Dept. for Speech, Music and Hearing
Quarterly Progress and Status Report

Eigenmodes and tone quality of the double bass

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journal: STL-QPSR
volume: 23
number: 4
year: 1982
pages: 149-174



KTH Computer Science and Communication

http://www.speech.kth.se/qpsr

D. EIGENMODES AND TONE QUALITY OF THE DOUBLE BASS

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Abstract

The double bass has been studied by measurements of input admittance curves, spectra of isolated tones and Long Time Average Spectra (LTAS). The input admittance curves showed striking similarities with input admittance curves of the cello and also of the violin. A high quality bass was found to be characterized by an input admittance curve with (1) high, distinct peaks in the low frequency range, a little separated in frequency, (2) low resonance frequencies of the Helmholtz air resonance (<60 Hz) and the first top plate mode (<100 Hz), (3) a marked rise in the input admittance curve above 400 Hz.

Spectral analysis of isolated tones recorded in an anechoic chamber was used to study the relative amount of fundamental present in the radiated sound. The fundamental was found to be considerably weaker than the other partials in the lowest register in all of the basses measured. The fundamental was enhanced by a low resonance frequency of the Helmholtz air mode. It was concluded that a "full" tone quality in the low register is connected with the strength of the fundamental.

LTAS analysis of scales recorded in a very reverberant room was used to study the frequency distribution of the radiated sound. Influence from low resonance frequencies of the Helmholtz and first top plate mode in basses with "full" tone quality were found to be displayed in the LTAS.

Introduction

Research on bowed string instruments has traditionally been concentrated on the violin. It is, however, not obvious that the results from violin research apply also to the lower members of the bowed string family. The cello and the double bass of the conventional string ensemble are not only up-scaled versions of the violin. Apart from the differences in size they differ also both in shape and proportions of the body. Another apparent construction difference compared to the violin is the bridge with its high legs. Because of the deviations from the violin design it was considered desirable to make comparative studies of the cello and bass before more detailed conclusions about their acoustical properties were drawn. This investigation deals mainly with the double bass. Input admittance curves, spectra of isolated tones and Long Time Average Spectra (LTAS) are presented and discussed.

INPUT ADMITTANCE AND EIGENMODES

From studies of the input admittance of violins (Alonso Moral & Jansson 1982a), it is clear that essential information on the properties of the violin can be extracted from the input admittance curve. The cello has been investigated successfully with the same method by Lundberg (1982). The data on the cello included in this paper are from his study, which has not been published in English previously. To the author's knowledge input admittance measurements of the double bass have not been published earlier.

Eigenmodes

The vibration properties of a string instrument can be described by its eigenmodes. In a recent work the eigenmodes of the violin have been mapped by means of a novel interferometry technique (Alonso Moral & Jansson 1982a). It was found that the violin exhibits different kinds of eigenmodes, Fig. 1. In the low frequency region below 800 Hz, the violin vibrates as if it were made of a homogenous material. These eigenmodes are labelled body modes, abbreviated C (Corpus). In the lowest body mode (C1) the violin vibrates as the fundamental mode of a free bar. The next higher mode (N) derives from the neck together with the fingerboard. These two eigenmodes are one-dimensional and do not radiate sound. The next higher body modes C2, C3 and C4 are two-dimensional. The C3 and C4 mode can radiate sound. Above 800 Hz the eigenmodes of the violin are limited to either the top or the back plate (plate modes). In addition to these recently explored modes there is the well-known cavity resonance, labelled as the Helmholtz air resonance (A0). At this resonance the top and back plates move in opposite phase and alternatingly enlarges and shrinks the enclosed air volume in the instrument. The Helmholtz resonance often falls close to the neck resonance and an interaction between these modes can thus take place. Another prominent eigenmode is the first top plate resonance (T1), which shows a complicated vibration pattern, the major vibrations beeing located at the bass bar side of the top plate. The eigenmodes of the violin, with the exception of C2, have been verified to exist also in the cello (Lundberg 1982).

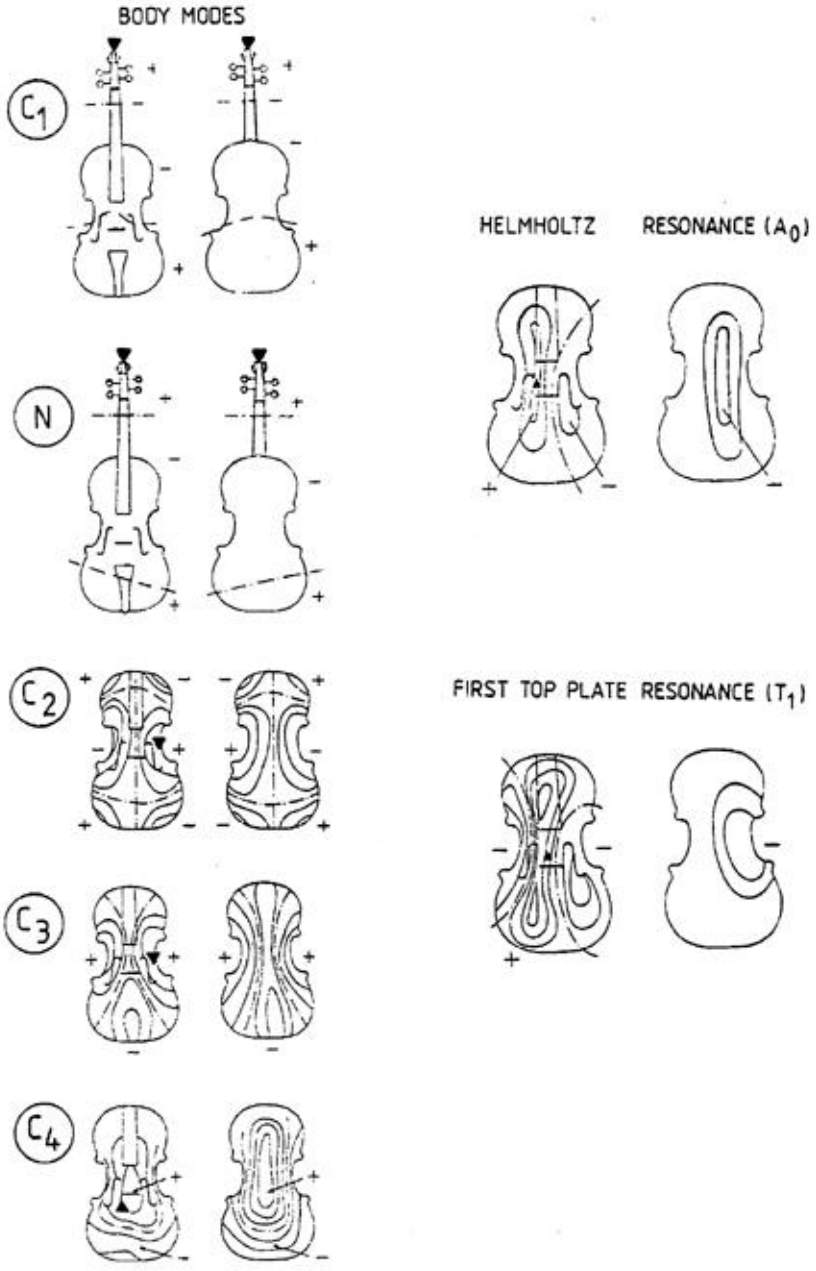


Fig. 1. Eigenmodes of the violin. Body modes C1, N, C2, C3, and C4 (left) together with Helmholz air mode A0, and the first top plate mode T1 (right). Driving point is marked with a triangle, the nodal lines with broken-dotted lines, and the phases of vibration relative to the driving with + and - signs, respectively. (From Alonso Moral and Jansson, 1982)

Measurement of input admittance

The mechanical admittance at a certain point on a vibrating object is defined as the ratio between vibration velocity and force at that point. In the present measurements the admittance was measured at the same point on the instrument as the driving force was applied, hence the term input admittance.

The driving unit consisted of an externally mounted coil, together with a small, very strong, magnet (weight 2 g) mounted on the bridge of the instrument with a piece of wax, Fig 2. The coil was fed from a constant current source which gave an almost constant driving force (+/- 0.5 dB) throughout the frequency range used (40 - 3000 Hz). The vibrations of the instrument were measured with a light accelerometer (B&K 4374, weight 0.65 g) attached to the magnet. This combined driving and measuring system, developed by Jansson, possesses almost ideal properties for admittance measurements of string instruments, featuring low weight and no disturbing internal resonances or losses. One drawback however is the massloading due to the magnet and accelerometer which limits the possibilities to study the properties of light objects, such as the violin bridge, cf. Fig. 2.

The velocity was obtained by integrating the acceleration signal in a passive network. As the driving force was kept constant the admittance was directly proportional to the velocity measured. A chart of the admittance versus frequency could thus be plotted directly on a X-Y recorder as the frequency of the driving signal was swept through the frequency range. The input admittance curves of the basses presented in this study were recorded with the driving at the low E-string side of the bridge in parallel with the top plate as illustrated in Fig. 2. This was found to be the most efficient driving point for cellos and basses. As some bodymodes were weakly excited by this arrangement, complementary measurements were undertaken on the body with the driving perpendicular to the top plate.

During the measurements the instruments were suspended in rubber bands or resting on the ribs on foam rubber supports. The eigenmodes were regarded as practically undisturbed when the instrument was hanging. It was found that the frequencies and levels of the eigenmodes were essentially uninfluenced by resting the instrument on the ribs. The strings were damped during the measurements.

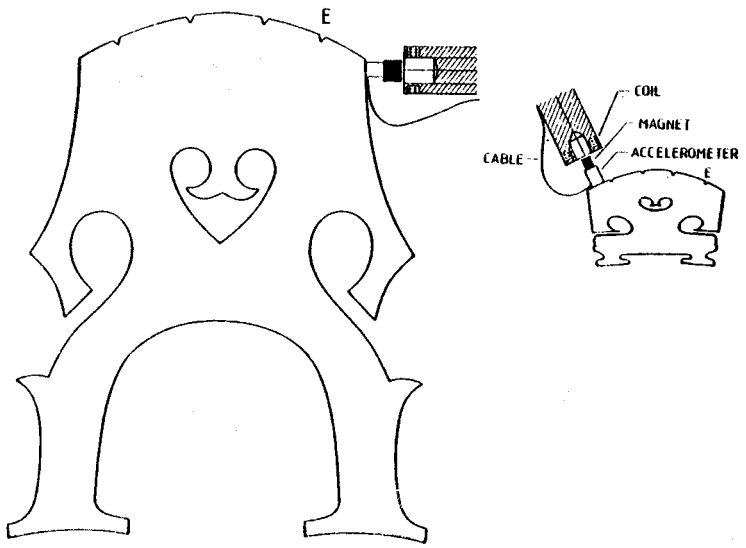


Fig. 2. View of the driving unit (magnet + coil) and vibration sensor (accelerometer) used in input admittance measurements of the violin (left) and double bass (right). The massloading of the bridge due to the magnet and accelerometer is about 30% of the weight of the bridge for the violin and 3% for the bass.

Interpretation of input admittance curves

A peak in the input admittance curve at a certain frequency implies a high vibration velocity and hence also a high vibration amplitude. Thus, the input admittance curve illustrates how easily the instrument vibrates at different frequencies. An eigenmode of the instrument is manifested in the input admittance curve by a peak. It is possible to identify such a peak as a specific eigenmode of the instrument by comparisons with interferometry measurements.

The sound radiation from the instrument may be estimated from the input admittance curve. However, the radiation efficiency of the different eigenmodes is not equal. A correction must be added to the levels of the peaks in the input admittance curve in order to give the radiated sound from the instrument. The effect of this correction for the violin is mainly to raise the radiation at the Helmholtz resonance and to lower the radiation at high frequencies (Jansson 1982).

Comparison of input admittance violin - cello

In a study of the violin by input admittance measurements (Alonso Moral & Jansson 1982a) it was found that instruments of high tone quality were characterized by input admittance curves with tall, equally high resonance peaks in the lower frequency range, followed by a steep slope from 1.4 kHz to 3 kHz. These characteristics of a high quality violin can easily be observed in Fig. 3 (top), which shows the input admittance of a violin made by Andreas Guarneri. The prominent peaks have been identified by means of real time interferometry as the first top plate resonance (T1) and corpus three (C3) and four (C4). It was concluded that the steep slope derives from the principal bridge resonance.

The input admittance curve for the Guarneri-violin can be compared with the input admittance of a high quality cello (Lundberg 1982), Fig. 3 (middle). Also for the cello the input admittance curve exhibits prominent peaks in the lower frequency region followed by marked rise in the curve, in this case starting at 1 kHz. But in contrast to the

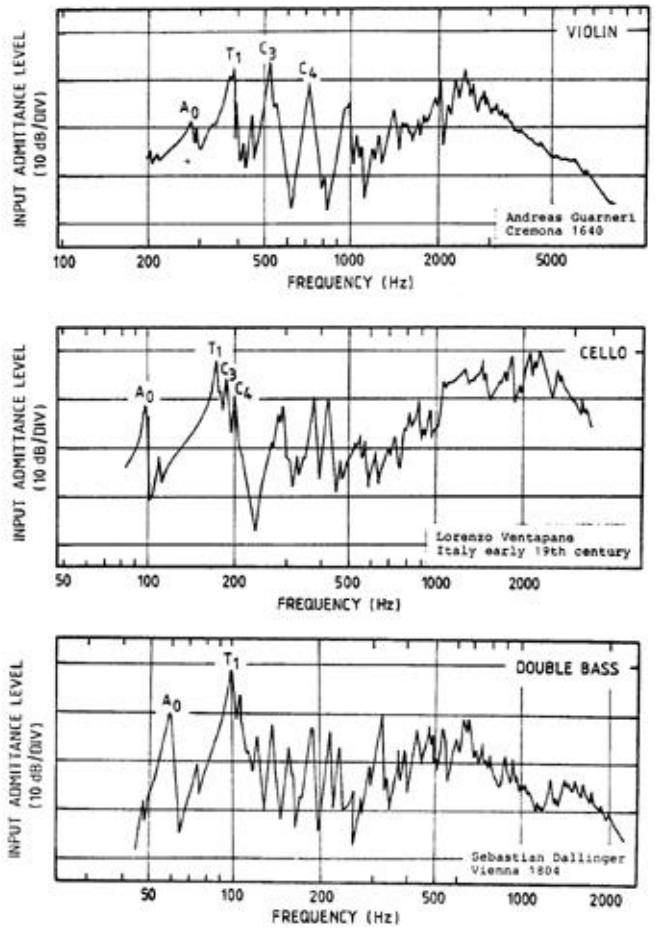


Fig. 3. Input admittance curves of three high quality string instruments, violin (top), cello (middle), and double bass (bottom).

violin, T1, C3 and C4 are clustered close together in the cello and constitute the second prominent peak. The lowest prominent peak is the Helmholtz air resonance which is more pronounced as compared to the violin. The higher prominent peaks consist of one or two plate modes.

From the comparison between the violin and cello it may be hypothesized (Lundberg 1982), that the input admittance curve of a high quality cello and violin respectively should show the same principal characteristics, with high, distinct peaks in the lower frequency range, a little separated in frequency. These similarities in the responses of the two instruments are however achieved in somewhat different ways. In the violin each prominent peak consists of one single resonance. In the cello some prominent peaks are assembled of several resonances. These differences between the input admittance curves of the violin and cello indicate that the cello cannot simply be considered as an enlarged violin.

Comparison of input admittance cello - double bass

If the input admittance curve of a double bass of high quality, Fig. 3 (bottom) is compared with the input admittance curve of the cello discussed earlier (middle), striking similarities can be observed. The first top plate resonance (T1) in the bass forms a prominent peak at approximately 100 Hz together with two other resonances, probably C3 and C4. Thereafter follows a range between 150 - 400 Hz with higher plate modes. In this frequency range the input admittance curve of this bass shows almost equally high and equally spaced resonances. Finally, above 400 Hz, the influence from the bridge resonances can be seen as two wide humps in the curve. The similarities with the input admittance curve of the cello make it reasonable to conclude that the double bass is more closely related to the cello than to the violin. A plausible explanation for this would be characteristic constructional details shared by the cello and bass, e.g. the high ribs.

Comparison of input admittance among double basses

Input admittance curves of four basses of conventional design but of varying quality are compared in Fig. 4. The instruments are ordered

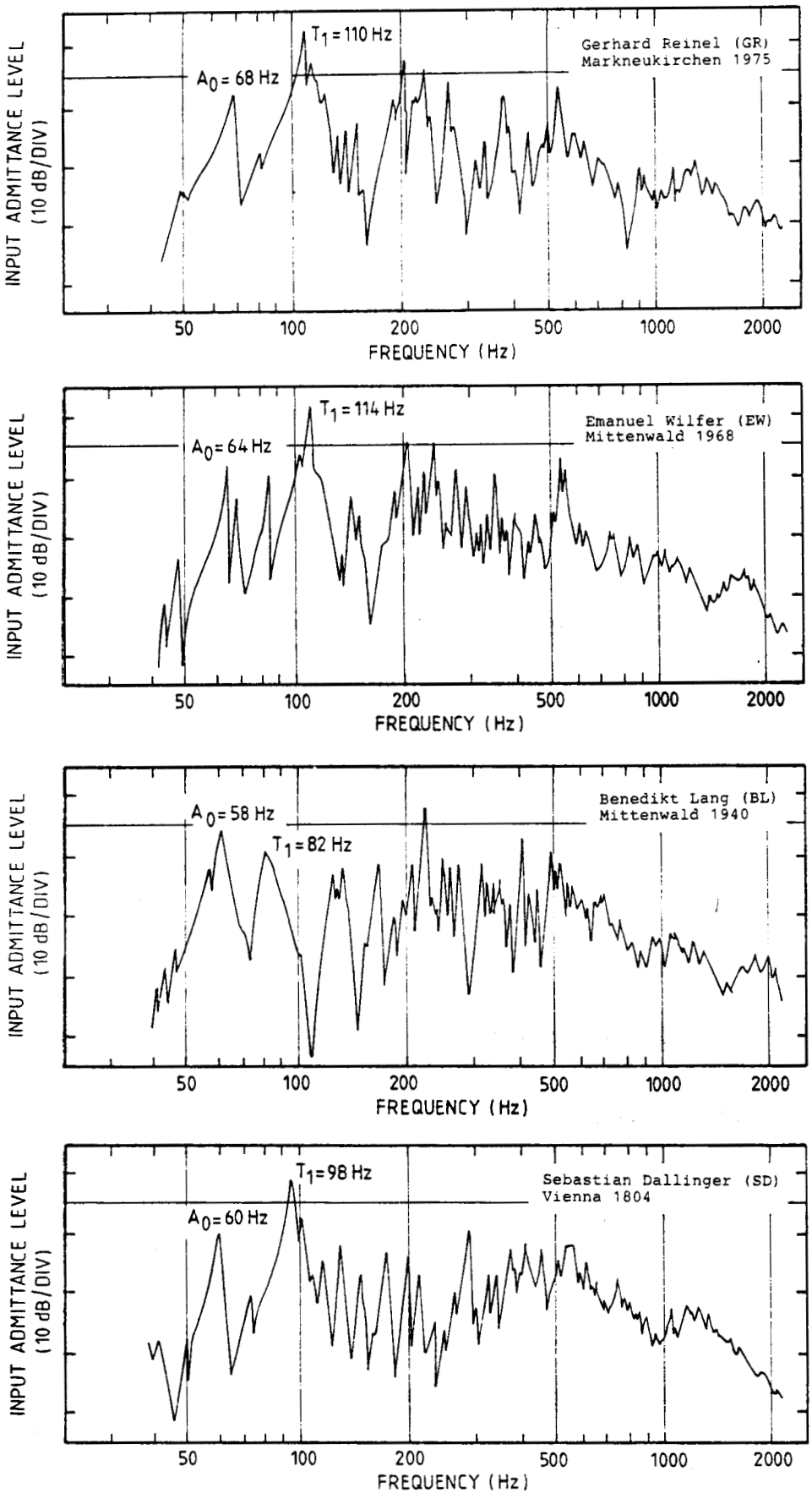


Fig. 4. Input admittance curves of four conventional four-stringed double basses. The instruments are ordered according to price with the most expensive instrument at the bottom. The instrument at the bottom of the figure is the same bass as in Fig. 3. The horizontal lines correspond to the same admittance level. The resonance frequencies of the Helmholtz mode (A0) and the first top plate mode (T1) are included in the figure.

according to price with the most expensive instrument at the bottom. The prices vary between approximately $600 - $20,000. Input admittance curves of the newly designed basses of the New Violin Octet (Hutchins 1967) are shown separately in Fig. 5.

The second bass from the top in Fig. 4 (EW) may serve as a representative of a medium quality bass. The character of the input admittance curve of this bass differs from the character of the curve of the high quality bass (SD), at the bottom of the figure. In the input admittance curve for the medium quality bass several small peaks interfere with the high peaks. A general tendency towards more developed and distinct peaks in the input admittance curves of expensive instruments is discernable as moving downwards in the figure. It is especially interesting to notice that only the high quality bass (bottom) shows a regular structure with equally spaced peaks between 150 - 400 Hz.

The resonance frequencies of C1, N, A0 and T1 for the six basses in Fig. 4 and 5 are compared in Fig. 6. Typical frequencies of the Helmholtz resonance (A0) and the first top plate resonance (T1) for basses of normal size are 65 Hz and 110 Hz respectively. The corresponding frequencies for the high quality bass (SD) are a little lower than could be expected according to the moderate size of this instrument. The Large Bass of The New Violin Octet (CMH LB), which has extraordinary dimensions (length 214 cm), has very low resonance frequencies, A0=42 Hz and T1=81 Hz.

It can be noted that the neck resonance (N) and the Helmholtz resonance (A0) fall close together for three of the basses in Fig. 6. The exceptions are a bass of poor quality in which the N-resonance is considerably lower than the A0-resonance, and the basses of the New Violin Octet which both have a rather high N-resonance, indicating a stiff neck. The frequencies of the C1 and N-resonance of the huge Large Bass are strikingly high with respect to the body length, but the relatively short neck of this bass may be responsable for this. The implications for the sound and playing properties of the instrument of the frequency relations betwen A0 and N are not yet understood. A coupling betwen these resonances is possible if the resonance frequencies are sufficiently close. It may be hypothesized that a neck resonance well separated from the Helmholtz resonance would benefit the playing properties of the instrument, if this decreases the vibrations of the neck, i.e. the string support. The bow-string interaction would then be less disturbed.

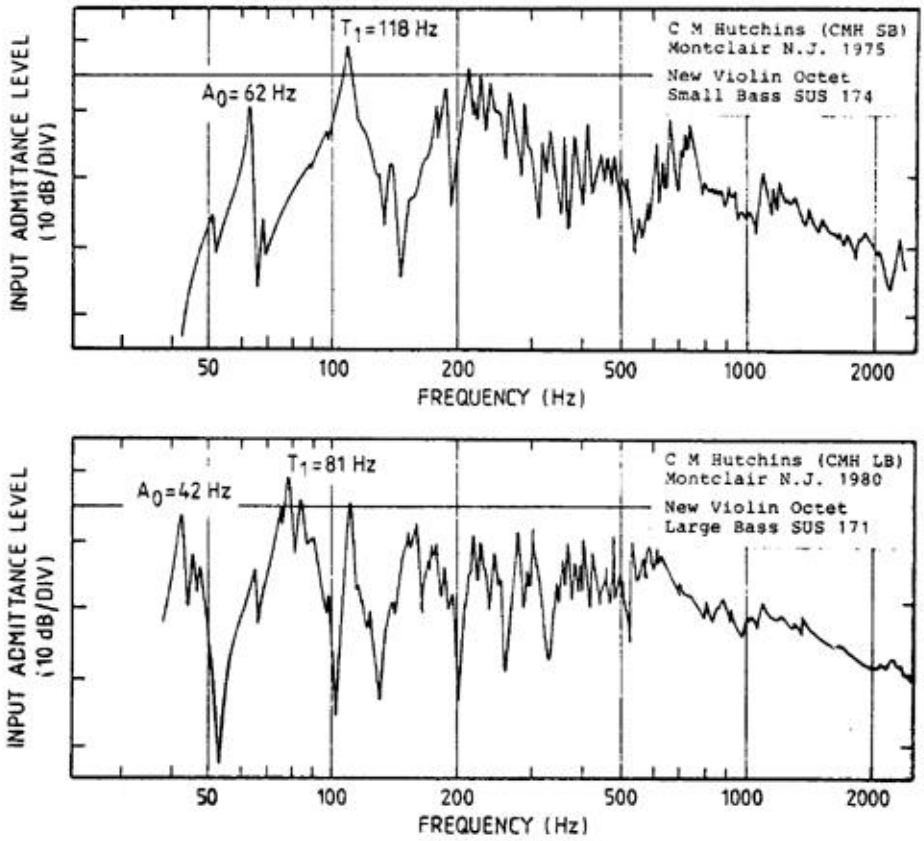


Fig. 5. Input admittance of the basses of the New Violin Octet, Small Bass (top) and Large Bass (bottom). The horizontal lines correspond to the same admittance level. The resonance frequencies of the Helmholtz mode (A0) and the first top plate mode (T1) are included in the figure.

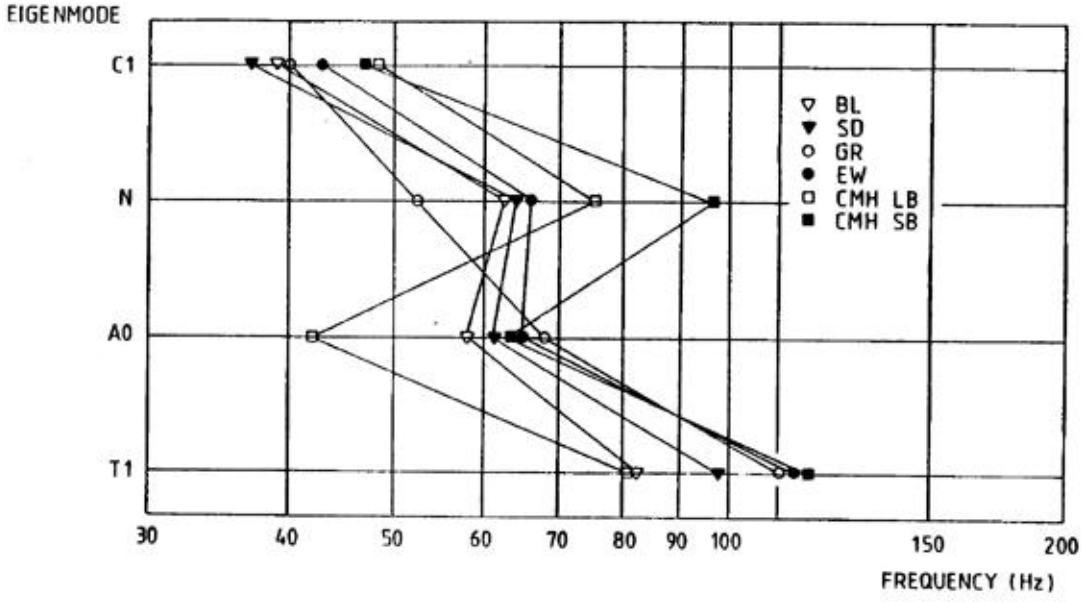


Fig. 6. Comparison of eigenmode frequencies for six double basses. The eigenmodes are from the top, the lowest body modes Corpus 1 (C1) and Neck (N), the Helmholtz air mode (A0), and the first top plate mode (T1). The abbreviations to the right of the symbols refer to the names of the makers in Figs. 4 and 5.

The lowest body modes, C1 and N, were recorded with the driving attached to the end of the fingerboard. The motion of the fingerboard is larger at the N-resonance than at the C1-resonance. Thus, these modes can easily be identified by attaching a weight to the end of the fingerboard. This massloading will have a considerable influence on the N-resonance, leaving the C1-resonance essentially undisturbed, cf Fig. 7.

The eigenmodes of a string instrument are not independent. For example, a bass with a low A0-resonance will automatically have a low T1-resonance. In order to obtain the low A0-resonance the bass must have a large body and also preferably thin top and back plates. This design of the instrument with a large and thin top plate will inevitably give a low T1-resonance, although the maker can adjust this frequency within a range of approximately 10 % by skilful adjustments of the top plate. The strong dependence between the A0 and T1-resonance is illustrated in Fig. 8. Apart from one clear exception, which probably is due to an unusual design of the top plate of this bass, it seems possible to predict both the resonance frequency and level of the first top plate resonance for a bass if the corresponding data on the Helmholtz resonance are known. The same strong connection between the A0 and T1-resonance has also been found in the violin (Jansson, personal communication).

Typical values of the resonance frequencies of the C1, N, A0 and T1 resonance for the violin, cello and double bass are plotted in Fig. 9. The relations between the eigenmode frequencies are seen to be similar for the three members of the string ensemble and also matched rather closely to their tonal range. This is indicated by the filled symbols above the frequency scale which give the frequencies of the open strings of the instruments. In all three instruments the C1-resonance falls close to the lowest open string and the N and A0-resonances close to the second lowest string. The T1-resonance shows the largest variation, ranging from the highest open string in the bass to the second highest open string in the violin.

The eigenmodes of the bass are influenced by the player. This is illustrated in Fig. 10 which shows a comparison of the input admittance curves of a double bass when the instrument is suspended in rubber bands (top) and held by the player in normal playing position (bottom). The influence by the player on the input admittance is strong around 60 Hz

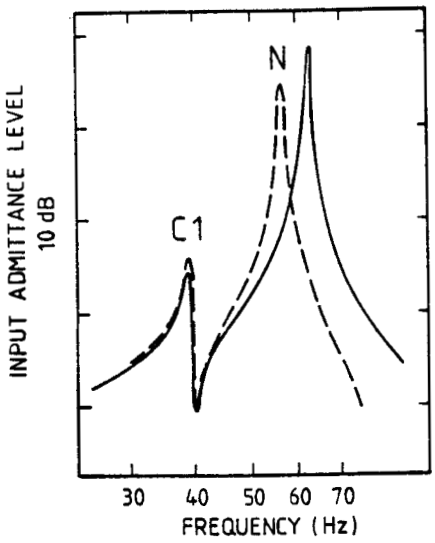


Fig. 7. Input admittance of a double bass with the driving attached to the end of the fingerboard. The two lowest body modes, Corpus 1 (C1) and Neck (N), are excited. The broken curve shows the influence of a light weight fastened to the end of the fingerboard, see text.

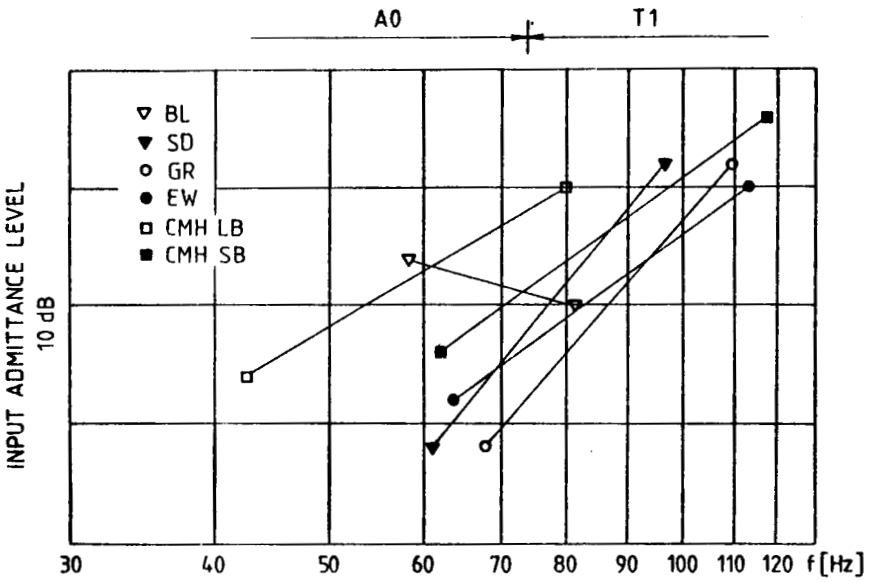


Fig. 8. Comparison of input admittance levels and resonance frequencies of the Helmholtz air mode (A0) and the first top plate mode (T1) for the six basses in Figs. 4 and 5. Data points for the individual instruments are connected with straight lines. The data points represent the A0-resonance (left) and T1-resonance (right). The abbreviations to the right of the symbols refer to the names of the makers in Figs. 4 and 5.

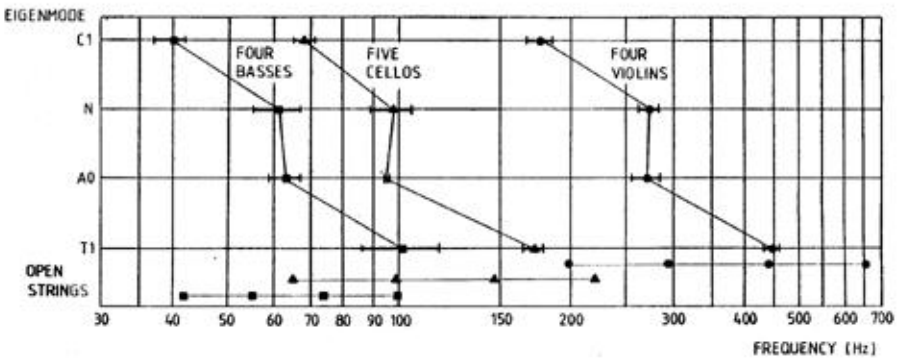


Fig. 9. Average eigenmode frequencies of four double basses, five cellos (Lundberg, 1982), and four violins (Alonso Moral & Jansson, 1982). The heavy lines around the data points indicate the standard deviation of the eigenmode frequencies. The frequencies of the open strings of the instruments are given at the bottom of the figure.

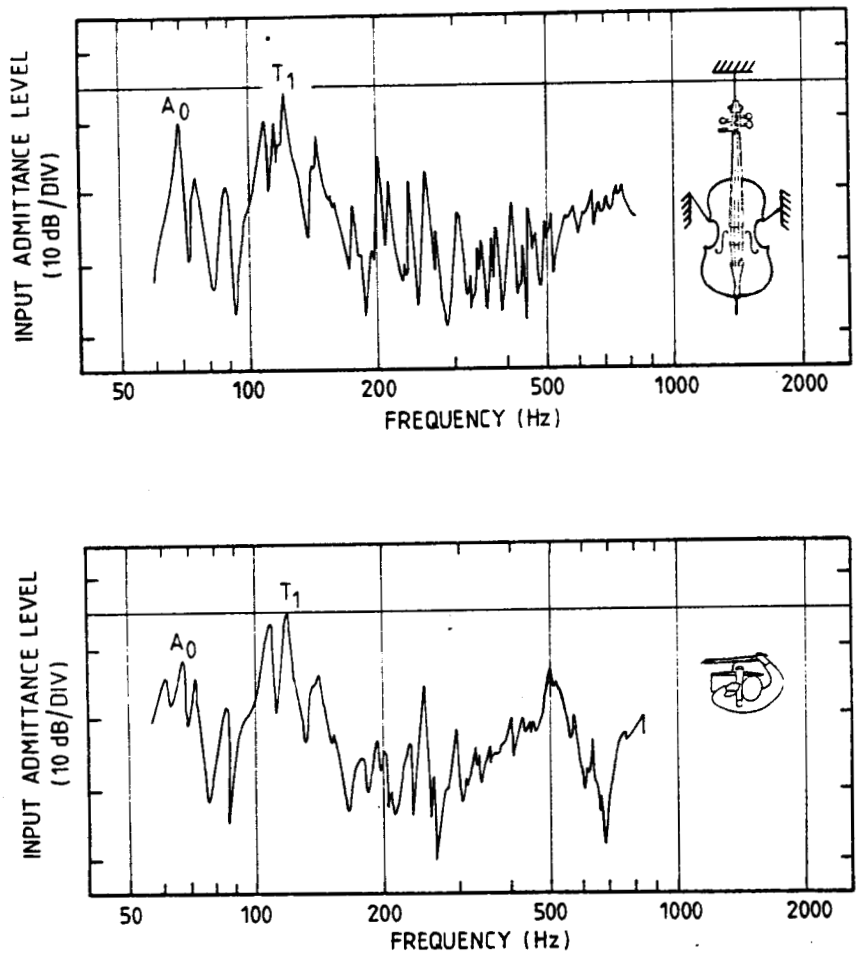


Fig. 10. Comparison of the input admittance of a double bass when the instrument is suspended in rubber bands (top) and held in normal playing position (bottom). The horizontal lines correspond to the same admittance level. The driving point is marked with a triangle.

(N and A0), which may be due to a disturbance of the neck resonance by the player's supporting arm. A clear difference between the curves is also seen above 200 Hz, probably reflecting the influence of the player's supporting knee on the plate modes.

Eigenmodes of the bridge

The properties of the bass bridge itself have been studied with the bridge clamped to a rigid support. By driving at appropriate positions three eigenmodes of the bass bridge were found, Fig. 11 a). As the bass and cello bridge are of very similar design it is reasonable to conclude that these eigenmodes are the same as those of the cello bridge reported by Reinecke (1973), Fig. 11 b). The lower resonance frequencies of the bass bridge due to larger dimensions reflect a necessary matching of the bridge to the lower resonance frequencies of the bass body. This is illustrated in Fig. 12 which shows the frequencies of the three bridge resonances together with the first top plate resonance (T1) for two basses and two cellos. Corresponding typical values for the violin are also included in the figure. The influence of the bridge resonances on the input admittance curve can be seen as wide humps around the measured resonance frequencies of the bridge, cf Fig. 4.

Desirable characteristics of the input admittance curve for basses

Some desirable characteristics of the input admittance curve of a double bass can be summarized from Fig. 4, 5 and 6. The input admittance curve should show high, distinct peaks in the low frequency region, a little separated in frequency. The main resonances in this range are the Helmholtz air resonance (A0) and the first top plate resonance (T1), the latter probably in combination with body resonances C3 and C4. More specifically it is desirable that the resonance frequency of A0 is not higher than 60 Hz and the T1-C3-C4 group not higher than 100 Hz. Expressed in bass making terms this means a large instrument with thin top and back plates. In the mid-frequency range between 150 - 400 Hz it is advantageous if the input admittance curve exhibits a pattern with equally spaced peaks. The properties of this frequency range is set by higher plate modes. Finally, above 400 Hz it is desirable with a strong

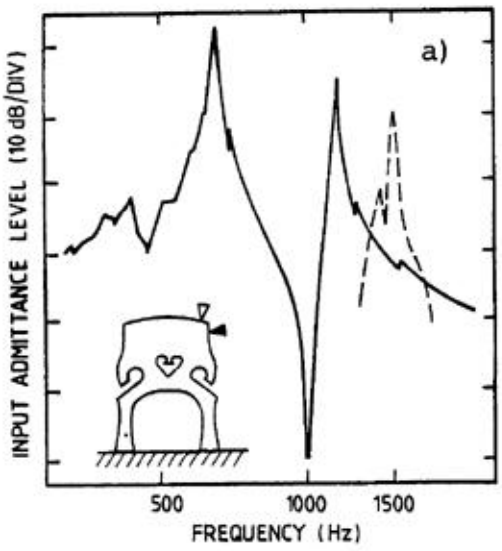


Fig. 11a. Input admittance of a double bass bridge mounted on a rigid support. The filled and open triangles indicate the driving positions for the solid and broken curve, respectively.

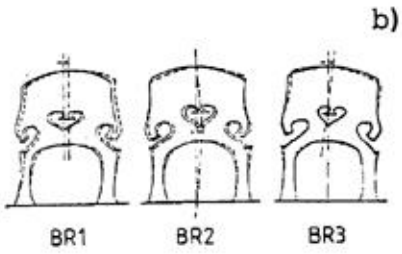


Fig. 11b. Eigenmodes of the cello bridge. (From Reinecke, 1973)

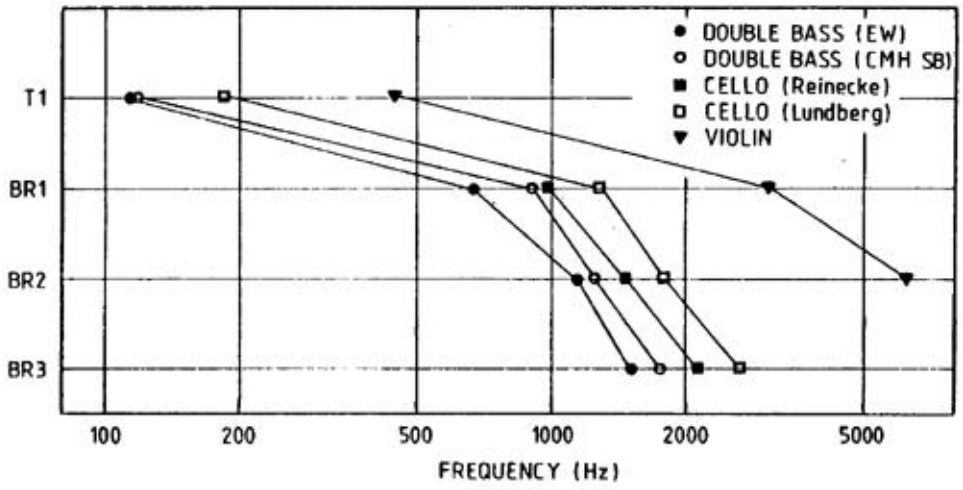


Fig. 12. Comparison of eigenmode frequencies of the bridge (BR1, BR2, BR3, cf. Fig. 11b) and the first top plate resonance (T1) for the double bass, cello, and violin. The data for the cello and violin are from Reinecke (1973), Lundberg (1982), and Alonso Moral & Jansson (1982a). The eigenmodes of the violin bridge are different from those of the cello bridge, see Reinecke, 1973. The abbreviations to the right of the symbols for the double basses refer to the names of the makers in Figs. 4 and 5.

influence from the lowest bridge resonance, giving a pronounced rise in the curve.

The term desirable has been used above only with the price of the instrument as a guide. No formal test has been undertaken as regards the correlation between the characteristics of the input admittance curve, stated as desirable above, and the tone quality of the instrument. However, it can be assumed that the price of the instrument is a reasonable reliable indicatior of the tone quality of the instrument with few exceptions. Informal playing tests by a professional bass player also support the rank ordering according to prices. The connection between the characteristics of the input admittance curve and the tone quality of the instrument will be discussed in the next section.

Tone quality versus input admittance

The measurement of the input admittance is a reliable and straightforward way of recording a "fingerprint" of the eigenmodes of an instrument. However, knowledge of the connections between the tone quality of an instrument and the characteristics of the corresponding input admittance curve is however yet rudimentary. One question is whether the tone quality of an instrument can be predicted by considering only a few parameters of the input admittance curve.

In a recent work on the tone quality of the violin incorporating a large number of instruments (Alonso Moral & Jansson 1982b), it was found that a weighted sum of four parameters extracted from the input admittance curve correlated well with the tone quality of the instrument as rated by experienced violin players. Tall, equally high peaks in the low frequency range followed by a steep rise at higher frequencies of the input admittance curve was found to correspond to high rates of tone quality, cf Fig. 3 (top).

Only preliminary suggestions have been made as to why these characteristics favors the tone quality of the violin. The high peaks at low frequencies may give a strong response in the low register of the instrument. Equally high peaks may give an even response between adjacent notes. A steep rise in the input admittance curve towards higher frequencies may be necessary to compensate for a decreasing radiation efficiency (Alonso Moral & Jansson, personal communication).

The input admittance curves of the violin, cello and bass in Fig. 3, which are all of high quality, show a similar pattern. Prominent peaks in the lower frequency region, a little separated in frequency are followed by a marked rise in the curve at higher frequencies. The criteria of the input admittance curve which were found favorable to the tone quality of the violin can thus be assumed to apply also to the cello and bass. Support for these assumptions can be found in Fig. 4, where input admittance curves of basses with prices ranging from low (top) to very high (bottom) were compared. An application of the characteristics given above will give essentially the same rank order as the prices.

TONE QUALITY

One desirable characteristic of a double bass is a "full bass sound" in the low register. This section is focussed on this aspect of the tone quality. The term "full" here is used to describe a deep bass sound, whose character resembles a low organ flue pipe.

Radiated spectra

All members of the bowed string family are small as compared to the wavelength of the low spectral components of the lowest notes of the instrument. This leads to a weakly radiated fundamental in the lowest register. As an example it can be mentioned that the violin radiates a fundamental in the lowest register which is about 25 dB weaker than the strongest partial (Meyer 1972). This fact is especially embarrassing as regards the bass, as there is no instrument in the string ensemble to substitute partials in the low-frequency region.

The most efficient way to produce and radiate a strong fundamental is to make a large instrument. However, if a musician is to be able to play the instrument a limit for the size of the bass is set. The Large Bass of the New Violin Octet (CMH LB) with an overall length of 214 cm touches this limit of "playability". On the other hand this bass offers a fully developed full bass tone quality in the low register, as judged by professional bass players. The fundamental radiated from this bass on

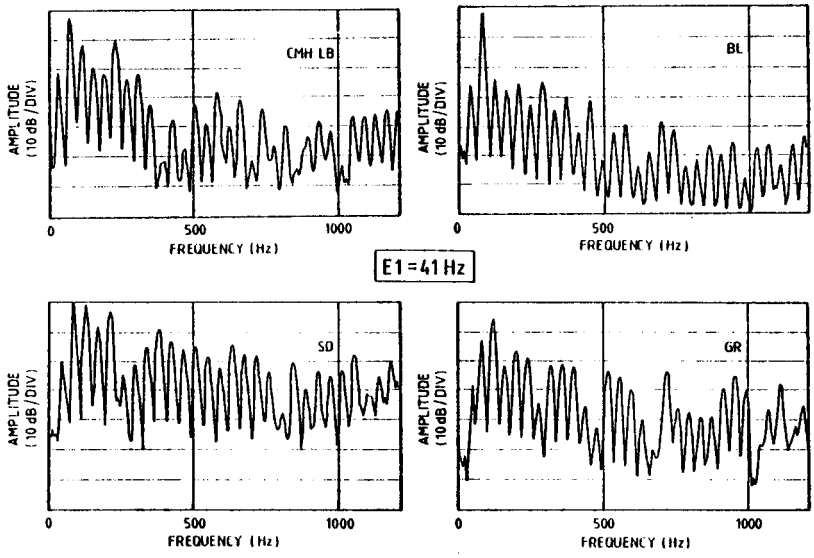
the lowest note is however not especially prominent as compared to the higher partials. This is illustrated in Fig. 13 which shows a comparison of spectra of isolated tones from some of the basses in Fig. 4 and 5, recorded in an anechoic chamber. On the lowest note E1 (upper half of the figure) the Large Bass (CMH LB) radiates a fundamental which is almost 20 dB weaker than the second partial. Similar proportions between the fundamental and the higher harmonics are seen in the spectras of the valuable bass (SD) discussed earlier and the bass (BL). The tone quality of these two basses were nevertheless also characterized as full.

The inexpensive instrument (GR) produces a very weak fundamental on the lowest note, and the second harmonic is also weak as compared with the other basses. Three semitones higher, Fig. 13 (lower half), the fundamental has gained considerably in all basses. Still the inexpensive instrument (GR) radiates a relatively weak fundamental.

The tone characteristics of the three basses with a pronounced full tone quality (CMH LB, BL, SD) seem to be related to the low resonance frequencies of the Helmholtz resonance and the first top plate resonance in these instruments, cf Fig. 4 and 5. These resonances will enhance the fundamental and second partial respectively in the lowest register. However, the promotion of the fundamental by the Helmholtz resonance is not sufficient to make the radiated fundamental as strong as the other partials on the lowest notes. The difficulties associated with the radiation of a low fundamental is always considerable, as can be inferred from the following.

The wavelength of the fundamental of the lowest note on the bass is 8 m. This should be compared with the dimensions of the body of the instrument, roughly 1 x 1 m. The source is undoubtedly small as compared to the wavelength at this low frequency , which limits the possibilities of radiating sound. For the second partial the dimensions of the source are almost a quarter of a wavelength which gives a much more efficient radiation.

The spectrum analysis yields as a result that the fundamental itself contributes to a full tone quality. However, it is not necessary that the fundamental is stronger than the other partials in order to ensure a full bass tone sound. It is sufficient that the fundamental is present in the radiated sound with reasonable strength and that the instrument radiates a strong second and possibly also a strong third harmonic.



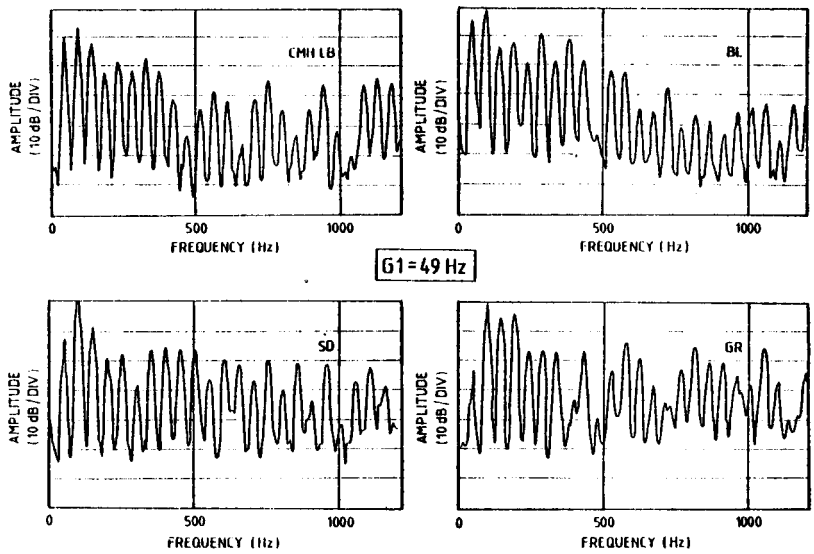


Fig. 13. Radiated spectra of four double basses showing the note E1=41 Hz (upper half of the figure) and G1=49 Hz (lower half) played mezzoforte. The recording was made approximately 1 m in front of the instrument in an anechoic chamber. The abbreviations refer to the names of the makers in Figs. 4 and 5.

Long Time Average Spectra (LTAS)

The radiated sound was also investigated using an alternative method. Chromatic two octave scales from seven basses were recorded with four microphones in a large, very reverberant room. The scales were analyzed by means of LTAS, which gave an estimation of the radiated sound power in 1/3-octave bands. In this way differences in the radiated sound among the instruments could be observed as a function of frequency. It was hypothesized that the varying tone quality of the instruments tested should be reflected in the LTAS. More specifically, the acoustic characteristics of the full tone quality of some of the instrument was expected to show up clearly in these measurements.

The result is shown in Fig. 14 in which LTAS of three basses are compared. Each LTAS is an average over several recordings and over the four recorded channels. As expected the method displays the influence from the unusually low resonance frequencies of A0 and T1 in the radiated sound for the two basses (CMH LB) and (BL), cf Fig. 4 and 5. These resonances can thus be assumed to give important contributions to the full bass sound of these instruments as discussed earlier.

The curve for the bass (EW) is typical for the other five basses analyzed. The differences in LTAS among these other basses were not significant, although the instruments represented a wide range of tone quality. In a similar experiment with the violin (Gabrielsson & Jansson 1979) it was found that certain characteristic differences in LTAS between high and low quality rated instruments could be observed. The number of instruments in that investigation was however considerably larger than in this study.

Further, it is known that the usefulness of the LTAS analysis for the purpose of estimating tone quality is largely dependent on the manner of playing the instruments (Jansson, personal communication). The variations between players and between different recordings of the same player can be considerable as shown in Fig. 15. This figure shows a comparison between a professional and a non-professional bass player. The professional player is seen to produce a stronger fundamental in the low register (40 - 80 Hz) than the non-professional player. The difference between the two recordings of the professional player is rather large in the low frequency range. This is probably due to

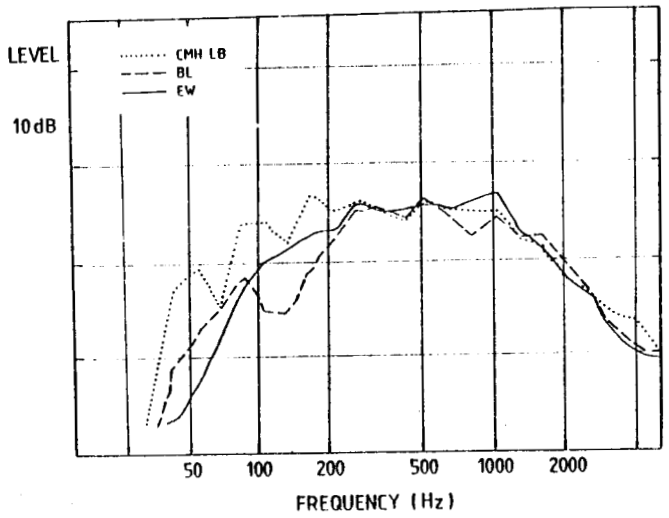


Fig. 14. Long Time Average spectra (LTAS) of chromatic scales of three double basses played in a very reverberant room. Each LTAS is an average over four microphones and several recordings. The abbreviations to the right of the symbols refer to the names of the makers in Figs. 4 and 5.

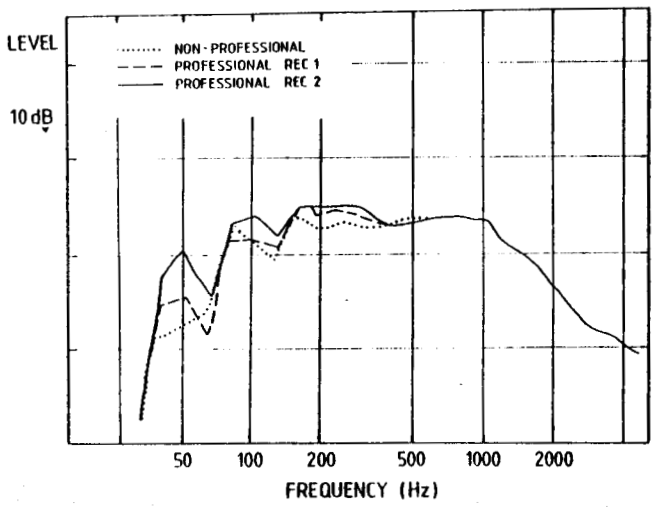


Fig. 15. Comparison of LTAS of different recordings of the same instrument.

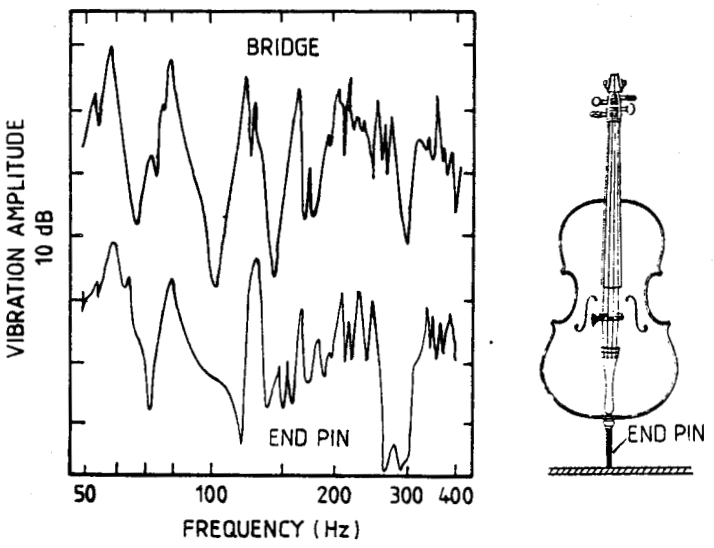


Fig. 16. Comparison of the magnitude of the vibrations at the driving point (top) and end pin (bottom). The driving point is marked with a triangle. The accelerometer measured the vertical component of the end pin vibrations.

imprecise instructions to the player. The differences between these recordings thus reflect different ways of playing rather than a poor reproducibility on the part of the player.

Tone quality and roughness

Important characteristics of the perception of sound are associated with the critical bands of hearing. The critical bands are approximately 100 Hz wide up to 500 Hz (Zwicker and Feldtkeller 1967). As the conventional four-stringed double bass operates down to E1 = 41 Hz this means that there are several partials in all critical bands, when the bass is played in the low register. If two or more strong partials occupy the same critical band this will give rise to a "rough" sound quality (Terhardt 1974). However, an input admittance curve showing comb-filter like parts, such as the curve at the bottom of Fig. 4, will reduce the likelihood of producing spectra with strong adjacent partials. The sound of an instrument with an input admittance curve of this type would thus be less rough, than the sound from an instrument which lacks such a well structured part in the input admittance curve.

An additional mechanism of suppressing a rough tone quality is also possible. A strong fundamental might assist indirectly in producing a desired tone quality by masking higher partials which would otherwise have contributed to roughness. This masking effect can not occur in the lowest register where the fundamental is considerably weaker than the other partials.

End pin vibrations

The end pin represents an indirect way for the bass to transmit sound to the air. If the vibrations of the end pin are strong enough to set the floor in vibration, this may increase the contribution of the lower partials in the radiated sound. As seen in Fig. 16, vibrations in the end pin do exist, but they are of relatively small amplitude as compared to the driving point vibrations. Only minor differences could be observed in the input admittance curves when the bass was hanging and standing on the end pin respectively.

The help in radiation of low frequency sound components which can

be obtained from the end pin vibrations depends on the properties of the supporting floor. As the vibration amplitude is small a large area must be set in vibration if any significant contribution to the radiated sound is to be obtained. The practical experience is that the reinforcement of the the low frequency register may be substantial under suitable conditions.

Summary of tone quality

The analysis of the tone quality has focussed on the aspect of a full bass tone. It was found that an instrument which was characterized by a full bass tone quality in the low register, radiated a stronger fundamental than other basses. However, even the basses possessing a full tone quality radiated a fundamental considerably weaker than the second and third partials. Low values of the Helmholtz and first top plate resonance were found to favor the fundamental and the lower partials.

An analysis using LTAS gave an estimation of the spectral content of the radiated sound. A boost at low frequencies due to the influence of low A0 and T1-resonances could be observed in the LTAS of two basses with pronounced full tone quality. No other connections between a tone quality and radiated sound could be observed in this analysis.

Acknowledgements

The author thanks Erik Jansson, Jesus Alonso Moral, Göran Lundberg and Alf Peterse´n for generous cooperation.

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