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ON THE INFLUENCE OF THE NECK ON THE GUITAR BODY VIBRATIONS

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Abstract

The neck of the guitar is generally assumed to be of little acoustical interest, and few investigations on its properties have been reported. In order to fill this gap, the following investigation was started. Four main questions were initially asked: Does the neck vibrate? How does the neck vibrate? Does the neck influence the body vibrations? Can the neck design influence the quality of a guitar? Two complete guitars in playing conditions and two experimental guitars were investigated. Introductory experiments showed that the body vibrations extended to the neck. In the main experiments, modal analysis was made of the complete guitars, of one of the experimental guitars with the neck removed, the free neck, and another free neck. Thereby, clear answers were found to the first three questions: The neck vibrates. In some eigenmodes the neck vibrations are strong and in the modes with the complete body bending, the neck influence is large. No simple answer was found to the fourth question but the large differences between the two free necks indicate that different neck properties may influence the quality of a guitar.

INTRODUCTION

The guitar can be said to have two main parts: a body and a neck. The neck is fastened to the body, a fastening which is reinforced by the gluing of the fretboard to the top plate. One end of each string is fastened in the center of the top plate in the bridge. The other end is fastened close to the free end of the neck, i.e., in the head of the guitar. Thus, a vibrating string may directly excite both the top plate and the neck. In addition, the vibrations of the body may be transmitted to the neck via the body-neck joint. The influence of the guitar’s top and back plate has been investigated in detail, but the neck is generally assumed to be of little interest.

No neck influence is mentioned in a recent book on the physics of musical instruments (Fletcher & Rossing, 1991) or slightly in earlier reports on guitar acoustics (Jansson, 1983; Meyer, 1985; Richardsson & Roberts, 1985) although it is reported that the thickness of the neck influences the quality of the guitar (Knatt, 1974). As a general theoretical background, it can be concluded that a vibrating neck should add resonances. Such resonances may store energy only (and consume energy from the body) and lower the quality of an instrument. They may, on the other hand, change the vibrational properties of the guitar and improve its quality. In order to understand and predict the role of the neck this investigation was started. Four main questions were asked:

1) Does the neck vibrate?
2) How does the neck vibrate?
3) Does the neck influence the body vibrations?
4) Can the neck design influence the quality of a guitar?

For the experiments, two conventional guitars and two experimental guitars were selected. The conventional guitars were a normally factory-made guitar, LG17, and a Ramirez, a high

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quality guitar. The experimental guitars were a modified LG17 (labelled guitar G10 below) and an experimental design from IFM Zwota (with a body made of plywood and it is labelled Z below). The four guitars covered a wide quality range.

INTRODUCTORY EXPERIMENTS
Massloading and fretboard stiffening of guitar 10
For the introductory experiments the guitar G10, made for experiments, was selected. This guitar was of "standard" design but it had its back additionally stiffened by three bars (5 mm thick and 20 mm wide) glued along the grains on its outside.

In the experiments, G10 was first manipulated by massloading its head with 15 g (15 g is much smaller than the mass of the necks, see below), and the input admittance was measured close to the mass load. The input admittance was measured by means of swept sine-wave excitation and by means of the measurement sond developed in our KTH laboratory (see Alonso & Jansson, 1982, now employing a B&K 4293 accelerometer). Without the mass load, strong resonance peaks were found at 75, 249, 502, 606, 658, and 731 Hz. With the mass load, the frequencies were lowered 4, 15, 8, 20, 13, and 11 Hz, i.e., there is a clear influence on the neck resonances.

The same experiment was repeated but with the input admittance measured in the center of the top plate. Thereby it was found that the neck resonances do not dominate and that the 15 g mass at the head made very small changes in the frequencies of the dominant peaks as well as in the levels' responses. Only the frequency of the lowest resonance was noticeably decreased (4 Hz).

The body was stiffened by a support between the top and back plate close to the sound hole. With the support placed under the fretboard, only the 500-Hz resonance was noticeably influenced. Similar stiffening on the bridge side of the sound hole also gave a noticeable influence.

The mass-loading experiment was repeated with the two normal guitars. First, the input admittances were measured at the heads. Both guitars showed strong neck resonances. The LG17 guitar had the neck resonances at slightly lower frequencies than the Ramirez guitar but clear neck resonances were found at higher frequencies. The resonance frequencies for both guitars were again lowered 5 to 10 Hz with the 15 g mass load.

Secondly, the input admittances were measured at the bridge. Comparison of the input admittance curves at the bridge with those at the head again showed that neck modes were excited but much weaker than at the head. It seems safe to conclude that the neck does vibrate also when the guitar is excited at the bridge only.

Mode identifications of the G10, Ramirez, and LG17 guitars
The vibration distribution over the complete guitar and especially the nodal lines is usually most informative. Therefore, Chladni patterns were made for dominating low frequency resonances of the G10, Ramirez, and LG17 guitars. A small loudspeaker was used to excite the guitar top plate, and saw dust (painted and prepared for model rail roads) was used to mark the nodal lines. Typical results are shown in Fig. 1. The lowest bending mode of the complete guitar has two nodes and the second lowest has three. Thereafter, three modes with five somewhat similar nodal patterns were found in the range 375-600 Hz. The similarity of the three modes indicates that there are coupled modes or a mixture of resonances – neither single plate, neck nor complete body resonances can explain the observed patterns. The measurements were supported by point measurements point for point with a handhold contact probe. The observed modes clearly show that the neck extends the body, but the combination does not always behave as a free-free bar. Thus more detailed experiments are interesting.
MAIN EXPERIMENTS
For the continued experiments, the dispensable experimental guitar Z was introduced. The guitar was prepared to have its neck easy to remove and refit. First two holes were drilled through the neck foot and the top block. In addition two holes were drilled between the 13th and 14th frets. Thereafter, the fingerboard was sawn off somewhat closer to the 14th fret, the neck foot was sawn off in level with the sides, and the fretboard was cut loose from the neck foot to the sawn slit. By means of the holes, the neck could accurately be rescrewed to the body. The input admittance was measured halfway between the bridge and the sound hole at the top plate with originally glued and later rescrewed neck. The measured responses looked rather similar (within ±1 dB) except in the 400-500 Hz range and above 700 Hz. In both ranges, a resonance in the high end of each range became more or less prominent. Anyway, it is safe to conclude that properties of the guitar with glued neck are to be found also in the guitar with screwed neck.

Fig. 1. Vibration modes (at resonance) of a guitar (G10) excited on the head.

Frequency responses of guitar Z
The input admittances were measured at the head, the center of the top plate, and the center of the back plate. The admittance curves were measured as described in the introductory experiments above. Examples of measured admittance curves are given in Fig. 2.

The input admittance measured at the head shows the lowest resonance of the Z guitar. At higher frequencies, a large number of small peaks is found. The three guitars look rather different at these frequencies. The LG17 shows clear and rather simple resonance peaks up to almost 1 kHz; above 500 Hz few such peaks are found for the Ramirez guitar. The neck was found to have torsional modes too, but these were not further investigated.

The input admittance at the bridge of guitar Z shows the typical response of a guitar. First, there is a peak at 80 Hz corresponding to the first bending mode followed by the A0 peak at 102 Hz, the peak of the first top plate resonance at 209 Hz, a second strong resonance below 300 Hz, and a number of higher resonances. The response looks surprisingly similar to the high quality Ramirez guitar – probably since the top-plate designs were somewhat similar for the two guitars. The two most prominent resonances are more prominent in the Ramirez guitar though. In the high-frequency range, the resonance peaks are more evenly spaced in the Z guitar than in the LG17 guitar, but there are a noticeably larger number of high frequency peaks in the Z guitar than in both the Ramirez and the LG17 guitars.

From the measurements at the center of the back position, it is found that the main resonance of the back should be at 270 Hz. Thereafter follows a large number of more or less clear peaks. The input admittance of the back was remarkably high, i.e., it was of the same magnitude as that of the top plate.
With the neck removed the input admittance curves look rather similar to the corresponding ones with the neck. There are, however, clear differences. In the top-plate curves, the peak of the first bending mode vanishes, the second most prominent peak becomes clean, and the response in the 400-600 Hz range is changed. About the same changes are found in the back-plate measurements. The first prominent peak at 270 Hz then becomes clean, and the frequency range 300-500 Hz is slightly changed.

![Graphs showing admittance curves](image)

*Fig. 2. Input admittance of guitar Z measured at the head (top frame), at the bridge (middle frame), and at the bridge of the body without neck (lower frame).*

Resonances and modal analysis of free necks

The free Z neck is a homogeneous wooden one with a 25 mm free fretboard at its foot. A second free neck, L, was introduced which was straight cut at the 12th fret (the dove joint on the neck foot was left though). The neck was closely the same as that of LG17 and G10. The L neck was more slender and was reinforced by a steel tubing underneath the fingerboard. The mass of the Z and L necks were 480 g and 400 g, respectively.

The input admittances were measured at the heads with the necks placed on top of two pieces of plastic foam. Thereby, it was found that the guitar Z only had two strong resonances below 2 kHz, but the L neck had four. The differences are likely to derive from differences in design and material.

For the modal analysis, the neck to be tested was again placed on top of the two pieces of plastic foam. The Z neck was excited at 23 equally displaced points along the center line but the L neck only at 18. The accelerometer was placed close to the top of the head at the center line. The obtained modal shapes are shown in Fig. 3.

The modal analysis of the two free necks showed typical bar modes. For the Z guitar neck, only the modes with two and three nodes, respectively, were found (at 227 Hz and 607 Hz). For the neck L, two higher modes were found, both with four nodes which is somewhat surprising. A similar duality was found for the other higher modes. A careful comparison of the two modes reveals that the node position at the neck-head joint is slightly different as well as the one at the bridge foot. The differences indicate that the head and the neck have separate
modes, and that the concentrated mass at the bridge foot tries to enforce a node at the third resonance but acts as a mass load at the fourth.

Rather interestingly, the frequency ratios of the lowest two free neck resonances are very close to those of the free-free bar (2.67 and 2.70 compared to the 2.76 for the bar). The corresponding frequency ratios for the third and fourth neck modes bracket those of the bar.

Modal analysis of guitar Z with neck

First, the input admittance up to 1 kHz was measured at the top plate halfway between the bridge and the sound hole. A large number of resonance peaks was found. Thereafter, modal analysis was made with the guitar laid on two pieces of plastic foam along the edges and one piece under the head. The guitar was excited at 64 preselected points along the center line with a small impact hammer (PCB = 086M37). With the accelerometer (B&K 4393), the resulting vibrations were measured in two fixed positions also at the center line (at the top of the head and halfway between the sound hole and the bridge). Frequency responses were recorded with an FFT-analyzer (HP 3562A), and modes were obtained with a modal analysis packet (SMS Star struct). In all, some 20 modes were obtained with eigenfrequencies below 1 kHz.

A simple visual inspection of the modes gave that the vibrations qualitatively are of four types: mainly in the top, mainly in the back, in both, or in the whole body with the neck, see Fig. 4. As we are mainly interested in the importance of the neck vibrations, we shall limit our investigation to the major modes and to the modes with large neck vibrations. In the lowest mode of the guitar (at 80 Hz), the complete guitar vibrates as a bar with both ends free, with two nodes, and with large vibrations of the neck. This resonance may influence important starting transients, but is unlikely to radiate sound (Strong, Beyer, Bowen, Williams, & Maynard, 1982 report neck radiation only above 200 Hz in addition to the body radiation for their tested guitar). At 102 Hz, the A0 mode is found where the top and back plates move as to shrink and enlarge the enclosed volume at the same time. At 209 Hz, the top plate (below the sound hole) vibrates in and out. The neck vibrations are relatively small in the latter two modes. At 269 Hz, the top and back plates vibrate in phase, and the vibrations are extended to the neck. There are three nodal lines, one at the bridge, one at the neck-body joint and one at the head. The vibrations of the neck are large. At 329, 350, and 403 Hz, a triplet of resonances is found. The first one is likely to be wall vibrations coupled to the second air mode (A1). The second mode is a bending of the guitar with five nodal lines. The neck vibrations are large. The top and back move in phase. In the third mode, the top and back move in anti-phase but similarly as in the mode below. The neck vibrations are small. At 439 Hz, an example of a mode with mainly back plate vibrations is found. There are other modes too, but mostly not with large neck vibrations compared to the body vibrations.
Modal analysis of the Z guitar without neck
First, the input admittance up to 1 kHz was again measured at the top plate halfway between the bridge and the sound hole. Thereafter, modal analysis was made with the guitar body laid on the three pieces of plastic foam, and the complete measurement procedure was repeated.

The lowest bending mode of the complete guitar is now missing. The two main resonances of the guitar, the "Helmholtz resonance" and the "first top plate resonance," were found without neck. Their frequencies were hardly different and the modes look much the same as with the neck. The triplet of modes of the complete guitar is also found in the body alone. The frequencies are little shifted. In the body alone, the resonance frequencies are at 347, 355, and 404 Hz compared to 329, 350, and 404 Hz, respectively, for the body with neck, thus implying that the lowest resonance is influenced by the neck. A mode is found at 269 Hz in the body alone which may be a distorted version of the 268-Hz mode with neck. The back-plate mode at 439 Hz for the complete guitar is found at a slightly higher frequency in the body alone. The last two resonances are, thus, also influenced by the neck. Higher back-plate modes can, however, be found without (and with) neck.

Modal analysis of guitar 10 (with neck)
The experimental guitar 10 was also investigated by means of modal analysis. The main difference between the two guitars seems to be reflected in higher Q-factors for guitar 10 than for guitar Z, possibly as a consequence of homogeneous wood and plywood, respectively. The more slender neck is also reflected in more clear vibration modes of the neck. The lowest bending mode of this guitar was at 76 Hz, A0 at 103 Hz, and the first top plate at 212 Hz. The following body-bending resonance is found at 242 Hz and the triplet of modes at 345, 379, and 446 Hz. The earlier found isolated back-plate mode is not refound in this frequency range. The frequencies of the plate modes of the guitar 10 are higher than the corresponding ones of guitar Z and they show up more clearly. The bending modes tend to be lower for guitar 10. The uncertainty of the measurements makes comparisons at higher frequencies rather hazardous and are, therefore, not made.
CONCLUSION

In this paper we report on work on the neck's influence on the properties of a guitar. Four questions were initially asked:

1) Does the neck vibrate?
2) How does the neck vibrate?
3) Does the neck influence the body vibrations?
4) Can the neck design influence the quality of a guitar?

Our experimental investigation gives clear answers to the first three questions:

1) The guitar neck vibrates in the different eigenmodes of the guitar.
2) In some modes, the plate vibrations are dominant but in some other modes, the body with the neck vibrates as a bar with large vibrations in the neck.
3) In the modes with dominant plate vibrations, the influence of the neck is small but in the bending vibrations of the complete guitar it is large.

The experiments do not give a simple clear answer to the fourth question. The vibrating neck adds resonances and possibly also losses to the other guitar resonances. A neck resonance may couple to a plate resonance and give a less favourable response (cf. Fig 2). The losses are not effected in a simple way, at some resonances they seem to increase and at some others they seem to decrease with the neck attached. If proved that such losses add to the losses of the dominant resonances, the losses may give a perceivable effect (cf. Chaigre, Askenfelt, & Jansson, 1990). The two investigated necks evidently have different loss properties built-in by the choice of material and design. If this difference is sufficient, we may conclude that the neck influences the quality of a guitar. It is interesting to note that both string partials and body resonances can be seen in spectra of played tones when measured at the top plate. Modal analysis of the string excited guitar also shows stronger neck vibrations.

For the maker, our experiments support the general assumption that the top and back plates are more important than the neck. For a high quality guitar, the neck properties cannot be neglected though. It seems safe to recommend a stiff (rigid) and light neck with low internal damping. The fretboard at the top plate should be stiffened as its large vibrations otherwise may result in considerable losses of vibrational energy.

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