RESONANCE STUDIES OF THE GUITAR

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Introduction

Measurements have been made on the top plate of a guitar (BR9) during various stages of construction in order to examine the changes that occur in the frequencies and amplitude distribution of the resonant modes. Such a study gives information concerning the relationships between the movement of modes and the important stages of guitar construction. This enables the luthier to change the free plate (plate tuning) in order to influence the placing of the modes in the completed instrument.

Experimental Measurements

Several series of measurements have been made on the top plate at the following stages of construction: (I) the free plate, (II) when glued to the back, side and neck assembly, (III) after addition of the bindings (which involves rebating the top and back plates), (IV) after the fingerboard is added, (V) after the bridge is added, (VI) after the strings are added (which includes carving the neck), and (VII) when polished and complete.

At each stage in construction a series of measurements were made of the frequency response of the instrument to sinusoidal excitation for four different driving positions in the vicinity of the bridge. For series (III)-(VII) modes were identified using a real-time speckle interferometer and then permanently recorded by time-averaged holography.[1] Comparison of the interferograms and frequency response curves enabled indirect identification to be made for some of the modes in Series(II).[2] A limited number of modes were identified in the free plate using Chladni patterns.

As most of the important motion of the top plate was confined to the lower bout (the area below the soundhole), top plate mode distributions have been categorised as (m,n) by counting half-waves across the grain (m) and half-waves along the grain (n) in the lower bout only. Except for some lower frequency measurements, most top plate modes had a node at the perimeter of the plate and along the cross brace directly below the soundhole.

Figure 1 shows a summary of the measurements made.

Major changes of mode frequencies and amplitude distribution occur at stages (II) and (V). As might be expected, a change in the plate's boundary conditions affects a large number of the modes and indeed generates some new modes (eg (2,1)). The changes seen at (V) show the bridge to be an integral part of the strutting system and a major factor in selectively adjusting the frequencies of certain modes in the completed instrument.

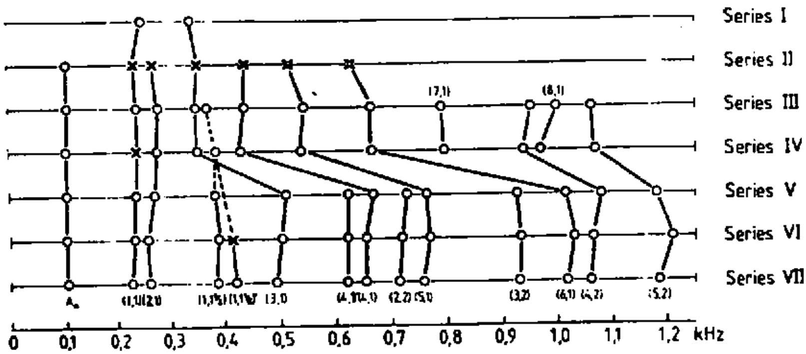

Figure 1. A mapping of the changes in mode frequencies for the various stages of construction investigated.
o - indicate absolute mode-identification
x - indicate extrapolated mode-identification
Solid lines connect modes of the same type. Broken lines connect ambiguous mode categories (i.e. they may involve combination modes).
The (1,1½) mode has an antinode along the lower cross brace (immediately below the soundhole).

Addition of the bridge is seen to affect mainly (M,1) type modes (for M>2) where there is appreciable bending across the centre of the top plate. The bridge increases the stiffness (rather than the mass) of the top increasing the (M,1) mode frequencies; (m,2) type modes are less affected because the bridge lies along the existing node of stage (IV). An important observation is that the (1,1) and (2,1) nodes are little affected by the bridge which is thus ineffective in the adjustment of these two modes (contrary to suggestions made by Jansson[3]).

Mode Placement

Investigations of the modes on the top and back plates of two completed guitars (BR9 and BR2) have been made using the previously described techniques and these results compared with analyses of the sounds emitted by the instruments under normal playing conditions. Such comparisons have led to tentative proposals concerning the effective placement of resonances in the guitar.

A number of workers[4,5] have attempted to implement the Hutchins violin resonance-placement criteria[6] to the guitar. Fulfilment of these criteria provides resonance amplification of the first or second harmonics of as many notes as possible in the low frequency range of the violin by specific placement of the "air resonance" A_0 and "first wood resonance" W_1.

In the case of the guitar, it has been found that it is impossible to raise A_0 from its typical position approximately an octave below W_1 (the (1,1) mode) without considerably modifying the instrument. We wish to propose that, rather than raising A_0, the spacing of A_0 and W_1 should be actually increased to a frequency ratio of 5/2 (rather than the Hutchins ratio of 3/2). Then by adjustment of the (2,1) and (1,1½) modes (W_2 and W_3 respectively) resonance amplification of the first or second harmonics of as many as possible of the notes in the lowest two octaves is provided (see Figure 2). A similar technique has been employed by Hutchins[6] in the construction of a small bodied viola where its A_0 is raised above its normal position to provide second as well as first harmonic amplification.

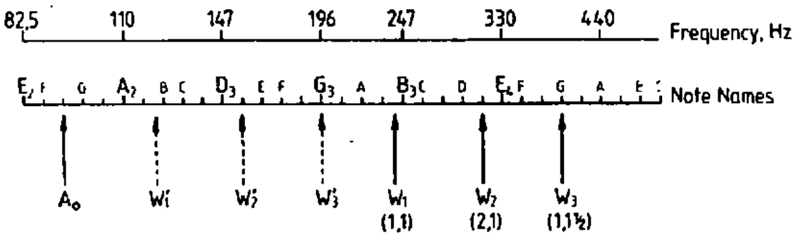

Figure 2. Proposed placement of resonances in the guitar. Solid arrows show mode placements. Dotted arrows show regions in which second harmonic enhancement of strong tones would be found.

Similar resonance amplification might be achieved by lowering the (1,1) and (2,1) modes (as was almost the case for guitar BR2) but it is more desirable to have these strong resonances in the playing range of the treble strings for the following reasons. The internal damping of these strings (the three upper strings made of plain nylon) is much larger than that of the wound strings (the three lower strings). When string frequencies and mode frequencies coincide, string energy is more easily radiated causing a rapid decay. Due to the higher internal damping of the treble strings, such effects are less noticeable[7] and thus the higher placement of the (1,1) and (2,1) modes is preferred as a more even response is then found when playing the instrument.

There is some evidence[8] to suggest that 'good' guitars typically have their A_0 and (1,1) modes in the position suggested in Figure 2.

Constructional Parameters

The results from our experiments and those of others appearing in the literature [2,9] suggest that it would be possible to be able to incorporate these resonance frequencies into a conventional guitar.

The results for guitar BR9 suggest that the top plate resonances in question could be adjusted whilst in its free condition. Hutchins and Dickens[10] have attempted free plate tuning of the (1,1) mode (ring mode) in the top and back plates of a guitar. They note that the ring mode is retained on the top whether the bridge is included or absent. Ring mode tuning was achieved with some success on the top plate of BR9 and this mode is seen to change very little during the construction of the instrument (which is typical of ring modes). Thus effective placement of this mode may be made in the free plate. Adjustments of the (2,1) mode in relation to the (1,1) could be achieved by (i) choice of materials and (ii) by changes in thickness of the plate and stiffness of the fan braces; both of which vary the ratio of stiffness along the grain to that across the grain. The $(1,1\frac{1}{2})$ mode, which has an antinode directly over the lower cross brace, could be controlled by variations in the size of this brace. Such variations would affect the frequency of the $(1,1\frac{1}{2})$ mode rather than that of the others.

The experiments of Hutchins and Dickens also involved relative tuning of ring modes between the top and back plates (which in the case of the back plates required unconventional strutting). In the violin, it is considered desirable to have a semitone difference between the ring modes of the two plates. However, measurements made on guitar BR2 in which the (1,1) modes on the top and back plates are closely spaced suggest that this is an undesirable feature. Strong coupling between the two modes and the string leads to an excessive response and rapid decay.

Conclusion

Although the experiments described are limited, we believe that a guitar built to conform to the criteria now proposed would possess good playing qualities and an even tone. We propose now to build an experimental guitar and to make measurements on as wide a range of existing guitars as possible.

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