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On the body resonance C3 and its relation to the violin construction

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Abstract
Earlier high, soloist quality violins have been found to have a dominating resonance peak between 500 and 600 Hz in their frequency responses. This resonance peak corresponds to a mode called C3. The same resonance peak can generally be found in less good instruments, but not prominent. It can be more than 10 dB lower than in good instruments. A natural question is: How is such a dominating C3 peak obtained, by the design of the plates and the ribs or by the final adjustment with the soundpost? The answer to these questions are sought in this report. First the influence of the ribs were investigated. A small weight was laid on the top plate in different positions, the ribs were cut loose from the plates and the width of the waist between the c-bouts was shifted. Thereby it was found that the maximum shift of the C3 peak was ca 10% in frequency and ca 5 dB in level. Secondly, the influence of the thickness of the plates was investigated. First the properties were measured with the top and back slightly too thick, thereafter with the thickness reduced to normal, and finally with the back plate much too thin. The frequency of the C3 peak was changed little in all steps but the last, in which was lowered 10%. The large change here indicates an importance of plate tuning, in spite of the small changes in the other steps. The results also indicate that the C3 resonance together with another resonance act as two coupled resonances. The peak level at resonance was moderately changed, 5 dB lower with thinned plates.

Introduction
In an investigation of 25 high, soloist quality violins belonging to the Järnåker foundation of the Royal Swedish Academy of Music, it was found that a dominant resonance peak in the 500 to 600 Hz range was one of their typical features (Jansson, 1994). This resonance peak is also found in less good violins but not dominant, c.f. (Jansson & Niewczyk, 1994). The resonance mode C3 has four antinodes, one at each c-bout and one at the upper edge in center, and one at the lower edge in center (Fig. 1). The vibration patterns are the same in the top and in the back, and the vibrations of corresponding parts are in phase, i.e. the assembled violin body vibrates as a free plate. The C3 resonance stands out clearly in assembled violins with optimum driving (Alonso Moral & Jansson, 1982a). The C3 resonance has also been found in numerical experiments (finite element calculations with a doubly symmetrical violin body consisting of ribs and two similar top plates without f-holes or bass bar (c.f. Isaksson et al., 1995). The second resonances of the free top and of the free back have similar vibration patterns as the C3 mode of the assembled violin, i.e. antinodes in the c-bouts and in the center of the upper and lower edges. The corresponding resonant frequencies are much lower than the C3 one. They are approximately 150 Hz for the

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free plates compared to the 500 to 600 Hz for the assembled instrument. In the frequency range 450 to 500 Hz of the assembled violin body another resonance, $T_1$, can be found. Corresponding resonance peak is found in most violins, also less good ones. The top and the back plates form a breathing motion in mode $T_1$ (Fig. 1).

![Fig. 1. Typical vibration distributions for the $T_1$-mode (left) and the $C_3$-mode (right) as seen from outside. Lines are equivibration lines, point-dashed lines are nodal lines. Plus and minus signs mark phase.](image)

The violin has been investigated during a long time by the research group around Dr. Carleen Hutchins. In this group, the terminology $B_1+$ was introduced for the resonance corresponding to our $C_3$ and $B_1-$ for our $T_1$ (Shelleng, 1971; Marshall, 1985; Knott, 1987; Hutchins, 1989, 1990; and Bissinger, 1995). The vibration distributions are somewhat differently interpreted in our group and in the Hutchins’ group. The $B_1$- and the $B_1+$ labellings indicates two coupled modes. In a previous investigation in Sweden, it was hypothetically suggested that the soundpost is placed on a nodal line of the $C_3$ resonance (Saldner et al., 1995b). In the present report, we are interested in what properties of a violin affects the $C_3$ mode. So in conclusion we can say that the investigation was made to find answers to three questions: Is the normal position of the soundpost on top of a $C_3$ nodal line; do the $C_3$ and $T_1$ resonances work as coupled or single modes; and how do the ribs, the soundpost, the top and the back affect the $C_3$ resonance?

**Theory**

A mechanical structure such as the violin has many resonances. The resonances can be independent and act as simple single resonances. The frequency of a single simple resonance can be shifted independently of other simple resonances. When tuned to the same frequency, two simple resonances simply add together and give a single resonance peak. There are, however, also coupled resonances, i.e. resonances that can not act independently of each other (Jansson, 1974). For two coupled resonances separately tuned to the same frequency, there will still be two peaks at two separate frequencies. The coupling determines the smallest frequency difference that the two peaks can be tuned to. With such tuning, the two peaks share their properties and act differently to the two simple resonances.
Typical violin properties

A well developed method to measure violin properties is to hang the violin in rubber bands (Hutchins & Fielding, 1968). The method is simple to use, the measurements are well reproducible, and the hanging causes negligible losses. This method was initially used to determine the C3 frequency of 18 violins by hitting each violin with a small impulse hammer, PCB 86M37, at the lower end block, to record the vibrations with a small accelerometer, PCB 309A, at the same block, and to register the frequency response with a HP 3562A FFT-analysyer. Thereafter, the nodal line were sought. With the C3-resonant frequency known, the violin was laid topside down with the four supports close to the C3-nodal lines (Fig. 2). The violin was centered above a loudspeaker connected to a sinewave oscillator (Beldie, 1969; Hutchins, 1973). The back was sprinkled with particles (coloured sawdust) and the loudspeaker tone frequency was adjusted to resonance (maximum jumping of particles at antinodes). The level of the tone was adjusted so that the saw dust collected along the nodal lines. The method is a development of the classical Chladni method.

Without soundpost, the typical C3 modes were easily and clearly found. The distance between nodal lines of the C3 mode were 48 to 67 mm at the bridge (measured along a straight line between the lower corners). The typical maximum and minimum distances between the bridge feet are 15 and 40 mm, respectively (distance between inner and outer edges). Thus, the measured nodal line positions were outside the bridge feet. In addition, it was found that the maximum differences of the C3 peak level were approximately 15 dB, but the corresponding bandwidth differences were smaller (6 dB), i.e. the differences in peak level is not only set by resonance bandwidth.

With the soundpost inserted, the nodal line at the soundpost side remained outside the nearby bridge feet, but was moved slightly closer (between 18 to 28 mm from the centerline). The other nodal line was much less clear - the saw dust tended to slide off the back plate on this side (the side opposite to the soundpost). The experiment was repeated for two complete violins of soloist quality. Again only the single nodal line was found, now at 21 and 28 mm from the centerline at the soundpost side. Both violins show that the nodal line positions also were representative for good violins. Assuming that the soundpost is centered behind its nearby bridge foot, means that it is somewhat closer to the center than the nodal line. The influence of the soundpost on frequency was small, 1% frequency difference between the soundpost/no soundpost cases. A single observation should be mentioned. The soundpost had remained in a
violin for two years. When it was taken out and reset, the C3 level was 8 dB lower. This may be an effect of “playing-in”.

The hanging causes negligible losses. However, in real playing the holding of the violin causes extra losses. Measurements by hitting the bridge by the impulse hammer and recording the response by the accelerometer waxed at the other side (c.f. Fig. 3) showed that the additional losses were between 50 and 100% (6 and 12 dB), although the frequency shift was small.

Some simple experiments should be mentioned. Mode no 2 of the free violin plates have the same antinodal positions, as the C3 resonance (one in each c-bout and one in center of the upper edge and one in center of the lower edge). The nodal lines of the free top are longitudinal as for mode C3 of the assembled body, but the nodal lines of the free back plate are transversal. By crossgrain stiffening of a top plate (without f-holes and bassbar), the typical back plate mode no 2 was obtained with a frequency increase of 80 Hz.

By gluing ribs to a free top, the modal pattern of the no. 2 at 170 Hz of free top plate mode was refound at 520 in the same shape, i.e. a C3 mode. The same experiment with a back plate shifted the no. 2 mode from 185 Hz to a typical C3 at 615 Hz. For two assembled bodies without necks, the typical C3 was found at approximately 600 Hz. The experiments prove that the influence by the ribs is very large.

**Perturbations of a violin body - influence of added masses**

First experiments were made with mass perturbations. The violin was laid horizontally (with the top up) on two supports (Fig. 4), and a mass of 43 g was placed at various positions on the top plate. The experiments showed maximum sensitivity at the antinodes of the C3 mode (c-bouts and center of upper and lower ends of the body, Fig. 5). Thereafter, mass perturbations along the ribs were investigated. Weights of 12 g were placed at the c-bouts (without soundpost). Thereby it was found the nodal lines moved towards the mass. If masses were added at both c-bouts, both nodal lines moved away from the center line. For a mass added at the center of the violin, the nodal lines of the lower half moved towards the center line. The frequency shifts were much smaller for the center loading than for the c-bout loading, 1% and 10%, respectively. The same experiment repeated for a complete good-quality violin gave similar result, but the differences in frequency shifts were smaller and the nodal line...
at the side opposite to the soundpost was influenced more. Thus it can be concluded that the influence of mass at the c-bouts is large.

Fig. 4. Sketch of the standard feltcovered supports.

Fig. 5. Sketch of areas most sensitive to mass loading: full line hatching - marking areas of maximum sensitivity; dashed line hatching - marking an area of slightly lower sensitivity.

Perturbations of a violin body - loosening of plates from ribs

The experiments were continued with an experimental violin with soundpost. It was tested laying horizontally on two supports (Fig. 4). The plates were cut loose from the ribs in steps (overhead film was inserted in the loosened joint as “grease”). It was found that the c-bout areas were the most sensitive to the perturbations.

The experiments were repeated in more detail for the c-bout loosening steps, with and without neck. It was found that influence of the perturbations were large, the neck (ca 150 g) lowered the resonant frequency approximately 10% but increased the admittance level (approximately 5 dB measured at the lower end block). Thus, it was concluded again that the perturbations of ribs along the c-bouts including the corner blocks make maximum influence.

The experiments were ended with perturbations of the c-bout shapes. The ribs were loosened between the four corner blocks, pressed firmly towards the center and reglued. The shift was less than 2 mm at maximum and no changes in the C3-properties were noted. Thereafter experiments were made with the ribs cut loose approximately 50 mm outside the corner blocks and regluing the ribs as close together and as far apart as possible (maximum difference slightly larger than 5 mm). Frequency shifts up to 10% and level shifts up to 5 dB were noted (higher frequency
and level with the ribs closest together). Nodal lines were little changed in the bridge soundpost region.

In conclusion, we can say that the C3 resonant frequency shifted as expected by c-bout (waist) perturbations, but the maximum level shift was only a third of what was wanted (5dB and not 15 dB).

**Thinning of plates**

An experimental violin was carefully selected for the plate thinning experiments. At the start, the top plate was slightly heavy, 83 g. The second and fifth free plate resonances were found at 188 and 359 Hz, respectively. (The first was unfortunately not measured). For the back, the mass was 109 g and the first, second, and fifth resonant frequencies were 138, 213, and 394 Hz, respectively. Again, the measures were on the high side. For the body assembled, the C3 resonance was at 560 Hz and the T1 resonances 506 Hz. (The level of the C3 is always higher at the lower end block than the level of the T1 resonances, c.f. Fig. 6, and the level difference identifies the two resonances when their frequencies are not known). The measuring point, at lower end block, in the middle of the violin, or at the bridge showed little influence on resonant frequencies. The stringing also showed little influence both on resonant frequencies and peak levels. The plates were thinned in three steps. The violin properties were measured with our standard method, c.f. Figs 3 and 4. A typical input admittance curve is shown in Fig. 7. (Similar measurements has been presented earlier by Beldie, see Cremer 1984, p 245).

First the back was thinned to a mass of 99 g, i.e. -9%. The resonant frequencies were lowered to 125, 194 and 356 Hz, i.e. only slightly more than the mass, and an average of -9%. The C3 and T1 of the assembled violin was 544 and 494 Hz, i.e. rather small shifts, -3 % on the average, i.e. a third of the frequency shifts of the free plate. The influence on the peak levels was moderate, -4 and -3 dB, respectively (c.f. Fig. 7).

Thereafter the bassbar was removed and the top plate was thinned. The plate was refitted with a new bassbar. The mass was decreased to 80 g (-9%) and the frequencies of the free top plate were 100, 181, and 356 Hz (an average shift of -11%). The frequencies of the assembled violin were 556 and 487 Hz, respectively (an average shift of -1%). The frequency and level shifts were even smaller than in the first step, c.f. also Fig. 7.

Finally the back was much thinned. The mass was decreased to 75 g (-24%, a rather thin back plate) and the frequencies of the free back were reduced to 88, 131, and 256 Hz, i.e. -31%. The frequency of the C3 is now much lower (-19%) but the level is little lowered. The level of the T1 peak is considerably influenced but the frequency little (-1%), c.f. Fig. 7. This indicates that the T1 mode is mainly influenced by the top and the C3 mode mainly by the back. The frequency response shown in Fig. 7 (soundpost in normal position) was the violin condition (with much too thin back), which was liked the best by the player. The peak level could be shifted much (more than +-5 dB) by shifting the soundpost position. The result implies that the player was appreciating
another property than a maximum input admittance peak, most probably the tone quality received at his left ear.

![Graph](image_url)

**Fig. 6.** Frequencies measured and peak levels of the C3 (hatched lines) and T1 (full lines) peaks in the four steps of plate thinning. Frequencies (a), peak levels measured close to the bassbar bridge foot (b), at the lower end block (c) and at the bridge.

A remark on the levels and frequencies. The measured levels are the highest at the bridge foot and the lowest at the bridge top. The levels are little to moderately shifted in the four steps. The measured peaks (T1 and C3) look like those of coupled resonators, but give no direct proof.
Fig. 7. Frequency responses of an experimental violin with level (0 dB corresponds to 2 s/kg) and phase (normal top plate, too thin back plate and soundpost in normal position).

**Conclusion**

In earlier investigations we have found the level rather than frequencies at resonances to be a quality measure (Alonso Moral & Jansson, 1982b). But as the frequency is rather simple to measure accurately, we find it fair to use a frequency shift as a sign of general shift of properties.

In the introduction the three questions were raised which we shall try to answer with this investigation.

1. *Is the normal position of the soundpost on top of a C3-nodal line?*
   In the investigation it was found that the answer is no. The soundpost position is close to the nodal line but slightly towards the center of the violin. This seems also to be true for high, soloist quality of violins. The function of the soundpost seems to be to give the best sounding tone by optimising another parameter in addition to a high level of the C3 peak in the admittance curve.

2. *Do the C3 and T1 modes work as coupled resonators?*
   The answer is that they may form two coupled resonators. In the frequency responses, the resonant frequency of C3 is higher than that of T1 with a sharp minimum in between. With the plate thinnings, the C3-resonant frequency is lowered and jumps below that of T1 in the last step. There is a sharp minimum between the two peaks in all steps. These observations support the interpretation of coupling, but is not sufficient as a proof. We need C3 and T1 tuned to the same frequency separately and to find out whether the complete frequency response has a single peak (separate single resonators) or two peaks with a sharp minimum in between (coupled resonators).
3. How do the ribs, the soundpost, the back, and the top affect the C3 resonance?

The investigation show that all four parameters may affect the C3 but that some parameters may be more important than others. The experiments show that the c-bouts (the waist) of the ribs is an area which is especially sensitive for the C3 mode, both resonant frequency and peak level. The resonant frequencies of C3 seems to be more sensitive to the back plate than to the top plate. However, the large shift by the much detuned back plate indicates that proper tuning is important. Thinner plates do not favour a high C3 peak in the input admittance. Soundpost/no soundpost makes little difference for the soundpost in normal position. The C3 peak level may be adjusted considerably by adjusting the soundpost position and in one case it was accidently found that a soundpost being left in the same position for a long time gave a considerably higher C3 level than after resetting. Is this the secret of “the playing in” of a new instrument?

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