Kungl Tekniska Högskolan

Dept of Speech, Music and Hearing

ACOUSTICS FOR VIOLIN AND GUITAR MAKERS

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Chapter VIII: The Tone and Tonal Quality of the Violin

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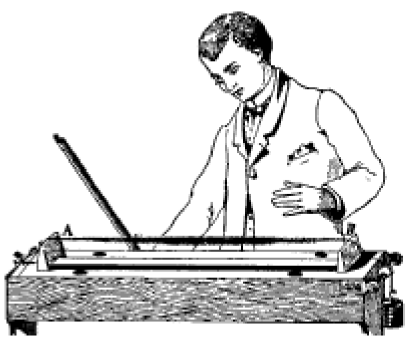

Index of chapters

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ACOUSTICS FOR VIOLIN AND GUITAR MAKERS

Chapter 8 – Applied Acoustics
FUNDAMENTALS OF THE VIOLIN TONE

Chapter 8.
THE TONE AND TONAL QUALITY OF THE VIOLIN
First part: FUNDAMENTALS OF THE VIOLIN TONE

INTRODUCTION
In this part fundamentals of the tone production of the violin will be presented, i.e. the road from bow via the violin to the tone radiated in the room. It starts with describing the interaction between the violin bow and the string. It continues with presenting how bowing parameters affect the violin tone. Finally the spectrum of the tone and limitations set by playing, by holding and by radiation properties of the violin are presented.

8.1. FUNDAMENTALS OF BOW-STRING INTERACTION
The tone of the violin is generated by the bow pulled perpendicularly across the string, see Fig. 8.1. The bow hair is in contact with the string at a certain distance from the bridge, at the contact point. The bow is pressed against the string with a certain force, the so-called "bow pressure". The bow is pulled across the string at a certain velocity, the bow velocity.

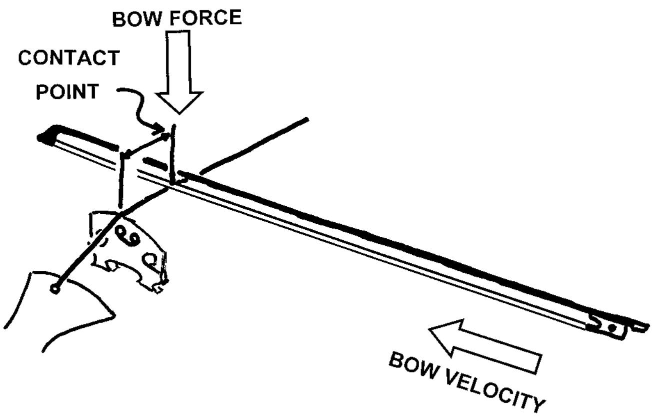

Figure 8.1. Physical bowing parameters, bow force (bow pressure), contact point and bow velocity.

The bow is pressed against the string with a carefully selected bow force (bow pressure). When the bow is pulled across the string, the bow hair is attached to the string at the start. The string is moved with the same velocity as the bow, i.e. the bow velocity. This phase of motion of the string is called the stick phase. When the string has been pulled sufficiently far from equilibrium, it is torn free from the rosined bow hair and slides quickly back. This phase of motion is called the slip phase. The string slips past equilibrium, is caught by the bow hair and a new stick phase starts. The procedure is repeated periodically, i.e. stick-slip-stick-slip-stick etc. The summed duration of a stick and a slip phase is constant and sets the fundamental frequency of the played tone. During the stick phase the string motion is slow and during the slip phase it is fast. The string vibration under the bow, stick, slip, stick, slip, etc., is typically as shown in the upper part of Fig. 8.2. This vibration of the string results in a sideways varying angle, small but still an angle variation at the bridge. The angle variations at the bridge results in a saw tooth force at the bridge, i.e. the Helmholtz-movement, a sawtooth curve. The saw-tooth force has a spectrum as shown in the bottom of Fig.. 8.2.

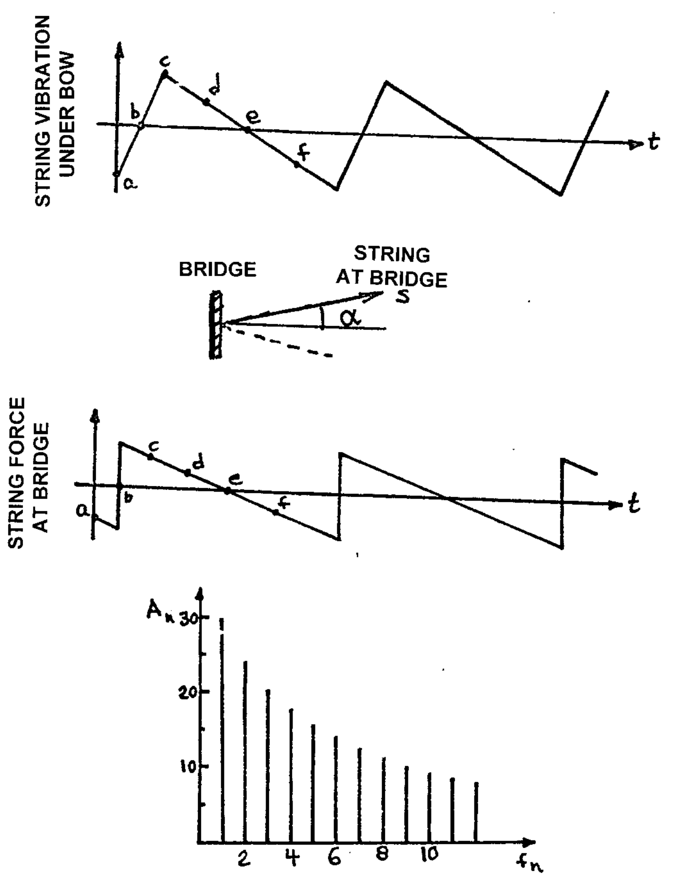

Figure 8.2. String motion at contact point, angle variations of string at bridge and string forces at the bridge (all three seen from above), and tone spectrum of bridge force.

At low frequencies, i.e. a long period time compared to the time window of analysis, a step is obtained at the slip. Thereafter in the stick phase the force of the string is close to zero until the next slipphase. This time function is the best record of the force signal and can be thought of as whip lashes repeated with constant time intervals, see Fig. 8.3. At high frequencies, i.e. short period time relative the time window of analysis, the forces of the string give a constant spectrum. The spectral description is very good. The partials of the spectrum decreases to 1/2 (6 dB) at every frequency doubling (octave).

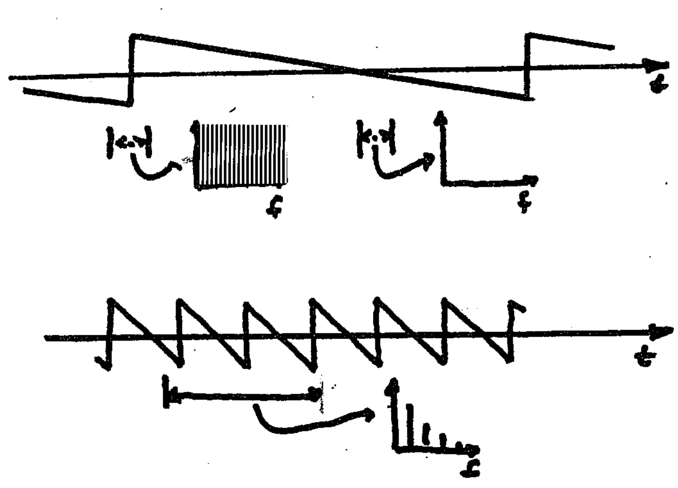

Figure 8.3. (Upper part) At very low frequencies a step of the force is caused at every slip and thereafter slowly varying amplitude. A short time window gives a flat pulse spectrum at the step, no spectrum signal between steps, and (lower part) with a time window long compared to the period of the force signal, the normal case, a tone spectrum is obtained.

8.2. BOW-STRING-TONE

A violin player selects the bowing parameters with high accuracy, consciously and unconsciously. The player selects bow velocity, contact point bow-string (bridge-bow distance), the bow position and the force the bow is pressed against the string (bow pressure), see Fig. 8.4. By means of the selection the "right" tone is obtained. The selection is continuously changed for the best result.

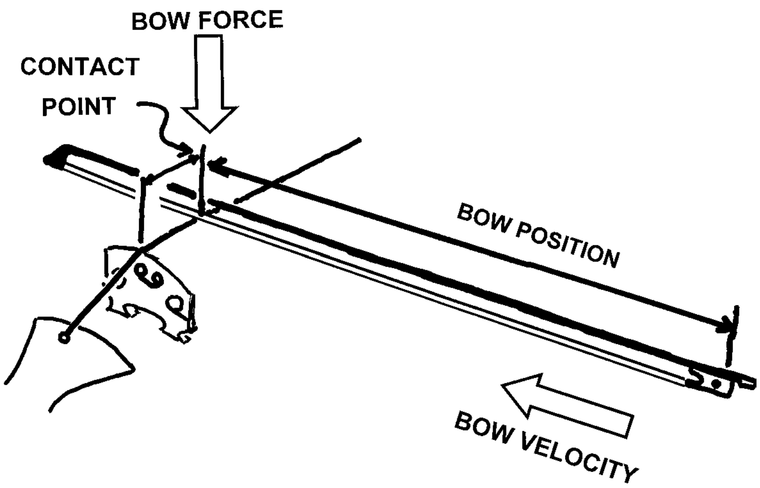

Figure 8.4. A violin string is played with a bow. The player controls bow velocity, bow position, bow distance to the bridge (contact point), and the force pressing the bow against the string (the “bow pressure”).

But the violin player can not select the bowing parameters freely. For a specific value of the bow velocity the "bow pressure" must be selected within a permitted working range to obtain a proper violin tone, a Helmholtz motion, see Fig. 8.5. Playing close to the bridge gives a brilliant but a tone difficult to control.

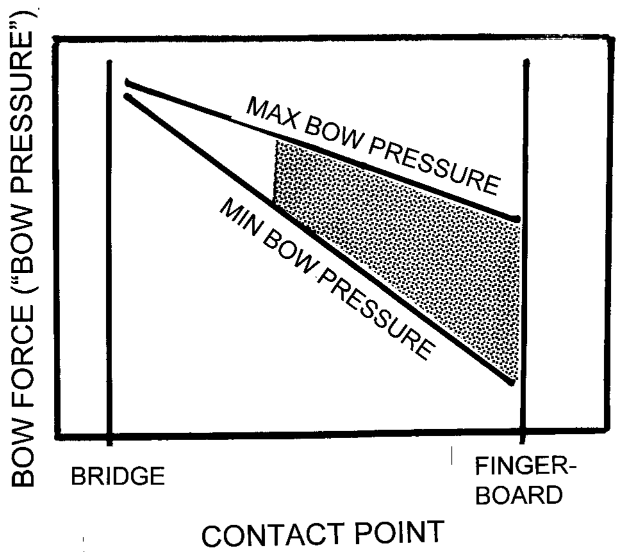

Figure 8.5. Allowed working range (shaded area) for "bow pressure" (the force pressing the bow against the string) at different bow contact points (after Schelleng 1973).

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But a player can play soft or loud. This is done mainly by increasing the "bow pressure", see Fig.. 8.6. The spectra show that increasing from pp to mf it is mainly an amplification of the partials. But with playing mf to ff it is mainly the strength of the higher partials that is increased. This is a typical feature of our traditional musical instruments. Playing louder is not a simple amplification. It is also an increase of the strength of the highfrequency relative the lowfrequency partials. One can hear if an instrument is played soft or loud independent of the loudness control of the amplifier of the record player.

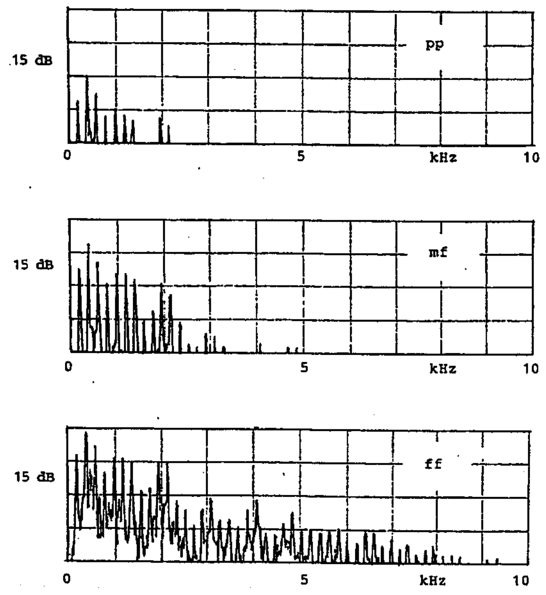

Figure 8.6. Spectral differences between pp, mf, and ff.

When a car is started it accelerates up to the wanted velocity. Without an initial acceleration no velocity can be obtained. The same is true for playing with a bow. Initially the bow must be accelerated up to the wanted velocity. As the tone start is crucial for a good tone the player must monitor the acceleration with high accuracy for the perfect tone start, see Fig.. 8.7. The tolerance is only 5/100 sec for the prolonged start and 9/100 sec for multiple slip start, if the tone start should be heard as perfect. Starting with a low acceleration demands a low and very well controlled bow force (“bow pressure”).

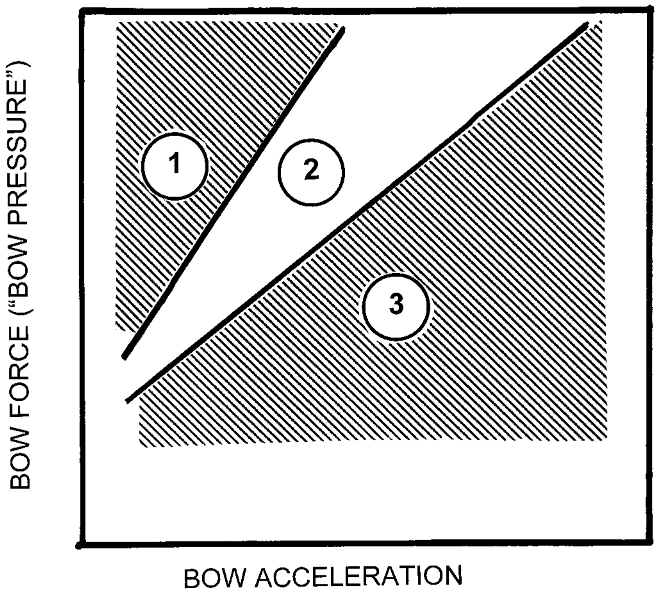

Figure 8.7. Typical allowed working range for perfect tone attack (range 2). Range 1 results in non-perfect "prolonged" attacks and range 3 in non-perfect "multiple slip" attacks (after Guettler 2002).

8.3 TONE SPECTRUM

Let us again look at a comparison of radiation, of 10 old Italian violins, and the bridge vibration sensitivity, of 10 soloist violins, i.e. two sets of the highest quality of violins, Fig. 8.8. The similarities in spite of the two different ways of measuring are obvious, i.e. in the P1, P2 and BH levels and frequency ranges. Unfortunately there excists no measurement of radiation and bridge vibration sensitivity of the same set of top class violins. Still it seems fair to draw conclusions, also for radiation, of violins tonal properties from their vibration sensitivities of their bridges.

The vibration sensitivity at the bridge of a violin can be measured under different "boundary conditions" without external disturbances. The vibration sensitivity can be measured for a violin freely suspended and held for playing, respectively (magnet coil replaced with a miniature accelerometer waxed to the bridge). If the sound radiation is measured in playing both the musician and the holding influences the result. A comparison of a violin measured in our standard way and held rather hard for playing is shown in Fig. 8.9. The P1 and P2 peaks are much influenced by the holding. Influence is moderate at higher frequencies. A closer look shows that the

P1 peak is almost lost in the holding for playing. This is a further support that the P2 represents the main resonance of the violin.

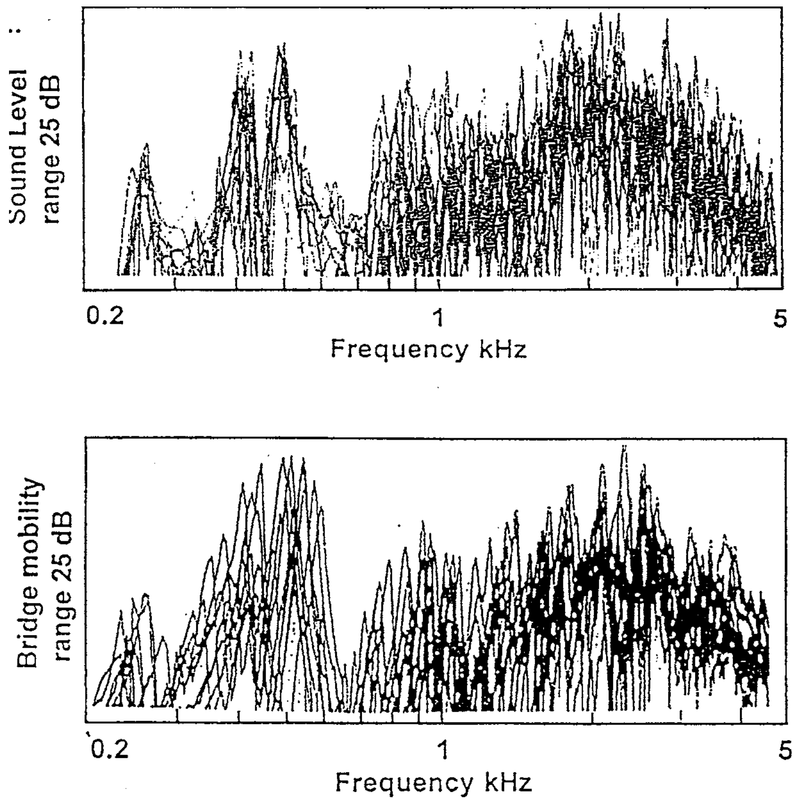

Figure 8.8. Sound radiation (sound level, after Dünnwald) and vibration sensitivity of bridge (mobility, after Jansson) of soloist violins.

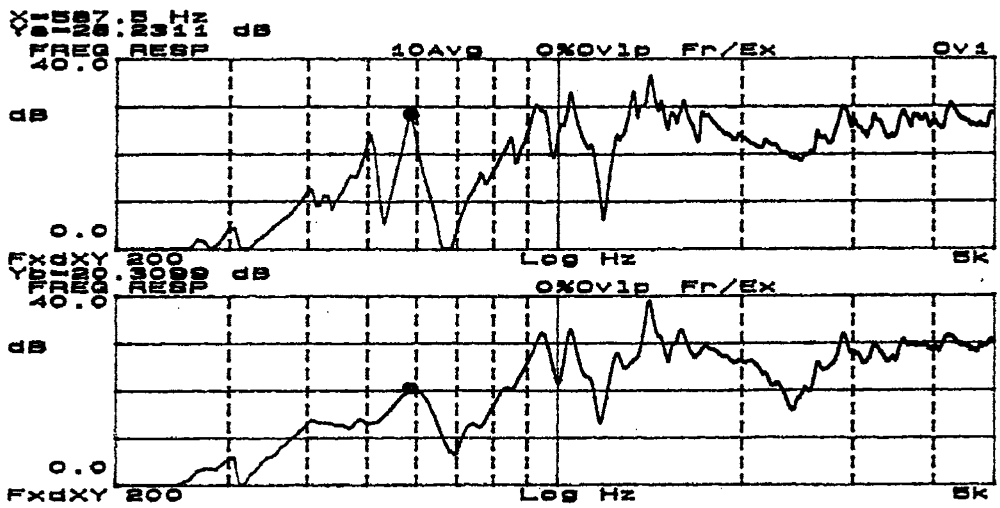

Figure 8.9. Vibration sensitivity of a violin free on supports and held for playing – violinLeon Bernardel 1909 with cursor on P2.

8.4 SUMMARY

The "correctly" bowed string results in a Helmholtz motion at the bowing point, a short slip-phase and a long stick-phase. The player must monitor the contact point, the "bow pressure" (bow force), and the bow velocity with high accuracy, especially with playing close to the bridge. For a perfect tonal start the bow force and the bow acceleration must be accurately selected. Playing ff results in stronger high partials and results in a perceived louder tone.

8.5 KEY WORDS

Slip, stick, contact point, bow velocity, bow acceleration, and bow pressure (bow force).

Chapter 8. second part: ACOUSTICAL QUALITY MEASURES

INTRODUCTION

In this part properties of the played violin, its tone and its quality are introduced. First the Catgut Acoustical Society is presented together with some major findings, especially by Carleen Hutchins. Secondly results of tonal quality and violin response properties, details as peakiness of the violin response curves by Mathews and course properties as findings by Alonso Moral. Finally two methods of investigating spectral properties (LTAS) and time properties (WPT), respectively, of played, violin tones are presented.

8.6. CATGUT ACOUSTICAL SOCIETY AND CARLEEN HUTCHINS

Around Frederick Saunders, a physics professor at Harvard in USA, a group of violin enthusiasts grew up and they called themselves facetiously, the Catgut Acoustical Society. Today this group has grown out to some 800 members all over the world. One of the methods used by Saunders was maximum sound level curves, i.e. the sound level of each note a semitone apart played as loud as possible over the complete range of the violin (these curves were somewhat unfortunately called loudness curves, which with today's standard terminology is misleading). In Fig. 8.10 such sound level curves are shown for the average of five and for two single Stradivarius violins (from Saunders: The Mechanical Action of Violins, J Acoust Soc. Am, October 1937). The air resonance A0 was found at C sharp ca 260 Hz and probably also the P1, P2 and BH as marked in Fig. 8.10. Saunders concluded there is "main wood" resonance is just above the open A-string frequency.

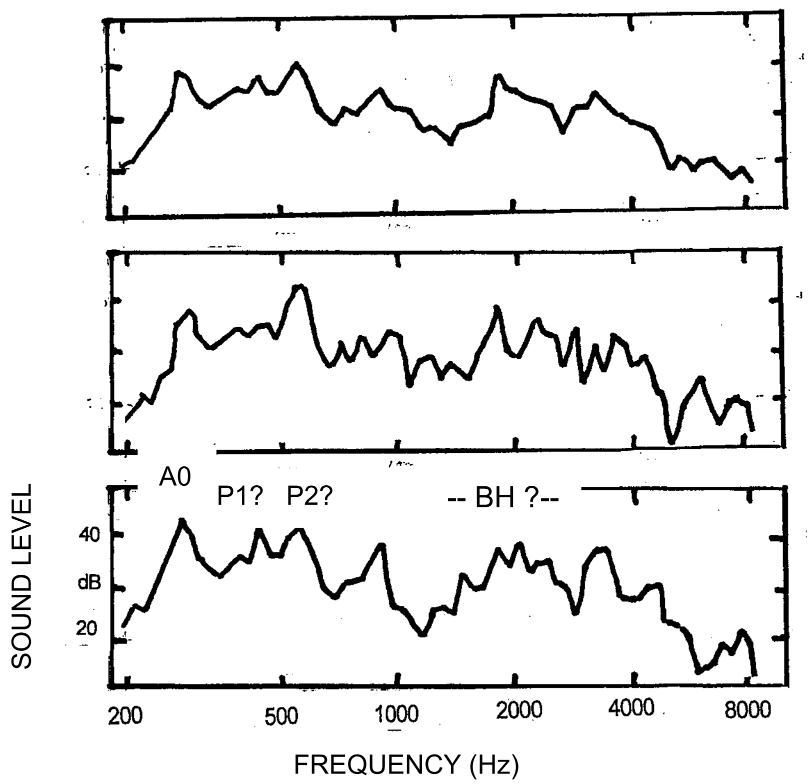

Figure 8.10. Sound level curves obtained from played tones (top frame) average of five Stradivarius violins and (lower two frames) two of the Stradivarius violins separate (from Saunders).

Starting from the two resonant frequencies for A0 and for the "main wood resonance" being close to the frequency of the middle two open strings of the violin, Saunders, Schelleng and Hutchins designed a new family of violins, "The New Violin Octet". The ordinary violin was acoustically rescaled into two new treble instruments and into five lower tuned instruments. The instruments were made possible to play by readjusting lengths, volumes and wood thickness. In the octet the ordinary violin turned out to be too weak and therefore a new "Mezzo violin" with a stronger tone was designed. This was obtained by increasing the size of the top and back plates and decreasing the height of the ribs. The instruments are most interesting from a timbre point of view as they are "acoustically normalised" to the working range of the instruments. Especially the vertical viola, which has a timbre and tone volume and which can be used as a solo instrument in the viola range (Hutchins: Founding a Family of Fiddles, Physics Today, February 1967).

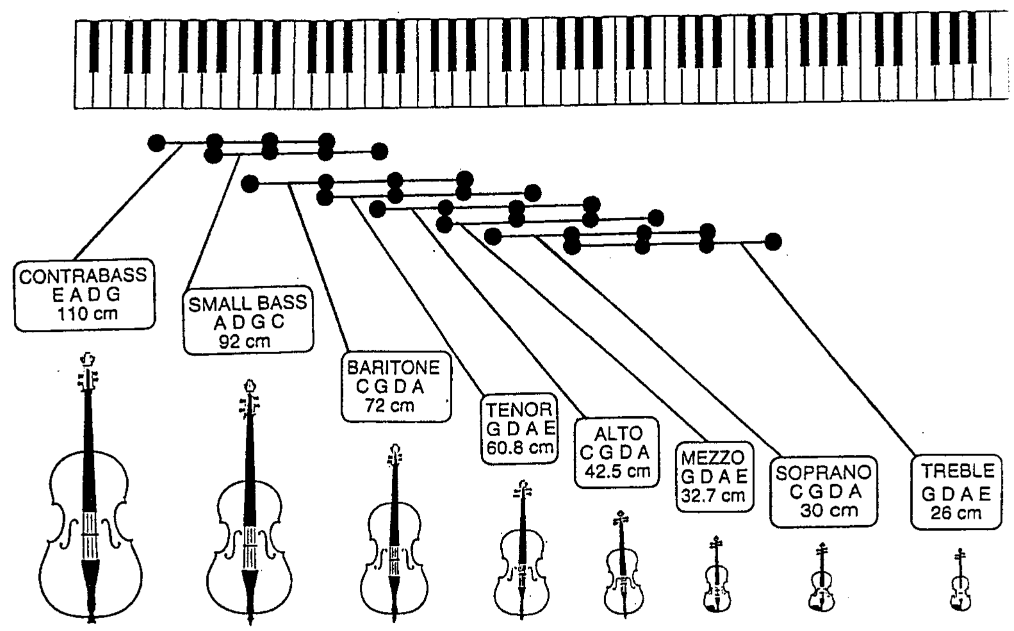

Figure 8.11. The new violin octet constructed Saunders, Schelleng and Carleen Hutchins and built by Hutchins - string tunings and relative sizes for the big bass, the small bass, the new cello (baritone), the tenor violin, the vertical viola (Alto), the mezzo violin, the soprano violin and the treble violin (after Hutchins).

Carleen Hutchins has lately published results from investigations with violins and violas of a new method (Hutchins: A Measurable Controlling Factor in the Tone and Playing Qualities of Violins, J. Catgut Acoust Soc, November 1989). By means of a small sound emitter inserted through one of the f-holes into one of the lower bouts of the air volume and a small microphone through the other f-hole in the other lower bout, the vibration sensitivity of the air cavity has been measured, c.f. Fig. 8.3. The measurement is technically simple to make with no influence on the violin. The vibration sensitivity has been measured for a number of violins and has been related to their quality. A strong relation was found between the frequency separation between two resonances, A1 and B1, and important quality properties of a violin, see table 8.1 (A1 is the air resonance similar to A1 for the guitar, see Fig. 6.11, and B1+ corresponds to the resonance at our peak P2).

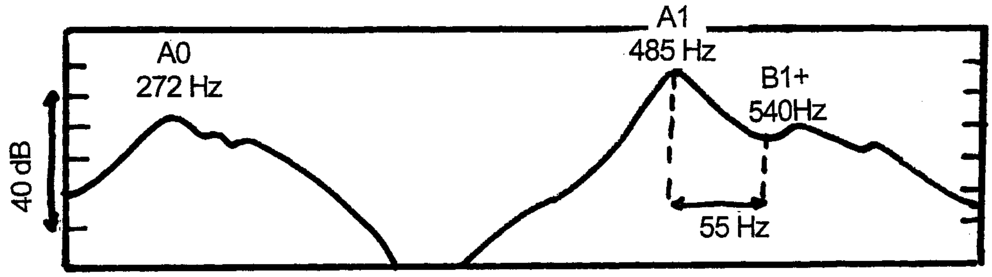

Figure 8.12. Examples of vibration sensitivity curves with the new test method: The frequency separation between peak A1 (at 485 Hz) and valley B1 (at 540 Hz) have been marked with a triangle and the separation measured in Hz (after Hutchins).

Table 8.1. Frequency separation A1-B1 and typical tonal character for corresponding instrument (from Hutchins, summary).

Frequency discrepancy Hz	Tonal character	Frequency discrepancy Hz	Tonal character
> 100	very rough tone	40-50	solo instrument
70-80	bright and carrying	30-40	easy to play, not carrying
60-70	Bright, fine and carrying	20-30	soft tone
50-60	solo instrument	< 20	soft and weak tone

Hutchins has also found that it can be advantageous to tune the free part of the fingerboard of the frequency of the A0 resonance. This can be done by listening to A0 with damped fingerboard and thereafter tune the fingerboard to the same frequency with, damped A0. Unfortunately there is no published set of data on a large number of violins suitable to test the Hutchins criteria on.

8.7. PEAKINESS AND FINDINGS OF J. ALONSO MORAL

The vibration sensitivity curve for a violin has many peaks and valleys. The importance of the peakiness has been investigated with an electronic experimental violin, see Fig. 8.13 (Mathews and Kohut: Electronic Simulation of Violin Resonances, J Acoust Soc Am vol 53 no 6 1973). Thereby it was found that an even frequency response like in the upper frame gives a peculiar insensitive violin tone, but a moderate peakiness as in in the middle frame gives a more violin sounding tone. Large unevenness as in the lowest frame gives a hollow tone. Thus it seems that a violin should have the right amount of peakiness. Later experiments with the same electronic violin have shown that a high level in the bridge hill range is very important.

A similar type of electronic viola has been made for conventional use, see Fig. 8.14 (Gorrill: A Viola with Electronically Synthesised Resonances, Catgut Accost Soc. Newsletter, no 24, Nov. 1975). A viola with damped top and back plate was

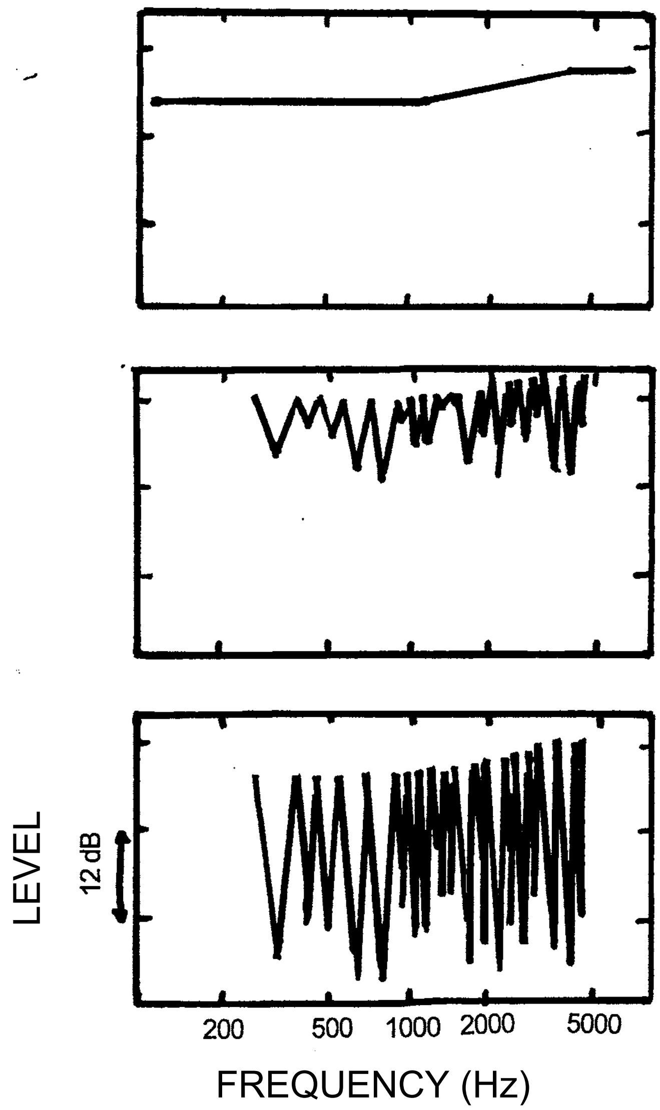

Figure 8.13. Different peakiness used in timbre experiments (from Mathews and Kohut).

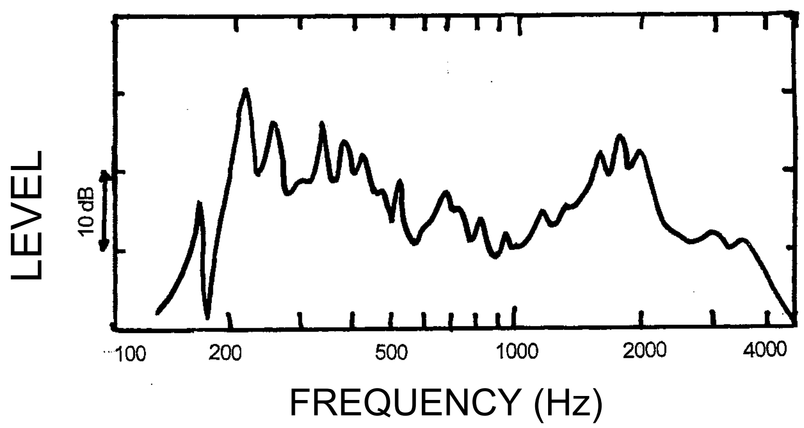

Figure 8.14. Vibration sensitivity (mobility) curve for an electronic viola (from Gorrill).

provided with a pickup system similar to the one used in Fig. 8.13. An electronic filter replaces the vibrating body and the sound is radiated via a loudspeaker in the back of the viola. The electronic filter gives peakiness and broad hills similarly to the vibration sensitivity of the viola, see Fig. 8.14. The instrument works well. According to Gorrill the viola is not very sensitive to how it is adjusted in solo performance and for playing together with piano. In the string quartet, it is very important that the right amount of peakiness is adjusted for a good tonal quality. Further the overall sound level must not be increased much, because this will make the viola unacceptable in the traditional quartet music (the composers have evidently tailored their music to fit the fairly weak viola tone and a removal of this weakness gives the instrument limited use).

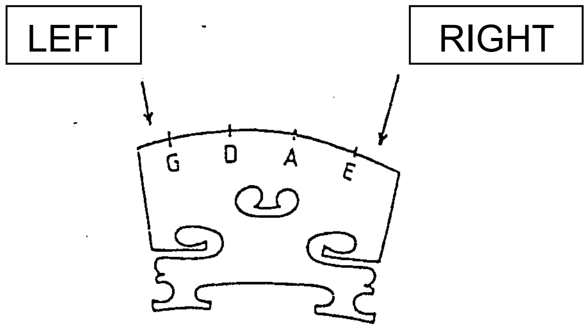

Figure 8.15. Measurement positions for vibration sensitivity, left and right.

ACOUSTICAL MEASUREMENTS

As a summary of our early investigations at KTH, the main parts of an investigation by J Alonso Moral are given (FIOL-80) with the important quality determining parameters for the violins The results should be regarded as a step on the way to determine the quality of a violin and not the final solution.

If a violin is set into vibration and the vibrations are measured at the driving point, a measure of the vibration sensitivity (mobility) of the violin is obtained. In this investigation the vibration sensitivity was measured at two positions on the bridge, one at the G-string and the other at the E-string, see Fig. 8.15.

The vibration sensitivity can be measured with a tone of specific frequency (pitch) and the vibration sensitivity at that very frequency is obtained. If the frequency is slowly changed from 50 Hz to 10 kHz, then we can measure the vibration sensitivity of the most important frequency range. This can be made automatically with electronic devices and curves like the ones in Fig. 8.16a are obtained. This violin was used as an example on a very good violin (it was lent to us before FIOL-80 and the vibration sensitivity was only measured on the left side). Thus the vibration sensitivity for 25 violins was measured in this investigation. Along the vertical axis of the diagram the vibration sensitivity can be read for the frequencies along the horizontal axis.

To avoid the influence from vibrating strings, the strings were damped with pieces of foam plastic against the fingerboard. The violins were hung in rubberbands and were thus isolated from external vibrations and resonances of the holding structures.

For the investigation, the tonal quality of violins submitted to the amateur violin makers´ exhibition FIOL-80, were put at our disposal. Violins were selected according to table 8.2.

Table 8.2. Violins selected from the FIOL-80 exhibition to the acoustical investigations.

number of violins	tonal quality points	Class
10	72-62	I
7	60-50	II
7	48-32	III

IMPORTANT ACOUSTICAL PROPERTIES ACCORDING TO MEASUREMENTS

By looking at the vibration sensitivity (mobility) curve for the violin with Andrea Guarnerius label, Fig. 8.16a, five peaks labelled A0, T1, C3, C4 and F are found. This good violin has three strong and clean peaks marked T1, C3 and C4. The level of these peaks we shall refer to as acoustical property 1.

Further we can see that these peaks are of similar height. The similarity in peak height for these peaks should be referred to as acoustical property 2.

Other properties seemingly favouring the quality of a violin are indicated by the best violin of the exhibition in Fig. 8.16b, in contrast to the not so good violin, Fig. 8.16c. The curve for driving at the left side (full line) and the curve for driving to the right (dashed line) follow each other for the good violin above 1 kHz but not for the less good one (for frequencies below 1 kHz. The vibration sensitivity is lower for driving to the right than to the bass side). The similarity in course above 1500 Hz for these two curves we refer to as acoustical property 3.

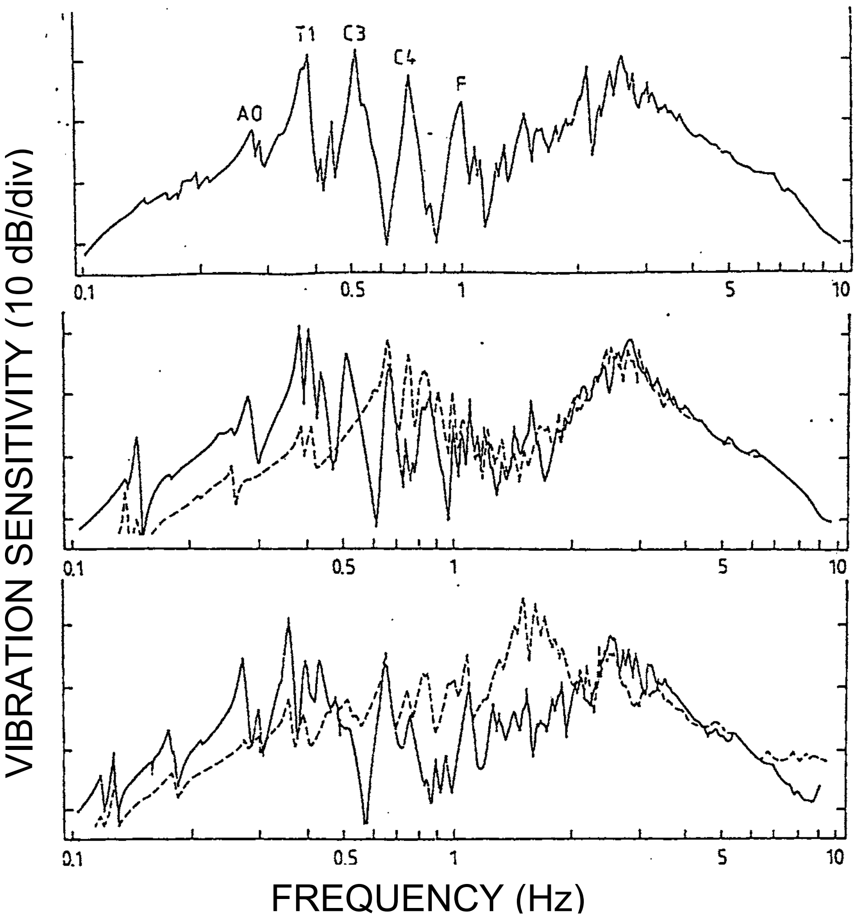

Figure 8.16. . Vibration sensitivity of a) a very good violin (measured earlier and only at the bass side, F Ruggieri with label Andrea Guarnerius), b) the best violin of FIOL-80, and c) a less good violin of FIOL-80. The vibration sensitivity measured at the bass side left is marked with a full line and at the treble side with a dashed line (from Alonso Moral)

From the same diagrams (Figs 8.16b and 8.16c) a more marked level increase can be found for the better violin for the driving at the left side. This acoustical property we refer to as acoustical property 4.

ACOUSTICAL QUALITY POINTS AND TONAL QUALITY POINTS

In the preceding paragraph four acoustical properties were introduced, which are likely to provide a measurement of the quality of a violin. These properties were "weighted" by the acoustical measurements and compared with quality points given by the test players. The result for the 24 violins from FIOL-80 is summarised in the following.

The acoustical property 1 was weighted by the average height for the T1, C3 and C4 peaks for driving to the left. High level gives high points and this property should correspond to a strong tone at low frequencies. The property correlates well with the test players tonal quality points (correlation coefficient 0.53).

Property 2 was weighted by the summed level deviation of the three peaks from their average. Small deviations give high points for this property. High points should mean that the violin is evenly excited at low frequencies. It should correspond to tonal evenness between notes in the low register of the violin (correlation coefficient 0.23 between property 2 and tonal quality points).

Property 3 was weighted by the similarity in level between 1500 and 3000 Hz for driving to the left and to the right. Small deviations give a high point. The property may predict the tonal evenness between different strings (correlation coefficient 0.17 between property 3 and tonal quality points).

Property 4 was weighted by the slope of the vibration sensitivity curves from 1500 to 3000 Hz, for driving to the left. A steep slope should result in a high point (correlation coefficient 0.38 between this acoustical quality point and the tonal quality points).

ACOUSTICAL EVALUATION

The relations between calculated acoustical quality points and the tonal quality points of the test players are shown in Fig. 8.17. There is a good agreement with the acoustical quality points and the tonal quality points, except for five violins.

The correlation between the acoustical quality points and the tonal quality points, the five deviating violins excluded, is good (correlation coefficient better than 0.92).

Thus we have seen that the quality points derived from the selected acoustical properties should be useful to predict quality of violins. This means that the vibration sensitivity curves should measure important acoustical properties and that the quality of a violin may be predicted from its vibration sensitivity curve. Unfortunately, the very good violin, carefully selected by one of the top Swedish violin players, was measured earlier and only at the bass side, an earlier standard used.

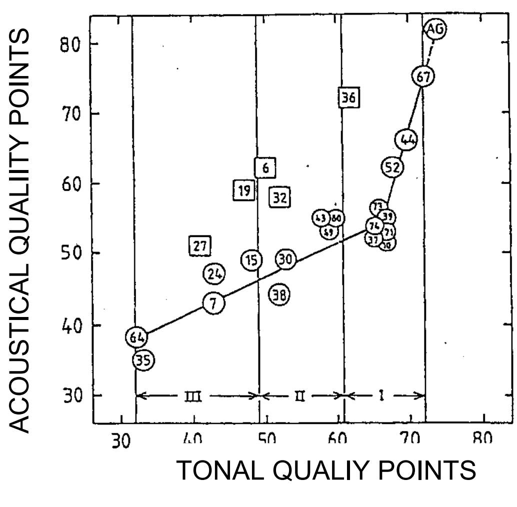

Figure 8.17. Relation between tonal quality points and acoustical quality points – circles with numbers for well fitting violins, and squares with numbers for not well fitting violins. The F Ruggieri violin marked with AG and the different tonal quality classes with I, II, and III.

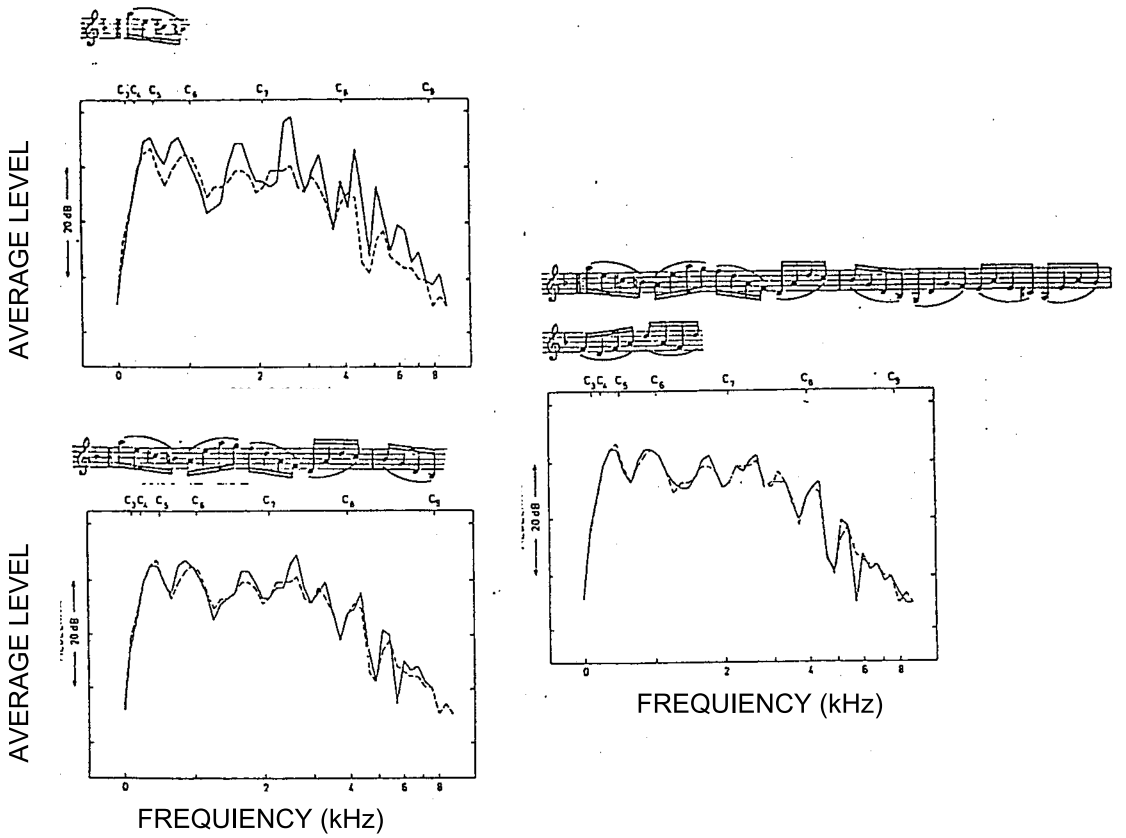

Figure 8.18 Long-time spectra and played music (full lines the noted sample 2, 10 and 20 s, respectively, dashed lines 100 s).

8.8. AVERAGED SPECTRA (LTAS) AND TIME FUNCTION (WPT)

It is well recognised that already after a few notes the player obtains a fair picture of how a violin sounds. This is difficult to understand from physical point of view as all partial tone spectra look different, even from the same violin. One way to attack this problem is to filter the sound in a way that corresponds to our hearing and average over a long time, long time average spectra (LTAS). In Fig. 8.18 it is shown that the long time average spectra quickly give a "constant" picture. Long time average spectra for 100 s is shown with a dashed line in the frames. Such spectrum for 2 s, the full line in upper left frame shows some resemblance with the 100 s one, the spectrum for 10 s and for 20 s show almost a perfect reproducibility of the 100 s spectrum, see the following two frames in Fig. 8.18.

Also, with long time spectra groups of violins can be compared, see Fig. 8.19. Full lines here correspond to the average spectra of 8 good violins, and the dashed line represents the average of 7 less good violins. In the upper part of the frame the difference between the two groups are shown. High levels for frequencies below 800 Hz, low levels around 1300 Hz, high at 2500 Hz and low level above 3500 Hz seems to be good.

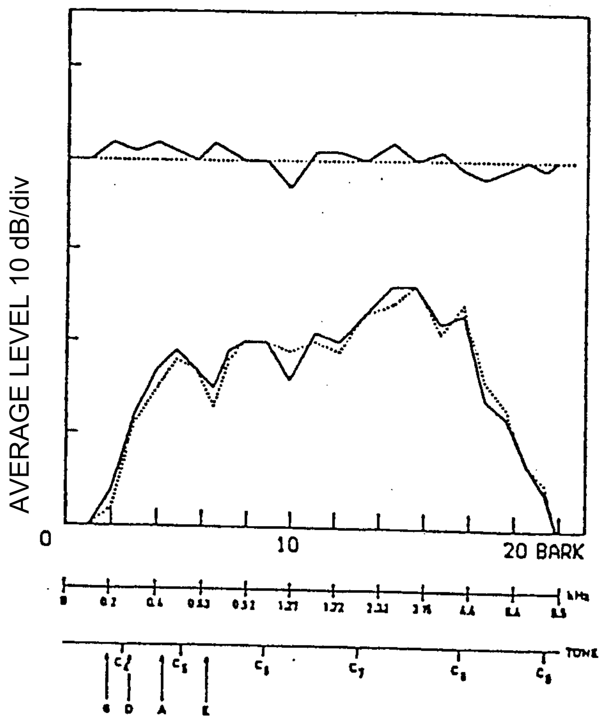

Figure 8.19. Long-time spectra and quality. good quality (full line) and poor quality (dotted line). Difference good-poor quality top curve. (observe the three "frequency scales" BARK, kHz and tone, from Gabrielsson and Jansson).

With long time spectra and filtering the properties of the sound can also be compared with the perception of the same sound, c.f. Fig. 8.20. Above 8 kHz there is little sound energy, which thus should influence the timbre of the violin little. Also partial levels above 4 kHz should give a moderate influence. The partials above 2 kHz should, however, give a considerable influence on the timbre in agreement with the picture shown in the middle frame (the shadowed area is beginning to become rather large). The main influence should however come from partials below 2 kHz. When you hear only partials below 1 kHz the tone is hollow with indistinct tonal attacks (a little of this effect can be caused by the filter). With more and stronger high frequency components, the tone becomes less hollow with more clear attacks. Too strong partials at very high frequencies give a rattling sound. If all partials below 1 kHz are removed it is still perceived as a violin although violins with such a thin timbre do not exist. If all partials above 1 kHz are removed one cannot recognise the tone as coming from a violin. A balance between different frequency regions is thus important.

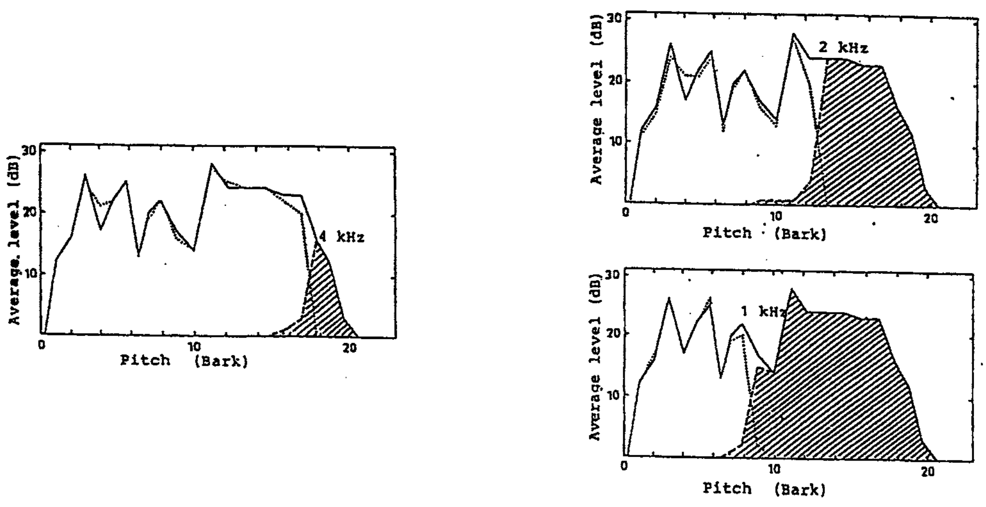

Figure 8.20. Long-time spectra and the influence of different frequency ranges on timbre (the Bark - kHz relation is given in Fig. 8.19).

Also with long time spectra the properties of different strings can be compared and can be characterised, see Fig. 8.21. The long time spectra of each of the four violin strings are shown in the lower part of the frame. It can be seen that except for the lowest hill the four curves closely resemble each other. Further it can be seen that the G-string has the lowest level at high frequencies and that the partials vanish at 18 Bark. The levels became increasingly higher at high frequencies for the D, A and E-string. This is shown even more clearly in the upper part of the figure where the difference in spectrum for all four strings and the single strings have been plotted.

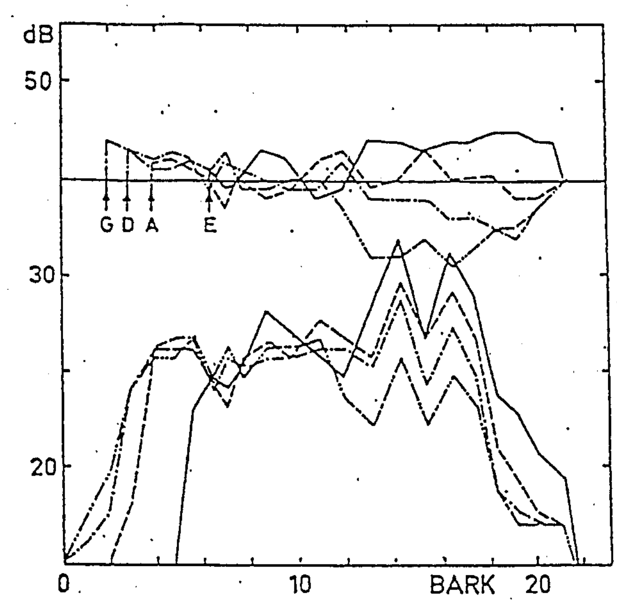

Figure 8.21. Long-time spectra and tones of different strings (the Bark - kHz relation is given in Fig. 8.19, from Alonso and Jansson).

TIME FUNCTION - WPT

A simple synthesis experiment was made in which the initiating impulses and four resonators are modelled as function of time, see Fig. 8.22. Result of the synthesis is shown in Fig. 8.23. In the first line a period of the recorded tone and the reverberation of the high-frequency resonance ("the bridge hill"). In the second line the response to P1 and P1 plus "bridge hill". The synthesis is now much better. Synthesis with P1, P2 and "bridge hill", the bottom line, makes fairly good synthesis - although the high frequency ripples in the end of the period is missing. The 1000 Hz resonator changes the waveform somewhat but not much. Listening indicates that the levels at the resonant frequencies and not the frequencies are the most important. Furthermore it showed that the high frequency resonances dominates the perceived timbre.

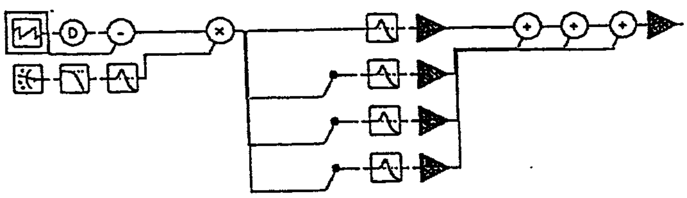

Figure 8.22. Tone synthesis in the time domain – sketch of synthesis program implemented in ALADDIN.

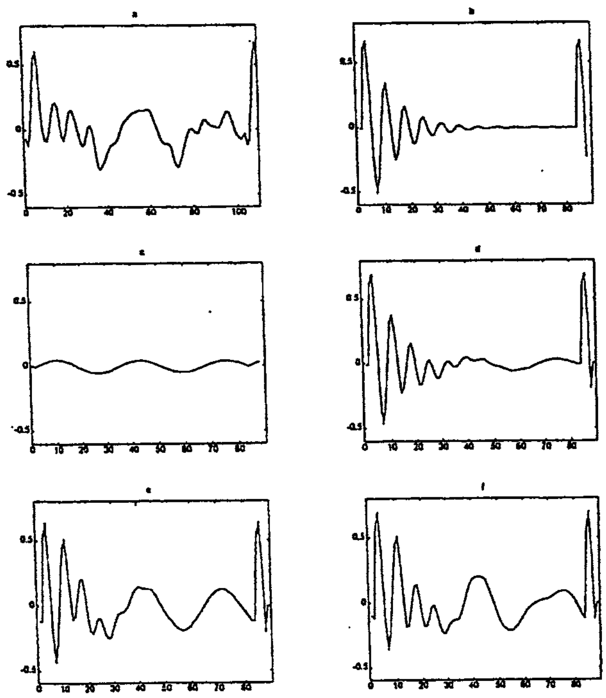

Figure 8.23 Result of tone synthesis in the time domain (upper row) one period of a played tone and synthesis of BH-vibrations, respectively, (middle row) P1-vibrations and P1- plus BH-vibrations, respectively and (bottom row) P1- plus P2- plus BH-vibrations, and P1-, plus P2-, plus 1000Hz- and BH-vibrations, respectively.

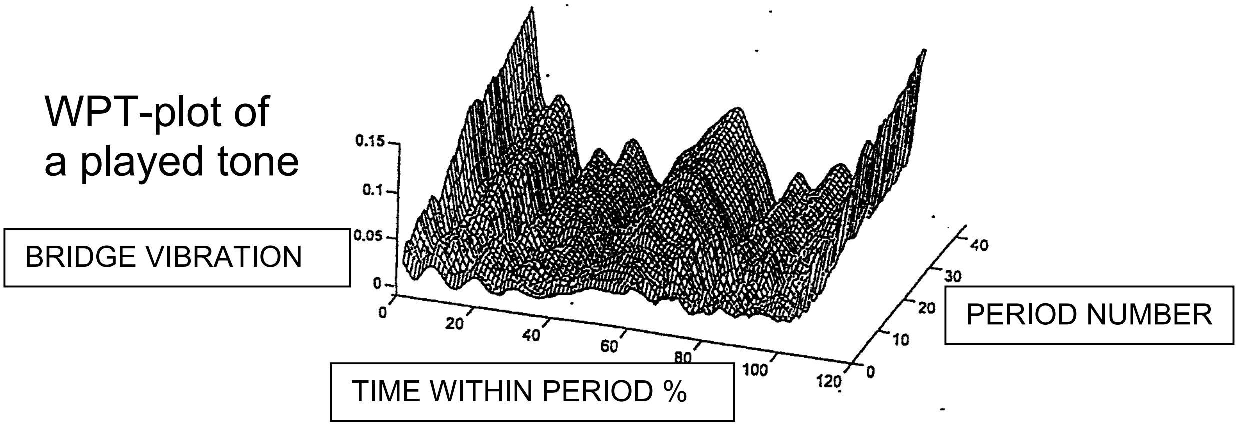

Figure 8.24. Time history of a violin tone (bridge vibrations, WPT-plot invented and developed by F. Le Coustumer).

As a part of his "technical training" Frédéric Le Coustumer developed the WPT diagram, i.e. the Wave shape of a Period as a function of Time and the period number, in a three dimensional drawing, see Fig. 8.24. The plot is of bridge vibrations. To begin with the first period is plotted from 0 % to 100 % of period time.. Thereafter the second period is plotted just behind the first (one step increase in period number). The plotting is repeated over and over. It starts every period from the x-value (0 %) and ends at x-value (100 %). The vibration is presented as the z-value, the vertical axis. In the WPT-diagram of the bridge vibrations of a played tone is shown in Fig. 8.24. The WPT-plot shows mountain ridges separated by parallel valleys. Initially the impulse of the slip phase, the high leftmost ridge, is seen followed by a highfrequency ripple, three minor ridges, a lowfrequency hump, a broad and not so sharp ridge, and finally highfrequency ripple, two minor ridges, before the periods end (100 %). The vibrations of later periods are larger than the initial ones but the shape remains, the ridges and valleys are similar but more and more clear. The period shapes are representative and varies little from period to period.

8.9. SUMMARY

P2 (B1+) is the main resonance at low frequencies, but the BH should be at least equally important. A specific peakiness is favourable. Synthesis in the time domain is informative. The peakiness of the violin response curve is something positive. High levels at low frequencies, low just above 1 kHz and high between 2 and 3 kHz and low above 4 kHz are favourable for the violin tone.

8.10. KEY WORDS

P1, P2 and BH. Frequency ranges, peakiness, resonance peaks and level.