BRACE TRIMMING FOR TONE IMPROVEMENT OF A GUITAR

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ABSTRACT

The aim of our research was to improve the tone of a guitar by trimming wooden braces on its top plate. As a criterion for tone quality we used the 'rule of consonance-dissonance' that correlates the aesthetic quality of a tone with its spectrum [1]. Experimentation with a test guitar and four sanded top plates suggested the following method for tone improvement: when the tone is sub-optimal, trimming of one of the two largest braces for a certain small amount results in improved tone quality. In contrast, this rule does not apply to the test guitar with four planed top plates, indicating the importance of the machining process on acoustic properties of an instrument.

NOMENCLATURE

E	modulus of elasticity parallel with grain
ρ	density
"F"	tone
"B"	tone
"g"	tone
$Q(k)$	relative quality of tone k
Q_m	average and relative tone quality
SPL	sound pressure level

1 INTRODUCTION

According to Richardson [2], systematic improvement of the tone of an assembled guitar can be achieved by trimming its braces. It has been assumed that changing the height of the braces changes the tone because of a decreased stiffness of the top of a guitar [3]. This influences its modal behavior and results in a better tone when certain rules are followed (see below). Recent research with measuring the acoustic response of differently machined square-shaped boards made of wood has shown that in general the cutting process influences the shape of the surface layers [4, 5]. It was measured that the acoustic response of the planed square shaped specimens is less damped (desirable) than that of the sanded specimens. The influence of these two tested machining processes was not so evident for the guitar top plates with two large braces [5]. Obviously the braces diminished the effect of the different shape of the surface layers which affected the mechanical (acoustic) properties of the wooden board.

In this paper the measurements of tones of a test guitar (with all braces) with differently machined tops are described. The effect of brace trimming was correlated to three guitar tones for which the criterion for tone quality determination called 'rule of consonance-dissonance' [1] can be applied. In comparison to the measurements of the acoustic response of the square-shaped boards without braces [5] the tests with built-in guitar tops show a different significance of the cutting process in terms of acoustic response of thin wooden boards.

2 METHODS AND RESULTS

2.1 Definitions

Our aim was to find those changes in the brace height that would result in an improved tone. All experiments were done with only one test guitar and tone recording started 1.0 second after the string excitation. The first variable whose effect on the sound was studied was the height of the two largest braces on the top plate. The second variable was the cutting process applied in top plate production (planing or sanding). Other braces were considered as part of the top plate and were replaced with the top. All braces were glued with a glue that was not resistant to heat. Thus, the braces could be removed with a hair dryer. The inner side of the top plate was made accessible by reversible screwing of the back plate onto the rim of the resonance box. The top plates were glued to the rim. The trimming of brace heights involved three phases: ungluing, planing, and gluing. All braces and top plates were made of spruce (*Picea abies* Karst.), which was seasoned for 30 years. Table 1 shows some properties of the samples of wood from which the braces and top plates were made (for a detailed description and explanation of their preparation see [5]). The schematic presentation of the applied cutting processes is shown in Figure 1, where also the shape of the top plates is presented. A and B indicate the two variable braces whose cross-sections were rectangular. All braces were machined by planing.

Ratio *std.dev./mean* for *E*	ρ	Ratio *std.dev./mean* for ρ	Moisture content
	kg/m^3		%
0.07	451	0.016	10

TABLE 1: Some properties of the braces and top plates.

This research is based on the 'rule of consonance-dissonance' (RC-D), which is described at length in [1]. Briefly, the RC-D, which was expressed in a mathematical form and interpreted in terms of the physical and musical theory, allows a comparison of aesthetic quality of any two guitar tones of the same pitch if they were recorded under certain and equal conditions. The RC-D is based on experimentation with three different tones; "F" (fundamental frequency of 87.3 Hz, 6th string), "B" (123.5 Hz, 5th string), and "g" (196.0 Hz, 3rd string), recorded in three different periods after string excitation. The aim was to define a significant difference between good and bad guitar tones as produced by good and bad classical guitars, respectively. The first 15 frequency lines (rms values) of a discrete amplitude spectrum of a good tone were compared to the first 15 frequency lines (rms values) of a bad tone. Each amplitude spectrum can be seen as a host of intervals, because the interval consists of two frequency lines. A-weighted sound pressure levels of 19 consonant and 6 dissonant intervals in dB(A) units were analyzed. It was shown that in comparison to bad tones the timbre of good tones consists of stronger consonant (pleasant) and weaker dissonant (unpleasant) intervals. This difference was quantified by function $Q(k)$, where k indicates one of the tones "F", "B" or "g". Larger $Q(k)$ indicates a better quality of the bad tone in comparison to the reference, good tone. Finally, the average tone quality Q_m is defined as the mean value of the three $Q(k)$ corresponding to the three tones "F", "B" and "g". A schematic presentation of calculating the quantities $Q(k)$ and Q_m is shown in Figure 2.

Reproducibility of the experiments was determined by repetitive gluing, measuring a tone, and ungluing the same brace ten times. This procedure was performed for braces A and B separately. For tones "F" and "B", the ratio of *standard deviation/mean value* of quantity $Q(k)$ was approximately 5% and for tone "g" 20%. This ratio expresses variation of the measured values with respect to their mean value, thus it enables a comparison of the quality of the measurement for the three tones. The reason for a greater error in measuring tone "g" relative to that of tones "F" and "B" is probably the Wolf tone [6]. The Wolf tone is the

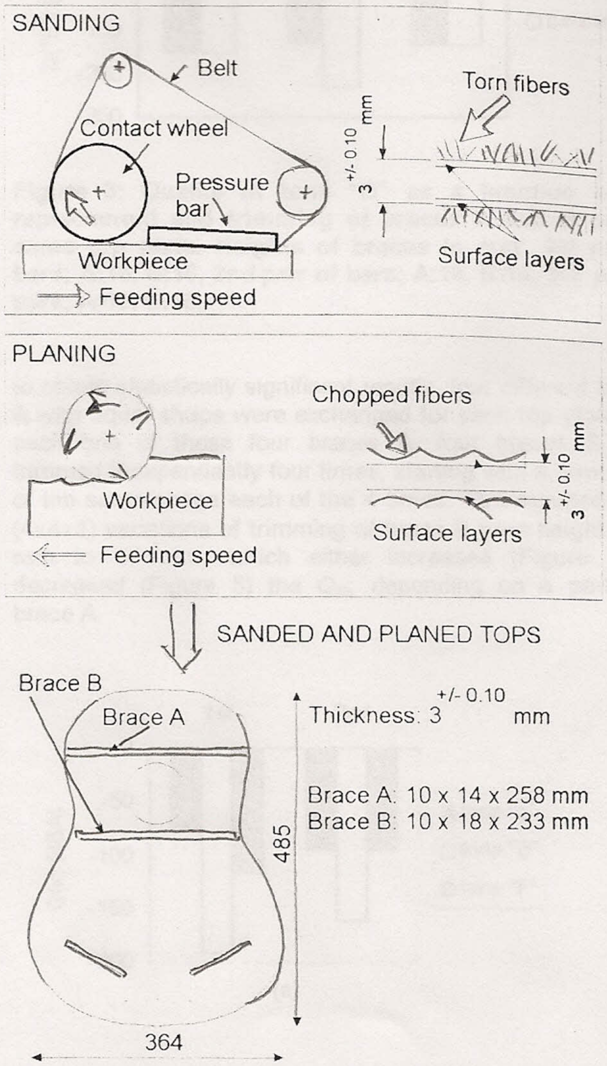

Figure 1: The tested cutting processes and the guitar top plate.

pulsation of sound intensity and occurs when the sound impedances of the essential instrument parts are not optimal. Additional experiments with four high quality guitars showed that the Wolf tone is more likely to occur at higher tones rather than lower tones. This is an example of the intricacy of producing quality high tones in a guitar that troubles so many luthiers.

2.2 Replacing and trimming of braces

A test showed that replacement of brace A or B with a brace of smaller height does not have the same impact on tone quality as their trimming (lowering). For tone "B" recorded 1.0 s after string excitation, the effects of replacement and trimming of braces A and B on the tone quality are shown in Figure 3. Note that in this test the height of brace A (18 mm) differs from those used in the following experiments (see

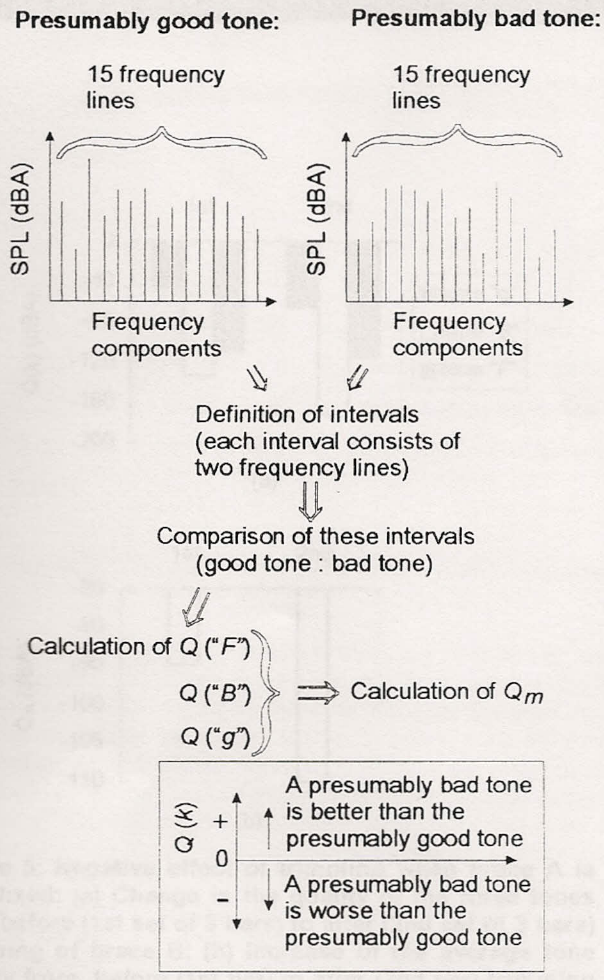

Figure 2: Determination of $Q(k)$ and Q_m [1].

also Figure 1). The second pair of bars in Figure 3 shows a significant difference in the tone quality of the test guitar as a function of brace trimming and replacement. Due to wood non-homogeneity [7], braces with equal shape affect the tone of the guitar in different ways. Therefore, it is expected that changing (improving) the tone quality with brace replacement is more stochastic than brace trimming. It is suggested that trimming of braces is a better solution for controlled tone improvement, because trimming of braces involves only one variable, brace height.

In this test and in the tests described in following sections quantity $Q(k)$ expresses the relative tone quality of a presumably bad tone, i.e. tested tone in comparison to the presumably good tone, i.e. reference tone, whose high quality was objectively judged by experts [1]. This is also true for the quantity Q_m, which expresses the average tone quality.

2.3 Sanded top plates - tone quality measurements

Four top plates were tested in this experiment. The final cutting process of their machining was belt sanding. In order

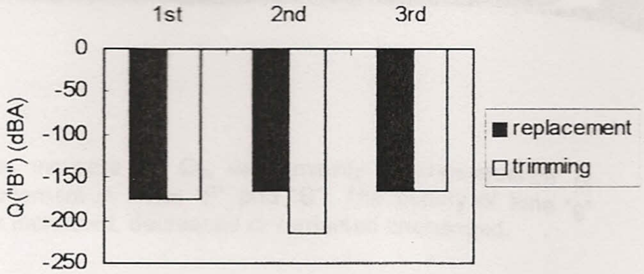

Figure 3: Quality of tone "B" as a function of the replacement and trimming of braces A and B on the same top plate. Heights of braces in mm: 1st pair of bars; A:18, B:18, 2nd pair of bars; A:18, B:16, 3rd pair of bars; A:16, B:16.

to obtain statistically significant results, four different braces A with equal shape were exchanged for each top plate. For each one of these four braces A, four braces B were trimmed independently four times, starting with a new brace of the same shape each of the 4 times. This resulted in 64 (4×4×4) variations of trimming of brace B from height of 18 mm to 14 mm, which either increased (Figure 4) or decreased (Figure 5) the Q_m, depending on a particular brace A.

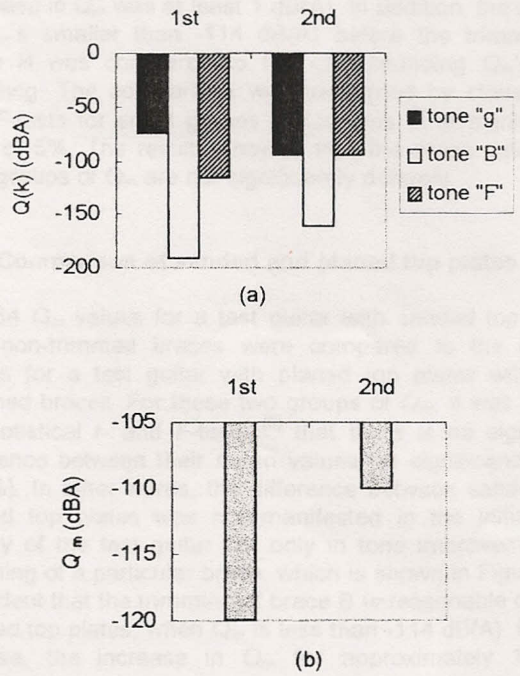

Figure 4: Positive effect of trimming when brace A is held fixed: (a) Change in the quality of the three tones from before (1st set of 3 bars) to after (2nd set of 3 bars) trimming of brace B; (b) Increase of the average tone quality from before (1st bar) to after (2nd bar) trimming of brace B.

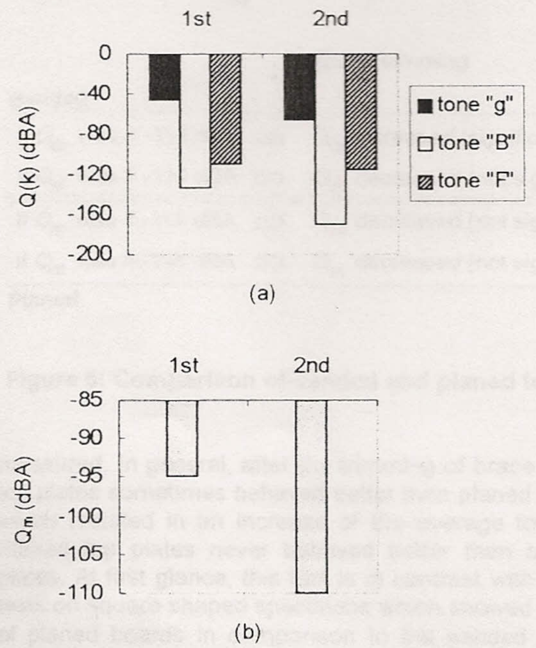

Figure 5: Negative effect of trimming when brace A is held fixed: (a) Change in the quality of the three tones from before (1st set of 3 bars) to after (2nd set of 3 bars) trimming of brace B; (b) Increase of the average tone quality from before (1st bar) to after (2nd bar) trimming of brace B.

It was assumed that Q_m is distributed according to the Gaussian distribution. The analysis of the 64 variations showed that:

1. The average tone quality of the test guitar always increased after brace B was trimmed, if Q_m was initially less than -114 dB(A). The increase in Q_m was at least 10 dB(A). In addition, the sample of Q_m's smaller than -114 dB(A) before the trimming of brace B was compared to the corresponding Q_m's after trimming. The comparison was performed by statistical t- and F-tests for small groups of samples [8] at significance level of 5%. The results showed that the mean values for both groups of Q_m are significantly different. It should be noted here that $Q(k)$ and Q_m are a measure of the relative tone quality and no direct physical explanation for "-114 dB(A)" exists. The negative sign is a consequence of the procedure of calculating the $Q(k)$ and Q_m [1] and only means that the considered tone quality is relatively poor in comparison to the good (reference) tone.

2. The average tone quality of the test guitar always decreased after the brace B was trimmed, if Q_m was initially more than -114 dB(A). The decrease in Q_m was always at least 1 dB(A). In addition, the sample of Q_m's larger than -114 dB(A) before the trimming of brace B was compared to the corresponding Q_m's after trimming. The comparison was performed by statistical t- and F-tests for small groups of samples [8] at significance level of 5%. The results showed that the mean values for both groups of Q_m are not significantly different.

3. An increase in Q_m was mainly a consequence of improvement in tones "F" and "B". The quality of tone "g" either increased, decreased or remained unchanged.

2.4 Planed top plates - tone quality measurements

Exactly the same experiment as with the sanded top plates was also performed with four planed top plates with the shape equal to that of the sanded top plates. Again, 64 variations of the trimming of brace B from height of 18 mm to 14 mm can be summarized as follows:

1. Trimming never increased the average tone quality of the test guitar, even if Q_m was initially less than -114 dB(A). In addition, the sample of Q_m's smaller than -114 dB(A) before the trimming of brace B was compared to the corresponding Q_m's after trimming. The comparison was performed by statistical t- and F-tests for small groups of samples [8] at significance level of 5%. The results showed that the mean values for both groups of Q_m are not significantly different.

2. Trimming always decreased the average tone quality of the test guitar, if Q_m was initially more than -114 dB(A). The decrease in Q_m was at least 1 dB(A). In addition, the sample of Q_m's smaller than -114 dB(A) before the trimming of brace B was compared to the corresponding Q_m's after trimming. The comparison was performed by statistical t- and F-tests for small groups of samples [8] at significance level of 5%. The results showed that the mean values for both groups of Q_m are not significantly different.

2.5 Comparison of sanded and planed top plates

The 64 Q_m values for a test guitar with sanded top plates with non-trimmed braces were compared to the 64 Q_m values for a test guitar with planed top plates with non-trimmed braces. For these two groups of Q_m, it was proved by statistical t- and F-tests [8] that there is no significant difference between their mean values (at significance level of 5%). In other words, the difference between sanded and planed top plates was not manifested in the initial tone quality of the test guitar but only in tone improvement by trimming of a particular brace, which is shown in Figure 6. It is evident that the trimming of brace B is reasonable only for sanded top plates, when Q_m is less than -114 dB(A). In such a case, the increase in Q_m for approximately 10% is expected.

From Figure 4 it is evident that after the brace trimming the quality of tones "F" and "B" increased if the initial tone quality was relatively bad. For tone "B" this improvement was drastically recognized by the ear as a disappearing of buzz tone.

3 DISCUSSION

No significant differences in an average tone quality between sanded and planed top plates built into the test guitar before the trimming of brace B (see Figure 6) was

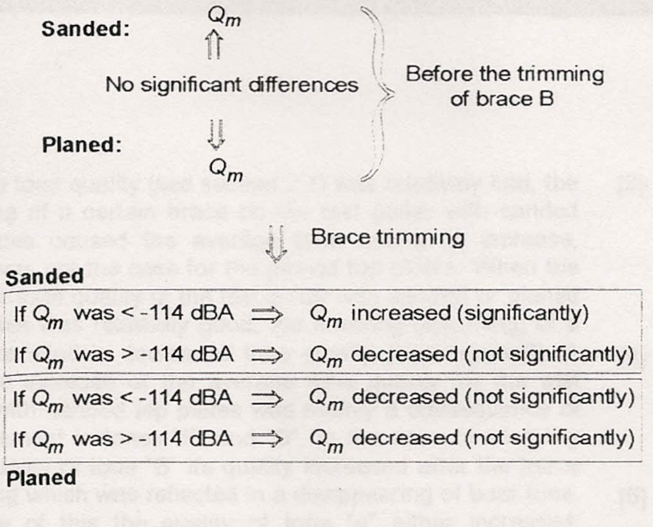

Figure 6: Comparison of sanded and planed top plates.

measured. In general, after the trimming of brace B, sanded top plates sometimes behaved better than planed top plates, which resulted in an increase of the average tone quality. Planed top plates never behaved better than sanded top plates. At first glance, this fact is in contrast with the recent tests on square-shaped specimens which showed superiority of planed boards in comparison to the sanded ones [4, 5]. Namely, in these tests significantly lower internal losses were measured in the planed square-shaped boards (desired) than in the sanded boards. Figure 7 shows a comparison between the recent tests with square-shaped specimens [4, 5] and the tests with brace trimming described in this paper. In both tests a common variable was a machining process applied to finish the specimens (square-shaped boards, top plates).

However, the brace trimming changed the modal behavior of a top plate and it seems that under given circumstances this change had a much greater positive influence on the sanded top plates than on the planed ones. Thus, sometimes the brace trimming on the sanded top plates improves the modes of the top plate, which are responsible for tones "F" and "B". However, in spite of this improvement the modes which affect the quality of tone "g" either improved, got worse or remained unchanged. The change of modes is a consequence of changes in stiffness and mass of the trimmed brace, which is described in more detail in [9]. Thus, it is assumed that for improvement of tone "g" (i) another brace or place on the top plate should be selected as an object of wood removal or (ii) another initial bracing of the guitar top would be more appropriate.

4 CONCLUSION

The current paper is based on the 'rule of consonance-dissonance' (see section 2.1) that allows comparison of aesthetic quality of any two guitar tones if they were recorded under certain and equal conditions. We proposed and tested a procedure for improving the tone quality of the

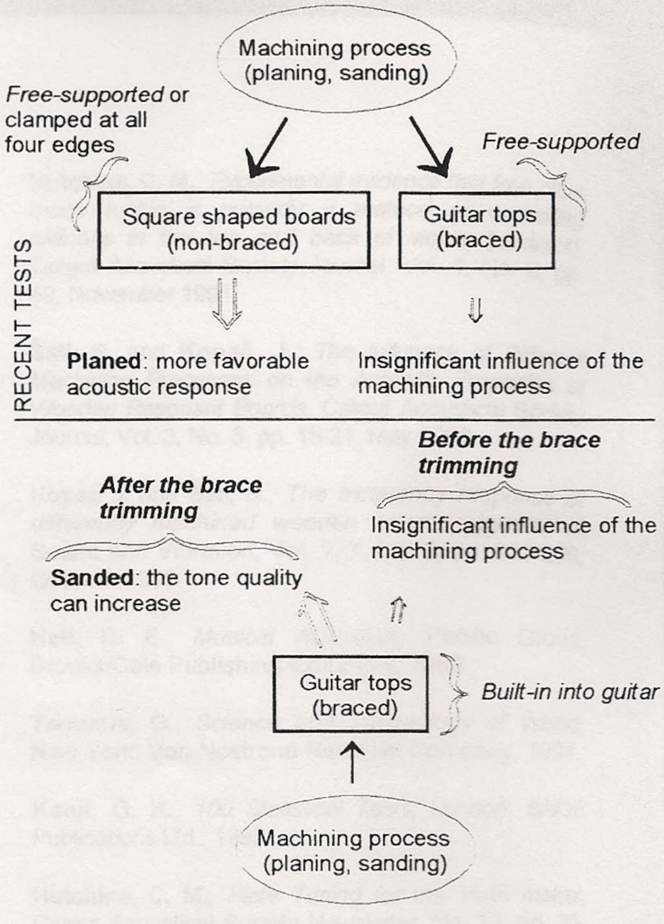

Figure 7: Comparison between recent tests and the tests with brace trimming.

guitar sound; it is based on the assumption that only three tones are sufficient to describe the guitar's register of tones.

According to this procedure, the improvement can generally be achieved by trimming one of the two largest braces for a certain small amount. In order to refine this procedure, it will be necessary to perform additional experiments exploring all braces of both sound boards.

The influence of the machining was not so evident for the braced top plates as it was for the square-shaped specimens [4, 5]. A probable reason for this could be the two braces A and B used in the experiments with top plates which increased the stiffness of the plate in the radial direction. Thus the ratio between the stiffness in the longitudinal and radial direction decreased (for spruce elasticity in the longitudinal direction is more than 10 times higher than in the radial direction [7]). In other words, the modes which depend on the stiffness in the radial direction significantly changed and probably this and the additional mass of the braces diminished the influence of the machining process on the acoustic properties of a board.

Sanded top plates behaved differently from planed top plates, although their sound quality was similar. When the average tone quality (see section 2.1) was relatively bad, the trimming of a certain brace on the test guitar with sanded top plates caused the average tone quality to increase, which was not the case for the planed top plates. When the average tone quality of the test guitar with sanded or planed top plates was relatively good, the lowering (trimming) of a brace resulted in decreased tone quality (see Figure 6). A possible increase of the average tone quality for the test guitar with sanded top plates was mainly a consequence of improvement in tones "F" and "B". In the case of relatively pure quality of tone "B" its quality increased after the brace trimming which was reflected in a disappearing of buzz tone. In spite of this the quality of tone "g" either increased, decreased or remained unchanged, which reflects the Wolf tone problem [6] and the problem of higher guitar tones in general.

REFERENCES

[1] **Šali, S.** and **Kopač, J.**, *Measuring the Quality of Guitar Tone*, Experimental Mechanics, Vol. 40, No. 3, September 2000.

[2] **Richardson, B. E.**, *The influence of strutting on the top-plate modes of a guitar*, Catgut Acoustical Society Newsletter, No. 40, pp. 13-17, November 1983.

[3] **Hutchins, C. M.**, *Experimental evidence that free plate mode tuning is primarily a method of controlling stiffness in the top and back of violins (abstract)*, Catgut Acoustical Society Journal, Vol. 1, No. 8, pp. 49, November 1991.

[4] **Šali, S.** and **Kopač, J.**, *The Influence of Different Machining Processes on the Acoustic Properties of Wooden Resonant Boards*, Catgut Acoustical Society Journal, Vol. 3, No. 5, pp. 15-21, May 1998.

[5] **Kopač J.** and **Šali, S.**, *The frequency response of differently machined wooden boards*, Journal of Sound and Vibration, Vol. 227, No. 2, pp. 259-269, October 1999.

[6] **Hall, D. E.**, *Musical Acoustics*, Pacific Grove, Brooks/Cole Publishing Company, 1980.

[7] **Tsoumis, G.**, *Science and Technology of Wood*, New York: Van Nostrand Reinhold Company, 1991.

[8] **Kanji, G. K.**, *100 Statistical Tests*, London: SAGE Publications Ltd., 1993.

[9] **Hutchins, C. M.**, *Plate Tuning for the Violin maker*, Catgut Acoustical Society Newsletter, No. 39, pp. 25-32, May 1983.