm, respectively. The modal frequencies CBR and B(1−) are not influenced by the bass bar tension, as the bass bar experiences torsion rather than bending in these modes.

The modal damping is not constant and slightly changes for modes and bass bar tensions under investigation (Table 2) but this fact does not influence the violin’s quality, as the damping trends are not robust quality discriminators (BISSINGER, 2008).

The modal frequencies A0 and B(1+) are especially important for the violin sound quality. In particular, the frequency of mode B(1+) acts as a “barometer” of the violin’s sound. When the frequency of mode B(1+) is lower than 510 Hz the instrument is “soft” and its sound is dark. The instrument with B(1+) frequency higher than 550 Hz is ‘resistant’ to the player, with bright sound with a tendency to harshness (BISSINGER, 2008; FRITZ *et al.*, 2007; SCHLESKE, 2002). The frequencies of modes A0 and B(1+) found in our exper-

Table 2. Modal parameters for top plate modes A0, CBR, B(1-) and B(1+).

Mode shape	Bass bar deflection [mm]					
	0		1.5		3	
	<i>f</i> [Hz]	<i>d</i> [%]	<i>f</i> [Hz]	<i>d</i> [%]	<i>f</i> [Hz]	<i>d</i> [%]
A0 	297	8.1	310	8.2	337	8.0
CBR 	483	3.3	483	2.8	485	2.6
B(1-) 	590	5.7	586	5.9	592	3.0
B(1+) 	671	5.0	681	4.3	687	4.6

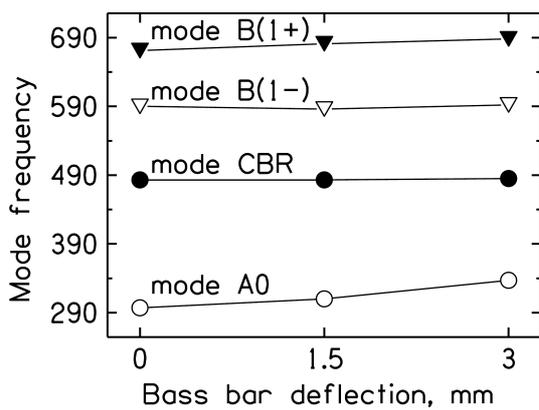


Fig. 3. Relation between the modal frequency and bass bar deflection, for modes A0, CBR, B(1-) and B(1+).

iment for all three conditions are significantly higher than those reported in the literature (MARSHALL, 1985;

BISSINGER, 2008; FRITZ *et al.*, 2007). It does not necessarily mean that our violin with any bass bar tested is a “bad” instrument, as it is known that signature mode frequencies are not robust quality indicators (BISSINGER, 2008).

The most important observation from our experiment is that the bass bar tension influences the two most important modal frequencies A0 and B(1+). The relation between the force necessary to adjoin bass bar ends to the top plate is proportional (in the range measured) to the gap between bass bar ends and the top plate surface. The increase in the bass bar tension causes an increase in the modal frequencies A0 and B(1+) but this relation is not proportional. However, bass bar tension seems to be a useful tool for tuning frequencies of the most important radiating modes A0 and B(1+).

Two additional remarks should be made: first, only one instrument with three bass bar tensions is inves-

tigated. This number is obviously not appropriate for any statistical considerations. Nonetheless, similar situations, when only a few instruments are investigated trying to formulate general conclusions, can be found in some reports (MARSHALL, 1985; WEINREICH *et al.*, 2000; SALDNER *et al.*, 1996; BISSINGER, 1995; 2006; RUNNEMALM *et al.*, 2000). Secondly, our investigation is carried out for a just mounted bass bar. Its ageing may induce important changes in the modal frequencies and may influence the sound of the instrument.

5. Conclusions

The experimental modal analysis of the violin equipped with the bass bar with three different tensions has shown some differences and similarities in the modal parameters. Hence, we conclude that:

- Increasing the bass bar tension causes an increase in the top plate modal frequencies of two important radiating modes A0 and B(1+). The increase in frequency is not strictly proportional to the bass bar tension. The bass bar tension is expressed as a gap in millimetres between the bass bar ends and the top plate in non-tension condition, and in our experiment it is 0–3 mm.
- Increasing bass bar tension does not change the top plate modal frequencies CBR and B(1–).
- The relation between the force value and deflection of the bass bar is proportional in the measured force range.

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