On tuning of the violin bridge

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ABSTRACT

This paper reports from some technical experiments on the violin bridge with information that can be used by a violin maker. Answers were sought to three questions: Is a specific bridge resonance frequency favourable, how can this frequency be obtained, and how can it be measured in the maker's workshop? For two violins it was found that a frequency of 2.9 kHz was favourable, it could be obtained by careful tuning of the bridge and it could be measured by means of a wolfnote on a violin with an E-string only. Measurements on bridge blanks indicated that a frequency as high as 2.9 kHz can be difficult to obtain. Information directly useful for the maker are found in the section "Practical hints".

INTRODUCTION

In experiments on the high frequency properties of the violin with playing tests, differently tuned bridges have proved that the bridge is of great importance. A specific resonance frequency of the bridge was found to be optimal for the experimental violin. Therefore a detailed investigation of the bridge was initiated. We have judged that some results are of general interest and therefore we have summarized these in this short report.

The function of the violin bridge has previously been investigated and Reinicke's investigations are classic [1]. He measured and modelled two bridge resonances, in which the bridge vibrates in its own plane and transmits vibration forces from the strings to the body. The lowest resonance is in the range of 3 kHz. The collected information has been further analyzed by Cremer[2], and experiments by Mueller showed that bridges of different designs gave a ± 5 dB variation in sound pressure [3]. The sound pressure was measured in third octave bands and indicated mainly a shift in the balance between levels at high and low frequencies (lower levels at high frequencies for lower resonance frequency). Hutchins has sketched a way for bridge tuning referring to Reinicke's findings [4].

At the Physikalisch-Technische Bundesanstalt in Braunschweig a simple way to measure the resonance frequency of the "isolated bridge" was introduced [5]. Experiments with bridges and a violin at KTH gave that shifts of the "3 kHz resonant frequency" of the bridge measured in isolation influenced playing qualities. A resonance frequency of 2.9 kHz was found to be the best for the experimental violin. For the experimental violin, the resonance frequency of the bridge influenced the playing qualities more than the sound post position and the bridge height.

In the present work answers to three questions were sought: Is a specific bridge resonance frequency favourable?, if so How can this frequency be achieved?, and Can the bridge resonance frequency be measured in the maker's workshop? Only the resonance in the 3 kHz range will be investigated and will be called the "3 kHz resonance" hereafter.

THEORY

When fastened to a heavy plate the 3 kHz resonance of the "isolated bridge" can be measured (c.f. Fig. 1). The bridge resonator can be modelled as an effective vibratory mass m attached to a spring. The effective vibratory mass m_eff can be measured indirectly. First the resonance frequency f is measured. A small mass (del m) is attached to the vibrating mass and the resulting resonance frequency shift (del f) is measured. The effective vibrating mass is obtained as

$$M_eff = - Vi \times (f / \text{del } f) \times \text{del } m \qquad (1)$$

In the 3 kHz resonance the bridge mass is rather making a rotational motion than a translational and the masses should thus be exchanged for moments of inertia (1). The moment of inertia

$$J = \int r^2 \, dm = m e^2 \qquad (2)$$

where r is the distance from the rotational axis to the mass element dm. The resonance can be modelled as by Reinicke with a spring, a lever bar of length e and a lumped mass m. With the data given m = 1.77 g and e = 1.3 cm the moment of inertia becomes 3.0 x 1Q^{-7} kg m^2 (data from ref. *1* p.232). The effective moment of inertia can be measured and calculated in the same way as the effective mass. By adding a small mass an additional moment of inertia (del J) is obtained as the product of added mass and squared distance to the rotation axis. Equation 1 can be used to calculate the effective moment of inertia by replacing the m terms with J terms.

EXPERIMENTS

TEST BLOCK TO MEASURE THE BRIDGE RESONANCE IN "ISOLATION".

Earlier a simple way to measure the "3 kHz resonance" of the bridge in isolation was developed (see Fig. 1 and ref. 5). The bridge is fastened to a small block of metal. The metal block is placed on a plastic sponge or held in one hand, and

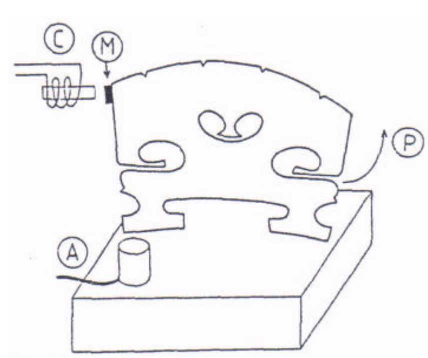

Figure 1. Sketch of bridge on test block with accelerometer A, magnet M, electric coil with iron core C and position of plucking P (screws, clamps and surfaces for fitting are not sketched).

on the metal block an accelerometer is rigidly attached. The bridge is excited by plucking or striking and the accelerometer response is analyzed by an FFT-analyser (here an HP 3562A Dynamic Signal Analyzer). Exciting by an impulse force hammer (PCS 86M37) the frequency response can be obtained in a fast and efficient way. The pluck excitation with a finger nail, c.f. Fig. 1, turned out to be easiest and most efficient to use in the experiments, especially as we mainly intended to measure the frequency of the resonance.

A special test block of a thick aluminium plate was made. Its mass (200 g) was much larger than that of a bridge *(2* g) and its resonance frequencies above the range of interest (above 10 kHz). The block was machined to coarsely fit the surface under the feet of the violin bridge and a bridge could be fastened by sealing wax. Alternatively a layer of sealing wax was applied, filed for accurate fit and the bridge was fastened by clips and screws. During the experiments it was found that a 100 g clamp also could be used. The clamp method demanded more care in fastening (clamping) at the feet but no time was lost in fitting the surface to the feet arch.

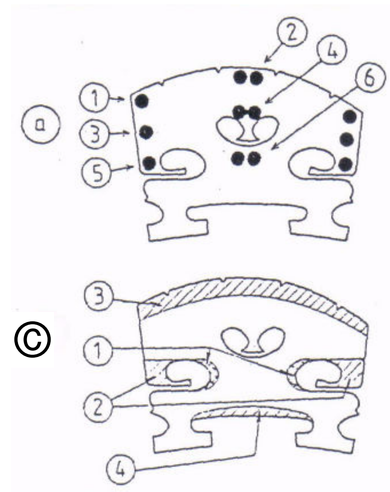

Figure 2. Sketch of violin bridge with a) positions of mass loadings, and b) positions of wood removal.

SMALL WEIGHTS ATTACHED TO THE BRIDGE.

A bridge with much wood was selected. Its resonance frequency measured in isolation (standard method with plucking) was 4.18 kHz and its mass 2.35 g. Two small masses, together 0.26 g, were attached with wax at different positions (Fig. 2a). For the central (even-numbered) positions the masses were attached close together. For the off-center (odd-numbered) positions the masses were symmetrically placed one to the left and one to the right. Measured frequency shifts of the "3 kHz peak" in response (c.f. Fig. 3a) are given in Table I.

The collected data can be used to estimate the effective vibrating mass of the bridge according to the simple mass model. A 10% frequency shift, i.e., the measured average frequency shift for the added mass of 0.26 g, gives the effective vibrating mass to 1.2 g. Table I shows, however, that the different positions of massloadings gave different frequency shifts (from -17% to -1%). These differences imply that the moment of inertia model may describe the function of the bridge more accurately.

The collected data can also be used to test the moment of inertia model (by estimating the effective moment of inertia for the different massloadings). The axis of rotation is assumed to be in position 6, c.f. Fig. 2a (the position of almost no frequency shift). The added moments of inertia are calculated using Equation 2 (the squared distance from the position of massloading to position 6 multiplied with the added mass). The added moments of inertia, the frequency shifts and Equation I give the effective moments of inertia, see Table I. The average value is 4 x 10~^{7} kg m^{2} but it varies from 2.6 to 5.8 x 10-'. The moment of inertia model clearly describes the function of the bridge more accurately than the simple mass model.

REMOVING WOOD FROM THE BRIDGE.

The bridge selected had much wood in position 1 (long distance between the holes), see Fig. 2b. Wood was filed off the bridge at four positions in steps. Bridge mass and the "3 kHz" resonance frequency were measured as before, see Table II. Much wood was removed to give clear resonance frequency shifts. The distance between the holes was initially 23 mm

Table I. Frequency shifts for the different massloadings (del m/m = 0.26/2.35), and effective moment of inertia (c.f. Fig. 2a).

position	del f/f%	moment 10-^{7} kxm^{2}	position	del f/f%	moment 10-^{7} kgxm^{2}
1	-17	4.8	2	-11	5.2
3	-13	4.4	4	-6	2.6
5	-8	5.8	6	-1	0

frequency reproducibility in measurements better than 1 %

Table II. Resulting frequency shifts from mass shifts in different positions (c.f. Fig. 2b), and different steps.

position	del f/f %			del m/m %		
	step 1	step 2	step 3	step 1	step 2	step 3
1	-10	-18	-11	-1.1	-1.9	-1.1
2	+ 1.8	+ 4.3		-2.4	-4.3	
3	+ 5.3	+ 4.0		-3.2	-2.2	
4	-2.4	-4.0		-4*	-3*	

*experimental error, the total 4 + 3 = 7% was measured, but the first step not.

and it was filed to 16.5 mm. The arch was filed from flat to' a maximum of 4 mm, and a 3 mm wide band of the bridge top was cut off.

The measurements indicate that wood removal in position 1 changes the frequency the most and decreases it (approximately -10 x del m/m). In positions 2 and 3 the frequency is increased (approximately +1 x del m/m) and in position 4 decreased (approximately -1 x del m/m). The frequency increases agree with the results of the mass loading experiments.

A SMALL MAGNET AS A GENERAL METHOD TO MEASURE BRIDGE VIBRATIONS.

A more general test method was adopted. A small magnet (0.024 g) was attached to the bridge (c.f. Fig. 1). Experimentally a frequency lowering was obtained of somewhat less than 3% with the magnet attached (which is in agreement with estimates by means of the moment of inertia model). Over a small airgap an electric coil with an iron core gives a signal proportional to the bridge vibrations. This system can be used with the bridge on rigid supports or on a violin.

BRIDGE WITH STRINGS.

A bridge to the'experimental violin EJN52 was selected. First the bridge resonance was measured in isolation with the small magnet attached. Thereafter the resonance frequency was measured with the bridge feet fixed into a rigid jigg, without and with an E-string in the A-string notch (Fig 3a). It was found that the resonance frequency was rather independent of the E-string and its tuning as long as no partial coincided with the bridge frequency (frequency shifts < 30 Hz). When a string partial and a bridge resonance coincided typical effects of coupled oscillations could be traced (two peaks instead of one). (It should be mentioned that there are other bending modes as at 750 Hz and 1400 Hz, which are suppressed by the strings. These modes were not investigated.) The same measurements were made with each of the other three strings and all four strings set on. With the lower strings and with four strings it became difficult to recognize the bridge resonance without damping the string resonances.

It was found that the bridge resonance was little shifted, i.e. within 2.61-2.59 kHz although difficult to read accurately for four damped strings.

The bridge was fastened to the experimental violin with sealing wax (the violin is not varnished) and the measurements were repeated (Fig. 3b). The "3 kHz" bridge frequency was lowered from 2.6 kHz in the rigid jigg to the range of 2.3-2.4 kHz. Thereafter strings were mounted in the same order as with the jigg and the bridge responses were measured, c.f. the response for the E-string (Fig. 3c). It was found that a clear maximum (a peak) is obtained in the 2.3-2.4 kHz range. The width of the peak was the smallest with the E-string only, larger for the G-string and the largest with all four strings (Fig. 3d). The bridge frequency is approximately the same whether the violin without strings is rigidly clamped or laid on a plastic sponge. (Note that the resonances of the violin body show in the diagrams 3b-c, and that the main wood resonance is the strongest peak of the diagrams).

TEST OF THE SUITABLE BRIDGE FREQUENCY

A final experiment on the resonance frequency of the "isolated bridge" was made. From a standard bridge blank (mass 3.26 g and resonance frequency 2.3 kHz) a bridge was shaped (2.8 g and 2.83 kHz) for a violin. In playing the violin it was judged to be normal. By removing wood along the edges (to 2.66 g and 3.03 kHz) the violin was judged to be better. Further removal of wood outside the bridge holes (the ears to 2.49 g and 3.22 kHz) the violin became stronger but with a shawnlike timbre. By adding two small masses symmetrically (together 0.28,0.54 and 1.0 g) four bridge resonance frequencies were obtained at 3.22, 2.72, 2.43 and 2.02 kHz, respectively. The masses were attached and removed and the violin was repeatedly tested by playing. Thereby it was found that the violin sounded the best with "2.7 kHz" bridge. The two frequencies 2.72 and 3.03 are in reasonable agreement supporting previously found 2.9 kHz as optimum. Bridge experiments with a "fresh" violin indicated the 2.9 kHz as valid not only for our experimental violin.

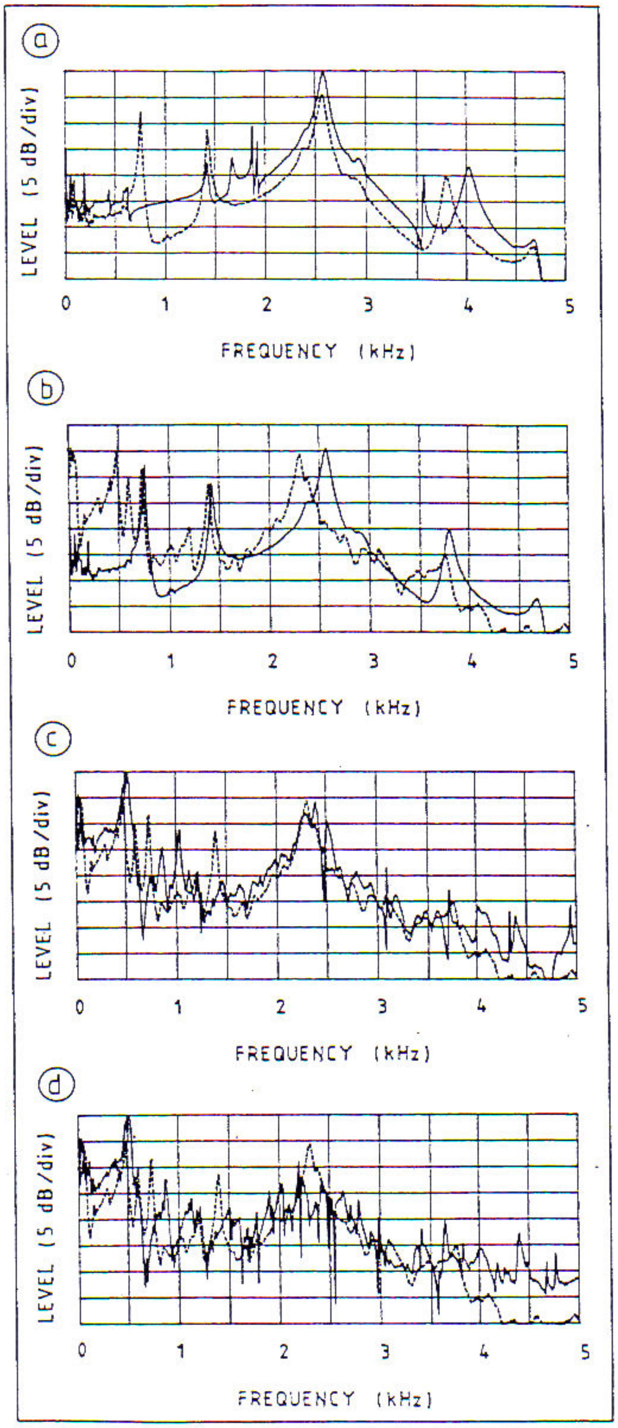

Figure 3. Frequency responses of bridge a) in jig without (dashed line) and with E-string (solid line), b) without strings and glued on violin (dashed line) and in jig (solid line), c) glued on violin without (dashed line) and with E-string, and d) glued on violin without and with four strings (solid line).

PRACTICAL HINTS

A VIOLINMAKER'S WAY TO MEASURE THE BRIDGE RESONANCE FREQUENCY ON A SPECIFIC VIOLIN

The presented results are of limited use without a practical way for the violin maker to measure the bridge resonance frequency. Therefore it was tested if a player with violin and bow could detect the bridge resonance frequency. Without help of a spectrograph it was found difficult. However, by removing all strings and resetting the E-string in the A-string notch a monochord violin was obtained (c.f. Fig. 3c). This could be played and when a partial coincided with the bridge resonance the tone became harder and stronger. With the fundamental of the played tone or its octave coinciding with the bridge resonance a strong wolf was obtained. The frequency was easily placed within plus minus a quartertone step. The method could be used by a maker in the workshop to test the importance of the tuning of the bridge. Investigations of the test indicated that when a bridge on a violin gives a clear bridge resonance, then the wolf is easily obtained (demands well-fitted bridge feet and no sliding of the bridge on the top plate). It is suggested that the interested violin maker investigate whether the described test is good for him or her.

ON TUNING OF BRIDGES

The collected data can be used for practical hints on tuning of the "3 kHz resonance". The mass model and the assumption that a 10% mass reduction in the upper part of the bridge gives a 10% frequency increase provide a simple way to estimate possible maximum frequency increases. Thinning the uppermost part of the bridge 30% (a 10 mm wide band) will increase the frequency 11.1 %. A drastic thinning of the whole upper part 30% (a 20 mm wide band) will increase the frequency 22%. By cutting away all mass outside the holes (a 4% mass shift) increases the frequency 4%. Thus it seems hardly possible to increase the frequency more than say 15% and keep the usual bridge design.

In a similar way the frequency decrease can be estimated by wood removal in the positions marked 1 and 4 in Fig. 2c and the measured frequency shifts from wood removing in these positions. Removing wood in a 1 mm band in position 4 the arch reduces the mass approximately 1.5% and the frequency is reduced 1.5% (the frequency shift is assumed to equal the mass shift). Removing 1 mm wood at the inner edges of the eyes reduces the mass approximately 1 % and thus the frequency is lowered 10%. The resonance frequency of a bridge should be easy to lower 15% by filing the inner edges of the eyes. Minor frequency lowerings are possible by removing wood from the arch.

QUALITY OF BRIDGE BLANKS

The tuning rules give measures for maximum frequency shifts from blank to a bridge. Assuming that a final frequency of 2.9 kHz is optimum, a quality measure for bridge blanks can be obtained. A set of bridge blanks was borrowed and measured, see Table III. The blanks were all of the make "Aubert" and had closely the same shape. For the two highest qualities the measurements were made more in detail.

The resonance frequencies are approximately 2.4 kHz which seems a bit low to be practical. Standard shaping of

Table III. Measures of bridge blanks.

Quality	no.	total mass		effective mass	resonance frequency		bandwidth
I	15	3.2	± 0.2g	0.96 g	2.40	± 0.08 kHz	50-60 Hz
II	10	2.9	0.3	1.02	2.42	0.06	60-80
III	6	3.3	0.1		2.41	0.12	
IV	5	2.7	0.13		2.37	0.13	

a bridge will result in a resonance frequency of 2,6 kHz, c.f. the section "test of the suitable bridge frequency". To obtain 2.9 kHz care must be taken to remove wood only in the right positions (2 and 3 in Fig. 2b). Tuning the bridge by opening the eyes towards the center should be practical as it can be done on a stringed violin. The measured blanks are not suited for such fine tunings without a very careful selection of the blank to be used. (Note that the variations in masses are considerably larger than those in resonance frequencies, which should be expected from theory as the frequency is proportional to the squareroot of the mass, c.f., Equation 1).

CONCLUSIONS

Earlier experiments gave that the tonal quality was sensitive to the frequency of a bridge resonance in the 3 kHz range, in this report called the "3 kHz resonance". For two violins investigated the frequency should be 2.9 kHz when measured "in isolation". By removing wood the frequency could easily be lowered a considerable amount but only moderately increased. Investigations of a set of bridge blanks indicated that the resonance frequency must be kept nearly as high as possible and that only small lowering adjustments are allowed. By removing all strings and resetting the E-string in the A-string notch the resonance frequency of the bridge can be determined within plus minus a quartertone step (3%). Such a method can be used in the maker's workshop to control the tuning of the bridge.

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