OPERATING DEFLECTION MODES IN FIVE CONVENTIONAL AND TWO UNCONVENTIONAL VIOLINS

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ABSTRACT

Operating deflecting modes in seven violins were studied using TV-holography and acceleration measurements. Two violins had a special inner support system. Mode shapes, vibration phase, -frequencies, levels and Q-values were recorded for frequencies below ~1,5kHz. Generally corresponding modes of the violins looked similar, though differences were seen, especially in the vibration phase. Combinations between modes were observed as the rule. The vibration levels was lower on the special violins up to around 600Hz, from then on they were comparable to the normal violins. The Q-values for the two special violins were slightly higher than for the other violins.

1. INTRODUCTION

The dynamic response of violin bodies plays an important role in the sound production, the playability and the instrument quality [1,2]. The analysis of modes also gives meaningful information in the process of making and modeling instruments [3,4]. The violin has been studied by scientists and makers in at least 250 years.

Two of the violins studied here are versions of a violin developed in Norway [5]. Basically it is a version of the "Chrotta", where the right foot of the bridge rest directly on the sound-post which is not in contact with the top plate [7,8]. Such instruments sound like violins, but how do they acoustically compare to a normal violin?

In this study we have used acceleration a(ω) over force F(ω) measurements and TV-holography for visualization of vibration shapes, levels and Q-factors in seven violins as seen in Table 1. We also have seeked answers if anything can be said about the connection between acoustical measures and instrument quality.

Violin	Builder and some information	Quality
V1	An unvarnished violin made by the author	Bad
V2	Joseph Baldantoni, Germany, 1834	Fair
V3	Violin tonally rebuild by Buen senior, 1965	Good
V4	French violin tonally rebuild by Buen senior	Concert
V5	Gaetano Guadagnini (II), Italy, ca 1800	Concert
V6	Mikal Hagetrø no 39, 1993	Fair
V7	Mikal Hagetrø, unvarnished plywood, 1994	Fair

Table 1: *The studied violins.*

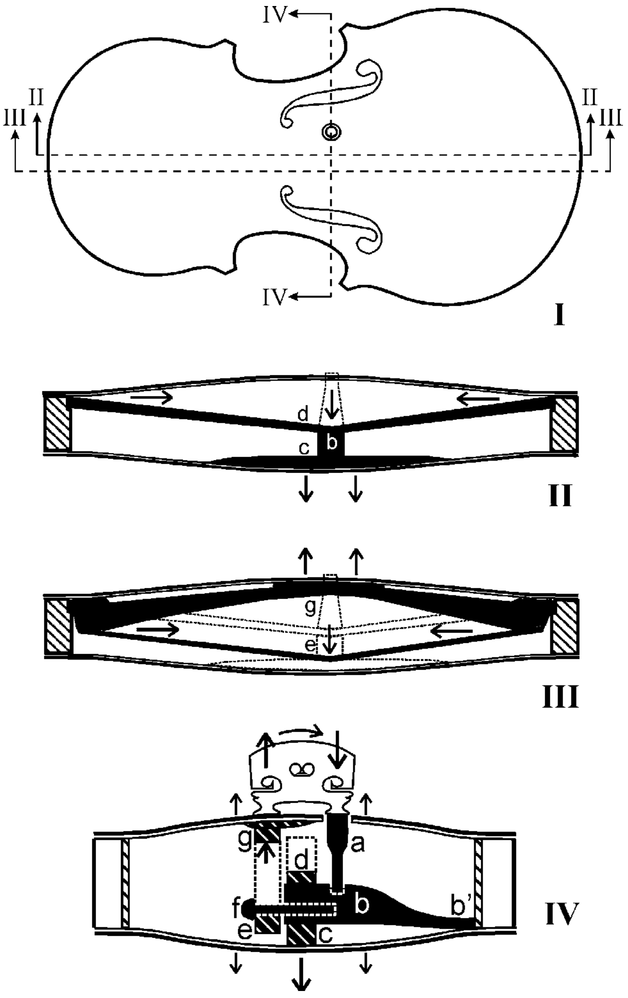

Figure 1: *The principle for the inner support system of special violins V6 and V7. Pressing down the sound post (a) causes the cross member (b) – fastened at (b') – to bend down (see IV). This forces the longitudinal member (c) and the back plate down, while the support (d), the wooden pin (f), and chord (e) follow (see II and III). The lowering of (e) pulls the neck and the tailpiece blocks together, which causes the trestle (g) to bend up. An expansion of the body has been achieved. Pressing down the bridge on the reverse side gives the reverse effect. Most of the string tension is taken up by the support (d) while (a), (b), (f), (e) and (g) counteract the vertical component, leaving both plates virtually unchanged. [6]*

1.1 The investigated violins

The investigated instruments were given quality ranking by a professional player as summarized in Table 1. Quality was judged like this (best violin first): V5, V4, V3, V2, V6, V7 and V1. V1 had rather thick plates, ~4mm in the top and ~6mm in the back, and it was unvarnished. V2 to V5 were normal varnished violins while special designs, V6 and V7, had the special inner support system as seen in Figure 1. The bar system was designed for a "breathing" motion of the violin body and it took up much of the string tension.

The plywood instrument, V7, had plates made of three crossed layers of spruce for the top and maple for the back. The laminating process with glue and arching of the plates was made simultaneously by cold pressing in a mould. The plate thickness were as low as 1,5-2mm or even thinner in some places, i.e. close to the thinnest areas in the conventional instruments made. V7 was not varnished.

2. THE MEASUREMENT METHODES

2.1 Transfer inertance

The acoustical measurements were made with a set up as seen in Figure 2. The violin was supported in a rig simulating holding for playing. The acceleration signal a(ω) was picked up behind the left bridge foot. The violin was driven by a light impulse hammer hitting the upper left bridge side. The excitation force F(ω) during the impulses was recorded so the transfer inertance curve a(ω)/F(ω) [g^{-1}] could be calculated and presented by a dual channel FFT analyzer.

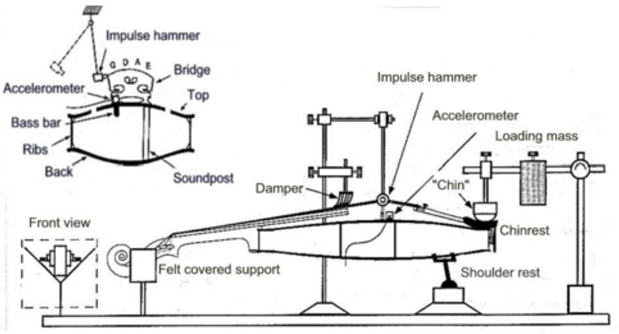

Figure 2: *The inertance measurement system. An impulse hammer hit the left bridge side and a tiny (< 1g) accelerometer picked up the vibrations just behind the left bridge foot.*

2.2 TV Holography

The optical measurements were made with the violin supported as seen in Figure 3. The static deflection of the foam rubber just to the left of the tailpiece was 4mm. Because of this soft vibration isolator it was expected that the measured modal frequencies was disturbed less than about 1Hz. At the same time the violin settled enough for the sensitive holography measurements to be accomplished. An angled mirror made the back side of the instrument visible to the TV-holography system. Details about the holography instrument can be found in [9].

The varnished violins were covered with talcum to increase the reflectivity and diffused possible glaring spots from the laser light. Excitation was a sinusoidal signal fed through a light piezoelectric disc (m<1g), a "buzzer", waxed to the top just behind the left bridge foot. The excitation was normal to the top plate.

The recording of the operating deflection modes was fully automated and typically made within a minute, depending on the wanted resolution and repetitions.

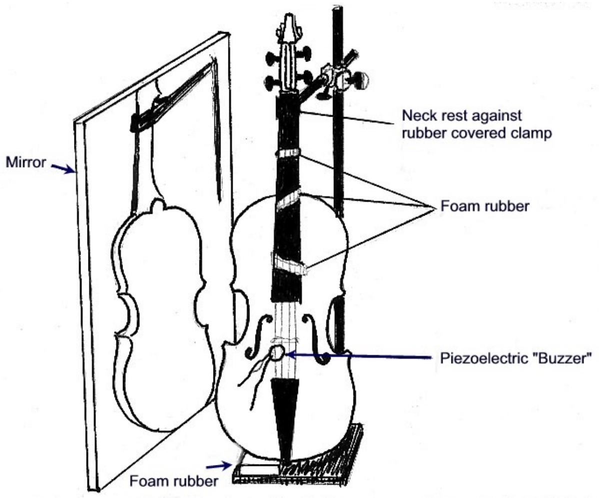

Figure 3: *The violin setup for TV-holography measurements.*

3. RESULTS

3.1 Transfer inertance

Figure 4 show the inertance curves of the best three violins, V3 to V5. They all have the high resonance level and width around 550Hz (the C3 mode, see Figure 9) typical of better violins [2]. The frequency region under about 600Hz is quite similar. In the old Italian, V5, the C3-resonance give significant response over a frequency width of about 170Hz. That is about five to six musical semitones. The C3 cover more than 10% of the played fundamentals and first harmonics in the best three violins. About 48% of played fundamentals are below 666Hz, this region is definitely very important.

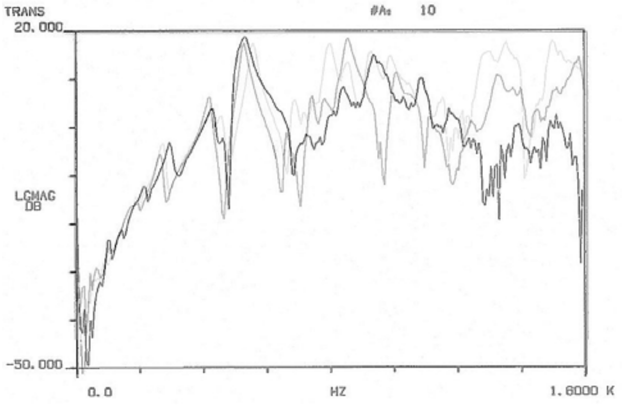

Figure 4: *Transfer inertance of the best three violins, V3 (light gray), V4 (darker) and V5 (black).*

In Figure 5 is shown the two special violins, V6 and V7, compared to the old Italian, V5. The stiffness region below 400Hz is 5-10dB weaker in the special designs. Around C3 the difference is 10-20dB. From about 600Hz the special designs are equal or higher in level.

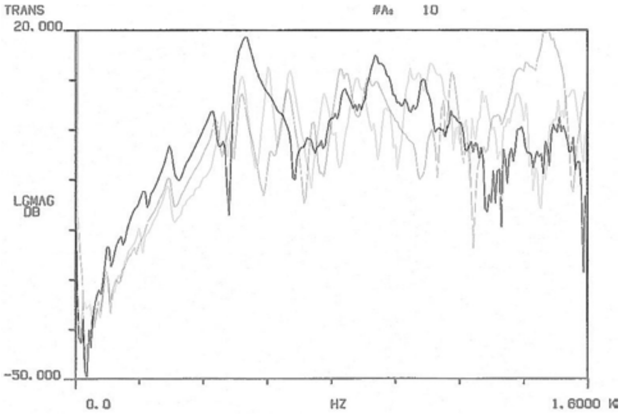

Figure 5: *Transfer inertance of V5 (black) and the special instruments, V6 and V7 (lightest gray).*

3.2 Holographic recordings

Velocity levels of modes

Figures 6 and 7 show the recorded levels of the modes in the top plates and back plates respectively. Figure 6 shows velocity levels relative to the top plate level of violin V1 at A0, the first air resonance. We see the trend that special violins are 6-10dB weaker up to about 600Hz. From 600Hz to 1kHz they are about equal. From 1-1.2kHz they are weaker again, because the modal overlap became evident. Special violins were not recorded beyond 1,2kHz.

We see that also the back plate vibrations are significantly lower in the special designs. Generally back plates are about 4dB weaker than the top plates reflecting the higher density of maple (about 25%), higher thickness (about 20%) and stiffer boundaries (no f-holes).

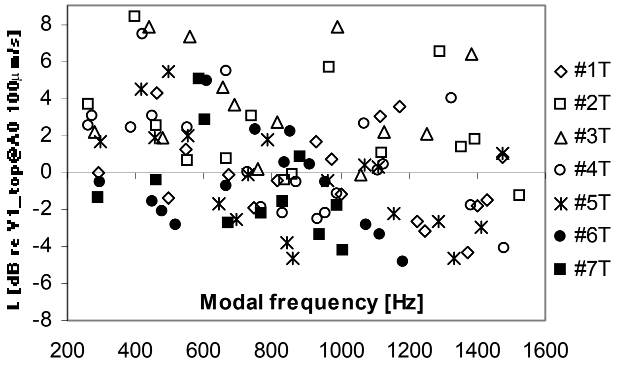

Figure 6: *Velocity levels of modes at the top plates measured with TV-holography. To compare with the inertance curves: a(ω) = ω*v(ω).*

We see from the spread of levels that the natural variation between the instruments is about 8-10dB. These differences in levels will definitely be clearly audible by playing.

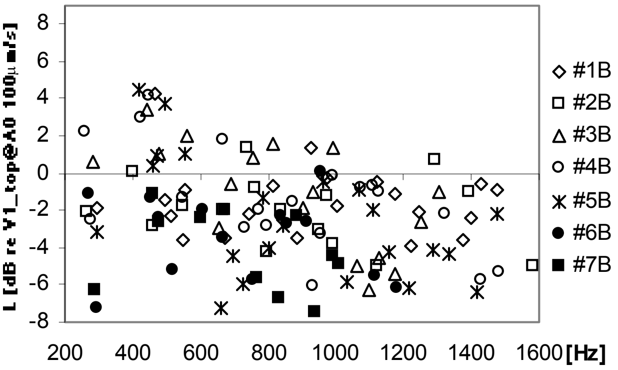

Figure 7: *Maximum velocity levels of modes at the back plates measured with TV-holography*

Q-factors

The measured Q-factors from each mode in the top plates are shown in Figure 8. We see the increasing trend with increasing frequency. Because of the thin plates and higher modal overlap in the special violins they are in the higher end. From linear regression the “Q-factor lines” follow this sequence in increasing order: V5, V3, V2, V1, V4, V7 and V6 respectively. For the back plates the sequence was: V5, V2, V6, V3, V4, V7 and V1. The unvarnished instruments, V1 and V7, seem to have higher Q-values than the varnished violins. Special designs V6 and V7 have slightly higher Q’s than the mean.

The old Italian instrument had the lowest Q-values reflecting a rather fat varnish. May be everyday use cause higher exposure to humidity and thus lower Q-values as well.

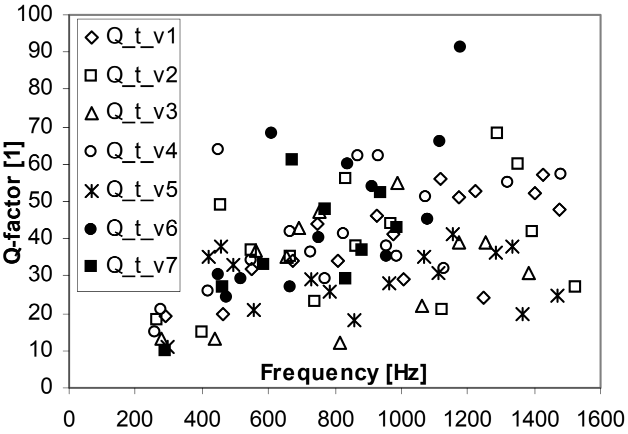

Figure 8: *Q-factors of modes measured with TV-holography*

Operational deflecting modes

Typical mode forms are shown in figure 9. They look similar to those seen in other publications [1,2]. Generally the vibrating shapes of the special violins were more complicated because of combinations of modes. Phase mappings show continuously changing phase over the structure like a shaken carpet or a flipping coin. Amplitude mappings show nodal *points* rather than nodal *lines* with areas 180° out of phase. The reason for less “clean” vibrations are probably parasitic vibrations in the inner bar structure, different boundary conditions like a cross stiffening bar and no support at the normal sound post position and thinner plates. “Clean” modes cannot be “a must” as e.g. the old Italian violin had a conglomerate of four resonances involving C2, A1 (first longitudinal cavity air resonance) and T1. The phase mappings show traveling waves typical of combinations. Because the string fundamental and harmonics seldom will be exact at a body resonance, we may expect the normal violin vibrations during playing to be combinations rather than “clean modes”.

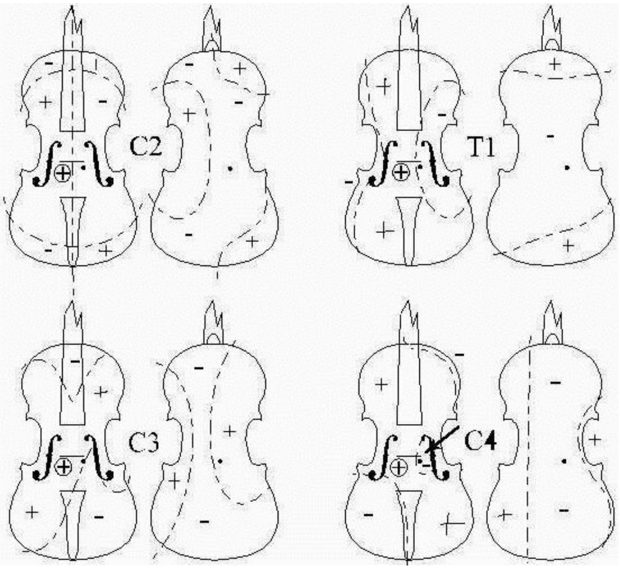

Figure 9: *Typical operating deflecting modes of violins measured with TV-holography. The arrow show a version of “the Ireland” of L Cremer in the C4 mode [8].*

The special violins had breathing C3- (~550Hz) and C4- (~670Hz) modes. The best two normal violins did show the same. Such pulsating modes should increase the sound radiation compared to plates vibrating in phase.

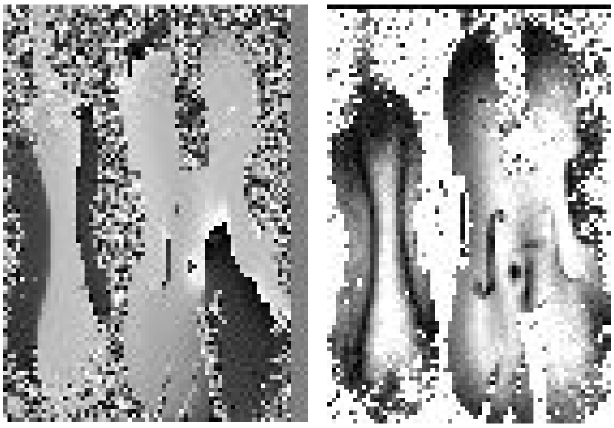

Figure 10: *Vibration phase (left) and amplitude (right) of a breathing C4 resonance in V7 at 672 Hz.*

There were similar modes seen at two or three maxima recorded in all violins indicating coupling between vibrating structures. The better instruments had stronger coupling with a larger width between the maxima, thus extending the mode over a larger frequency region. Such coupling may reduce the risk for a ”wolf” and smooth the response when fitted at high peaks. T1 was double in V3, V4 and V5. C4 was double in V3 and V5, several other higher modes as well.

The fingerboard was damped. The coupling might be with the tailpiece, although the phase mappings did not show clear vibrations here. Activity in the tailpiece should be highest between the splitted resonances. But there is a possibility that the plates themselves might give a resonance split due to mutual coupling. Possibly the right type of plate tuning may give this effect, similar observations have been found for the guitar [1].

4. CONCLUSIONS

The measurements have shown considerable differences between normal violins and special designs. Levels were 5-20dB lower for frequencies < 600Hz, vibration shapes were less “clean” and Q-factors somewhat higher in the special violins. From about 600Hz to 1kHz the levels were similar and the special design had “breathing” C3- and C4- modes equal the two best normal violins.

Later versions of the special violins sound more dark and better than the two special violins that have been tested, indicating improved low frequency response. Investigations into radiation indicate slightly higher radiation efficiency than in a normal violin [10], but also need for improvement in the “body hill” area.

More investigations should be made concerning splitted modes, higher frequencies including the “body hill”, timbre and the normal variation of levels in a larger set of instruments.

5. REFERENCES

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