PREFACE TO MEINEL'S ARTICLE

Hermann Meinel's classic article from 1937 presents a pioneering application of new measurement technology to some important "single-parameter" systematic investigations of the violin, viz., i) too-thick → normal → too-thin *plate tuning*, ii) loose(normal) → tight → removed *soundpost*, iii) too-high → normal → flat *arching*, and iv) before → after *varnishing*. Meinel used a bowing machine for excitation and a single microphone for response measurements. All the signature modes radiate nominally isotropically hence single microphone radiation measurements are still valid at low frequencies; in the high frequency region it is best to adopt a more statistical approach and look at an overall *amplitude envelope*.

Notes on translation

- Christina Fan made the complete translation from the German with George Bissinger responsible for minor translation modifications and annotations where difficult technical terms/phrasing or needed clarifications were present.
- The translation format is close to the original two column format with original figures modified/annotated. In text annotations are always enclosed inside square brackets [ ]. Figure & Figure captions in **blue**, **annotations in pink.**
- The original page-specific numbered footnotes revised to an increasing number format still appear approximately where originals did relative to the text.
- Numerous references to "outside" figures in other Meinel articles have been notated in **arial font** bolded.

Meinel's experiment in contemporary context

These systematic experiments from 1937 could have been of great practical importance to violin-makers over the intervening years if their generality had been properly understood and interpretable in the physical (structural) acoustics of the day:

- The violin research game changed virtually overnight as the pioneering vibrational modal analyses in the mid-1980s added *mode shapes* to the frequency-damping-amplitude resonance properties previously measured. It was now possible for a researcher to track specific "signature" modes (described below) for all properly setup violins violin-to-violin across violin quality classes (*and* a complete violin octet). Comparing modes between "bad" violins and "great" violins revealed a remarkable commonality for these "signature" modes across a wide quality range.
- Making vibration *and* radiation measurements for each violin greatly improved our understanding of the complicated structural acoustics of this ported, damped vibro-acoustic device.
- Meinel's systematic plate tuning and soundpost removal experiments exposed certain important frequency response trends but enjoyed no general structural acoustics context to exploit the findings so they became basically a "one-off".
- Contemporary measurements of radiation efficiency, effective critical frequency and low frequency cavity mode excitation incorporated in a modern structural acoustics environment underlie Bissinger's 2012 dynamic filter model (DFM). DFM simulation-based auralizations by Bissinger and Mores (JASA-EL free online article with auralizations http://dx.doi.org/10.1121/1.4915062) serve to recreate the basic sound trends accompanying plate thickness modification seen in Meinel's pioneering work for too-thick, normal, and too-thin plates (as well as the effect of tuning the bridge).

Contemporary mode and frequency response structure terminology

I. *"Signature" mode region* – five lowest frequency modes - sometimes with coupling to neck-fingerboard or tailpiece - in open string region below 660 Hz; seen across all properly setup traditional violins (and complete violin octet).

- *Cavity modes*: 1) A0, near 275 Hz, the compliant-wall Helmholtz resonator that *always radiates strongly* via volume flows through the violin's *f*-holes, is always the lowest strongly radiating mode for the violin, and 2) A1, near 470 Hz, the 1st longitudinal ("slosh") mode with intra-*f*-hole antiphase volume flows that effectively cancel net *f*-hole hole radiation; A1 occasionally radiates strongly through *induced* surface motion. A0 and A1 cavity modes are coupled.
- *Corpus modes*: 1) CBR, lowest corpus mode near 400 Hz, strongly excited mechanically, but rarely radiates significantly due to *inter-f*-hole antiphase volume flows and nominally matched antiphase surface motions (nodal pattern for top and back plates looks like ‡), 2) $B1^-$, lower of the 1st corpus bending modes, with large volume changes driving in-phase *f*-hole volume flows, *always radiates strongly*, falls nominally near 470 Hz, and 3) $B1^+$, upper 1st corpus bending mode, with large volume changes driving in-phase *f*-hole volume flows, *always radiates strongly*, falls nominally near 540 Hz,
- $B1^-$ and $B1^+$ radiate predominantly (>50%) through the *f*-holes, which boosts their overall radiation in a region with low radiation efficiency. They are coupled to A0 and thus share some A0 character.
- The B1 large-volume-change "mechanical" modes are now seen as primarily responsible for excitation of A0 *and* A1. A0 radiation has been successfully modeled as a (B1) wall-driven, dual-Helmholtz resonator in the DFM.

II. *Higher frequency spectra structures* notated in some figures

- BH – a broad region near 2.3 kHz with enhanced mode amplitudes, but not higher modal density. Likely an interaction between bridge feet and corpus following Beldie model (Catgut Acoust. Soc. J. vol **4**, no.8(Series II), 9-13 (2003).
- f_{rock} – a broad region near 3 kHz where the bridge top rocking frequency "filter" enhances mode excitation.

On Frequency Curves* of Violins[1]

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Translated from Hermann Meinel, Über Frequenzkurven von Geigen, Akust. Z., 2, 22–33 (1937) by Christina Fan and George Bissinger.

INTRODUCTION

Up to now, published papers[2] about the sound quality of violins tried to find characteristics of good musical violins by harmonic analysis of relatively few sounds or by recording several oscillating forms of violin corpori. In this paper, it is shown that you can acquire an enlightening picture of the sound quality of violins, if you record their frequency response. I will demonstrate the utility of recording frequency responses in researching some other problems of violin craft—varnish, sound post, arching, and the ribs' of the violin corpus; the eigenfrequency of the enclosed air inside the violin corpus; and damping. Besides, I will discuss the usability of frequency responses of violins, which are electrodynamically excited. Finally, some results of the directivity measurements of violins will be presented, which have to be taken into account for the evaluation of the frequency responses.

I. DESCRIPTION OF EXPERIMENTAL WORK

It is known that alteration of bowing conditions, which are mainly the alteration of bow pressure, bow velocity, and bowing width and position, can influence the sound color of string instruments enormously. Because it is not possible (at least not by experience) to keep the manual bowing condition reliably constant over a sufficient time period, we built a bowing apparatus to establish proper experimental conditions (see Fig. 1). This machine is similar to one constructed for another work.[3] It allowed us to contact each of the single violin strings with an infinite, elastic bowing strap, consisting of few threads of a specially manipulated silk,[4] with the desired pressure, which was measured by a spring scale (for the *g*- and *d*[1]-string: 55*g* and for *a*[1] and *e*[2]-string: 40*g*), by using movable plates. The bowing strap runs on notches on two turntable disks, which are powered by a synchronous motor. The velocity was 40 cm/s. To adjust the different frequencies, the strings are shortened by contact with a bolt,[5] which is spring loaded and covered by rubber and soft leather. This bolt is slidable and installed on the neck fingerboard, pressing the strings down like human fingers.

The holding of the bowing width (2 mm) and the bowing position (at 26 mm distance from bridge) does not represent any difficulties. All the examined violins were stringed with the same type of strings.

During the examination, the capacitor microphone, which was installed approximately 90 cm away from the center (longitudinal) line of the violin—above the *f*-holes, kept its position to the violin to avoid errors from varying directivity. We measured at an angle of 315° [45°] to the violin plane (see Fig. **16a**), which is supposed to correspond to the most important radiation direction. It leads straight to the audience, if the violinist's playing posture is normal and without reflections. The measurements occurred in a sound-absorbent room of the department; thus, only the instantaneous sound pressure amplitudes of the violin are measured. They are easily transformed into absolute values with the help of microphone constants and a 1000-Hz emitter of known amplitude.

To record frequency responses, the amplitudes of lower partial tones were measured with the help of the "Grützmacher" search tone method.[6] If one proceeds in small interval steps, in general at least those of 1/8 of a whole tone

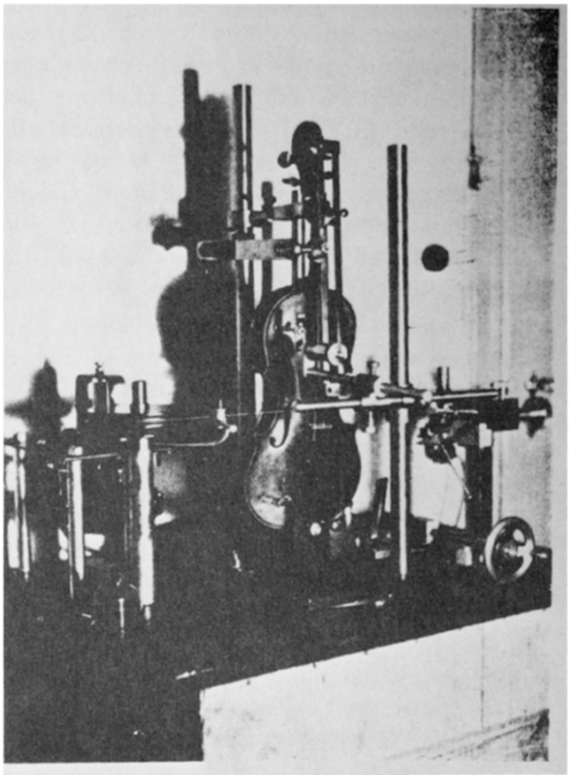

Abb. 1. Anstreichvorrichtung

Figure 1. Experimental setup with bowing apparatus.

[0.75% steps], because of the violin's low damping, one can obtain useful frequency responses.

Additional explanation is necessary, concerning the holding of the violin. In the beginning, violins were clamped on the lower end block on the left and right of the string holder buttons, a massive [rigid?] location that should be expected to have a negligible influence on the sound. Further detailed experiments to the reproducibility of frequency responses, however, showed that the reproducibility is sufficient for most, but not for all, frequencies. The amplitudes of a series of sounds are to a certain extent strongly dependent on the form of clamping. This fact finally leads to a new holding construction for the lower part of the violin. The violins—except one (*M VII*; Figs. 2 and **14**)—are pressed with the button against a soft rubber support and only clamped on the neck. Only now, this form of holding has brought satisfying reproducibility for all frequencies. The frequency responses in Fig. **14a** (old holding) and Fig. **4a** (new holding) provide information about the influence of the holding, which is extremely obvious mainly in the range of 350–500 Hz.

II. EXPERIMENTAL RESULTS

a) In General

Figure 2 shows the amplitude of the first four partial tones of a normal violin *M VIII*. On the abscissa, the frequencies are plotted on a logarithmic scale. The ordinate contains the sound pressure amplitude (in μB = dyn/cm^2) on a linear scale (unlike usual representations). This makes the eigenfrequencies explicitly recognizable; then, it also seems that the change of amplitude in the partial tones can be seen better linearly than logarithmically for the timbre—but not for the subjectively perceived intensity. The given frequencies correspond to the tempered tuning. The measured amplitudes of partial tones of different ordinal number but same frequency generally agree quite well with each other. Sometimes, one can almost speak of identity, in the range from a^1 to f^2 and b^3 to $c\sharp^5$. That especially the first partial tone sometimes showed stronger deviation in the range in between was mainly because of technical measurement reasons. Primarily, it is because the examination can be conducted in very small intervals only from a fundamental note frequency f^2. Thus, fundamental tone amplitudes in the range of f^2 are compared with amplitudes from overtones, which belong to lower fundamental tone frequencies, and therefore, they should be recorded in larger intervals. Inevitably, deviations in relatively narrow resonance curves are the result. These can indeed be reduced, as further samples have shown, if the sound examinations of all partial tones are performed for sufficiently small-frequency intervals. Although some differences between amplitudes of partial tones of different ordinal number but same frequency cannot be eliminated—due to the fact, for example, that the same frequencies by comparison are never from the same string or same string length—but the influence of these differences on the sound pressure amplitudes is obviously small, as the good agreement shows, then these can be neglected compared with the strong influence of the eigenfrequency positions (where the sound pressure amplitudes achieved an enormous maximum).

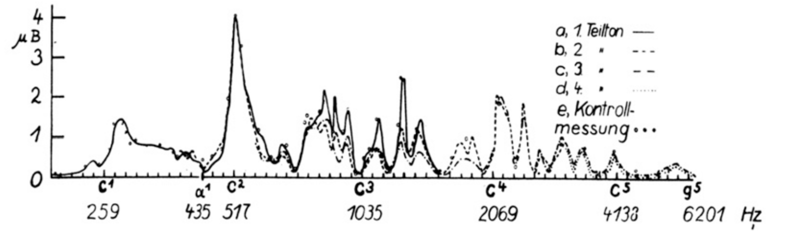

Abb. 2. Frequenzkurven der Geige *M VII 1*, von verschiedenen Teiltönen gewonnen

Figure 2. Frequency response of violin M VII I for various partial tones.

These agreements of the amplitudes of partial tones with different ordinal numbers but same frequency simplify the situation greatly. It is sufficient to measure the frequency dependence of the amplitudes of a partial tone in order to get a useful frequency response. Mainly because of purely practical reasons, the amplitudes of single partial tones are not used, but those of all following frequency responses between *g*—*e*³, the amplitudes of the first tone; between *e*³—*e*⁴, those of the second tone; between *e*⁴—*h*⁴, those of the third tone; and from *b*⁴ to the highest frequency, those of the fourth partial tone are measured. From *a*⁴, it would anyway be impossible to continue working with the first partial tone because the ordinary neck fingerboards of violins are insufficient [ly long].

Our frequency responses have another important meaning: In good approximation, we can read out all the sound spectra of the examined violins. Looking for the frequency position of the single partial tones of the sound in the frequency response, one can put together the sound spectrum from the found amplitudes.

Reading the frequency response, we have to consider that we can get closer to the musical impression of a violin if we think of a line drawn through the frequency response, which cuts off maxima and minima that do not belong to the musically used frequencies.

The reproducibility of the frequency responses was rechecked thoroughly, and the results were quite satisfying. As an example, we give a control measurement for the first partial tone and for some values of the third partial tone (see the small circles in Fig. 2e) that was made a couple of days after the original measurement. Thus, besides the possible errors from the adjustment of the excitement condition, there are also errors included, which are based on the influence of the change in air humidity. The recording of the frequency responses was used to clarify certain questions.

2.1 Thickness of wood and sound quality of violins

Most violin makers know that the violin corpus thickness of wood has an enormous influence on the sound quality of the violin. But, because of a lack of academic work, there are several points of view on the estimation of its importance compared with other possibilities to change the sound—like changing the form of the violin, the voice, the bridge, the bar, the ribs, the varnish, the size and shape of the air space, and the *f*-holes.

Therefore, three violins were examined (see Fig. 3) that had big differences in their thickness of wood. The violin *M II* shows exceedingly big thickness of wood and sounds bright, hard, shawm-like twanging, and by all means quite unpleasant in almost all sounds (except some of the higher). The violin *M VII* has normal thickness of wood and is considered very exquisite in sound. The violin *Sch II* has extremely small thickness of wood, which makes the sound hollow, too damped, and is also perceived as unpleasant. [Note thick-to-thin plate damping trends.]

The frequency responses of the three violins possess remarkable differences. Violin *M II* does not have big enough fundamental oscillation until *e*² because the amplitudes until *e♭*² are very small. The higher frequencies in contrast have approximately normal amplitudes. Thus, the subjective perception of the too bright, hard, and inferior timbre of violin *M II* becomes more understandable.

Even without mentioning any examples, in the strong slope of the amplitudes in the range of

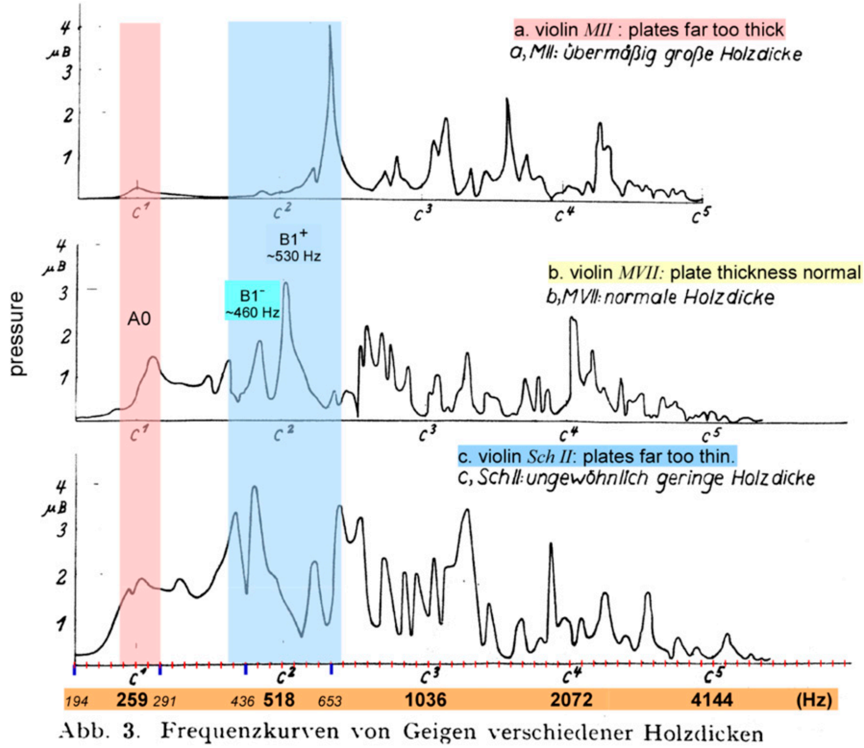

Figure 3. Frequency responses for violins of varied plate thicknesses [(a) too thick, (b) normal, and (c) too thin; traditional violin strongly radiating signature modes A0, B1⁻, B1⁺ noted; frequency scale added, small font = open strings].

g–*e*♭ with approximately constant amplitudes of the high frequencies, the frequency response of violin *M VII* lets us instantly recognize that the emphasis of the sound spectra has surprisingly moved to the lower partial tones and especially to the fundamental tone.

The amplitudes of the fundamental tones in the wide frequency range of $c\sharp^1$–$e\flat^2$ of violin *M VII* are mostly more than 10 times the amplitudes of the fundamental tones of violin *M II*. Such an increase of the important amplitudes of fundamental tone certainly has to be strongly perceived in the timbre as well. The sound essentially becomes fuller and softer. Even in the sound strength, the two violins differ enormously. Violin *M II* has a so-called "small tone" and violin *M VII* has a "big tone."

The amplitudes of violin *Sch II* increased even more for higher frequencies; the lower harmonics and, especially, the fundamental tone are now too strong. Most of the lower and middle sounds are, thus, perceived as too hollow and damped. It can be seen from this that a particularly favorable ratio of single partial tone amplitudes has to exist, which I have already mentioned quantitatively (see dissertation). However, the results obtained may mainly serve to estimate the influence of wood thickness compared with other possibilities to change the sound. But first, we should briefly discuss the applications of frequency responses in violin making techniques.

As soon as numerous frequency responses of great violins and, thus, good comparisons were collected, a violinmaker, who is well educated in physics, can see from recorded frequency responses whether the violin's wood is still too thick (which is relatively easy to solve) or if it is already too thin for the used resonance wood (which can be resolved by a method that is frowned upon by violinmakers and is only used for old violins: a necessary "lining"—a glued wood reinforcement). Because the maxima and minima of the frequency response move to lower frequencies with reduced wood thickness,[7] we can detect from a given frequency response what influence a change in thickness of wood will have on different sounds. Slightly reducing the thickness of wood of the violin *M VII* would, for example, increase the amplitudes of the fundamental note of the a^1-sound in a positive way, pitching the c^2-sound to a too-high value—which will be extremely uncomfortable, if one plays c^2 on the *g*-string—and the favorable amplitude of the fundamental tone of the $c\sharp^2$ sound would be diminished.

The frequency responses will serve for violin construction and also for judging (old and new) violins. But, our aim of making the frequency response of one violin resemble another one is still far away ["tonal copies"?!]—we need further examinations of all influences on the frequency response.

2.2 About the influence of the violin varnish

There are also still quite a few opinions, but none of them are sufficiently reasoned because of a lack of results in scientific research. To examine the influence of varnish, we recorded frequency responses of violin *M VII* before and after varnishing (including sufficiently drying). The varnish is completed in the usual way: fundamental varnish, colored varnish, and overlay varnish. All of them leave a smooth film. The dissolver was ethyl alcohol (C_2H_5OH); the drying, thus, happened quite fast. The results are shown in both frequency responses of Fig. 4. Particularly, the little change of frequency response because of the varnish is striking. Comparing Figs. 3 and 4 with each other, you realize immediately that the possible changes because of pliant varnish are much lower than the alteration which could be achieved by modifying the thickness of wood. The same conclusion was drawn earlier at the examination of the influence of hard varnish, which happened in similar way to that described above. But at that time, we did not record frequency responses, but sound oscillograms, which were analyzed with Mader's method. The influence of hard varnish in that research was even smaller than the pliant varnish.

At a more detailed comparison, however, both frequency responses for the unvarnished and varnished states allow the detection of discrepancy, which can be attributed to the influence of varnish because of the reproducibility and which are, thus, in fact not negligible. Mainly, it seems to be important that the maxima of almost all resonance curves diminished after the varnishing. This points to an increase in damping because of the varnish, which regarding the excitation process of oscillation will be expressed by a better, or, in this case, faster response [attack] of the sounds. This was indeed the subjective impression, although only slightly detectable. Accordingly, the varnish decreases the duration of excitation processes. Furthermore, it is remarkable that at high frequencies, the amplitudes generally drop significantly compared with those at lower frequencies. Just compare the amplitudes of the frequency range f^4–c^5 with the range $f\sharp^2$–b^2, for example. But also at lower frequencies, for example, the tones of the *g*- or d^1-string, it is remarkable that their amplitudes have fallen less because of the varnish than those at higher frequencies. This shows that varnishing with a pliant varnish in general increases the fraction of fundamental tones. Subjectively, the

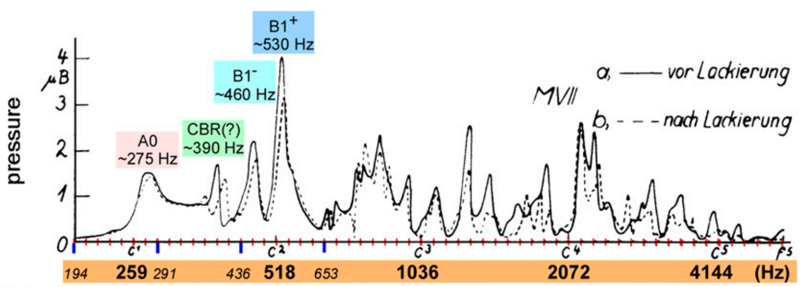

Abb. 4. Frequenzkurven der Geige *M VII* vor und nach der Lackierung

Figure 4. Frequency response for violin M VII before [—] and after [- - -] varnishing [signature modes noted].

sounds of varnished violins are perceived a little better sounding than those of nonvarnished violins. There is also a slightly perceivable roughness, possibly based on the high partial tones,[8] which could no longer be identified after the varnishing.

Other ongoing attempts to explain the influence of varnish from the alteration of elastic moduli and the density of spruce sticks did not lead to any satisfying results. It only showed that the density of spruce, varnished at only one side, increased by a couple percent, which should have made the eigenfrequencies decrease. The elastic modulus, using the same spruce sticks with the deflection method,[9] increased a couple percent, which should have made the eigenfrequencies increase.

Within a piece of spruce, which could be used as a violin's top plate, the elastic modulus often changes around 30% and more. It is usually lower close to the top joint[10] (i.e., if the annual rings of the wood become more narrow behind the top joint). Then, the curvature of the violin makes the elastic moduli of different locations within the violin corpus change in general, and the difference between the biggest and lowest elastic modulus usually increases. Because it further showed that the increase of elastic modulus after varnishing is bigger within sticks with lower elastic modulus than within higher ones, it seemed to be quite hopeless to estimate the change caused by the varnish, with density and elastic moduli opposing each other. However, a remarkable result of these experiments is that varnishing probably reduces the local differences of elastic moduli.

2.3 About the influence of the sound post

The sound post is a cylindrical stick of wood of about 6 mm diameter that is about 2–4 mm under the right bridge foot (i.e., behind the string holder), connecting the top plate with the back. Originally, there might be static reasons for the construction, but it is also of great acoustical importance, temporarily lacking a well-established explanation. That the sound post primarily transmits oscillations from the top to the back plate at all frequencies, as mostly assumed, does not, however, seem to be certain.

The acoustical influence of the sound post is shown in several examples of the frequency response, Fig. 5a–c, that belong to a violin *M IX* whose sound post was relatively loosely attached, then particularly tightly,[11] and at last even fully removed.[12]

It is remarkable that removing the sound post makes the fundamental tones of several sounds step back, compared with the normal case, while the high partial notes emerge strongly. If this happens in a way similar to this case, it is of course linked to a very significant sound degradation. Furthermore, the damping is greatly reduced. The sounds near to c^2 and f^2 could not be kept constant, but had a wolf-like character.[13]

Comparing the frequency responses for tight and loose insertion with each other, it appears that tight insertion is indeed similar [damping-wise] to removing the sound post, even though to a minor degree. A discrimination against the fundamental tone, especially the sound of the g^1-string, probably happened through the tight insertion of the sound post. The slightly bigger slope of some resonance responses seems to indicate that the damping is slightly diminished by the tight insertion of the sound post, thus comparing the resonance response between c^2 and d^2, $e\flat^3$ and e^3, and e^4 and f^4.

The importance of the thickness of wood becomes clear, when looking at the alteration of frequency responses because of tightening the insertion of the sound post—a removal is out of the question—that is much lower than changing the thickness of wood.

There were several further attempts to explain the influence of the sound post: first by directivity recordings (see Fig. 6a and b). About the way of reading the directivity diagrams, see Fig. 6a. They show that at low frequencies (see 400 Hz and 406 Hz), the removal of the sound post discriminates particularly against radiation of the back plate. This discrimination can also be seen clearly at 461 Hz and just slightly at 691 Hz or 711 Hz. But, at 1144 Hz or 1150 Hz, no discrimination of the radiation of the back plate can be seen at all. This agrees with the observation that at higher frequencies (see Fig. **16**), the radiation of the back plate is negligible compared with the top plate.

2.4 About the influence of violin corpus arching

To also get a first impression about the influence of the arching, frequency responses of a normally arched violin *M X*, an only slightly arched

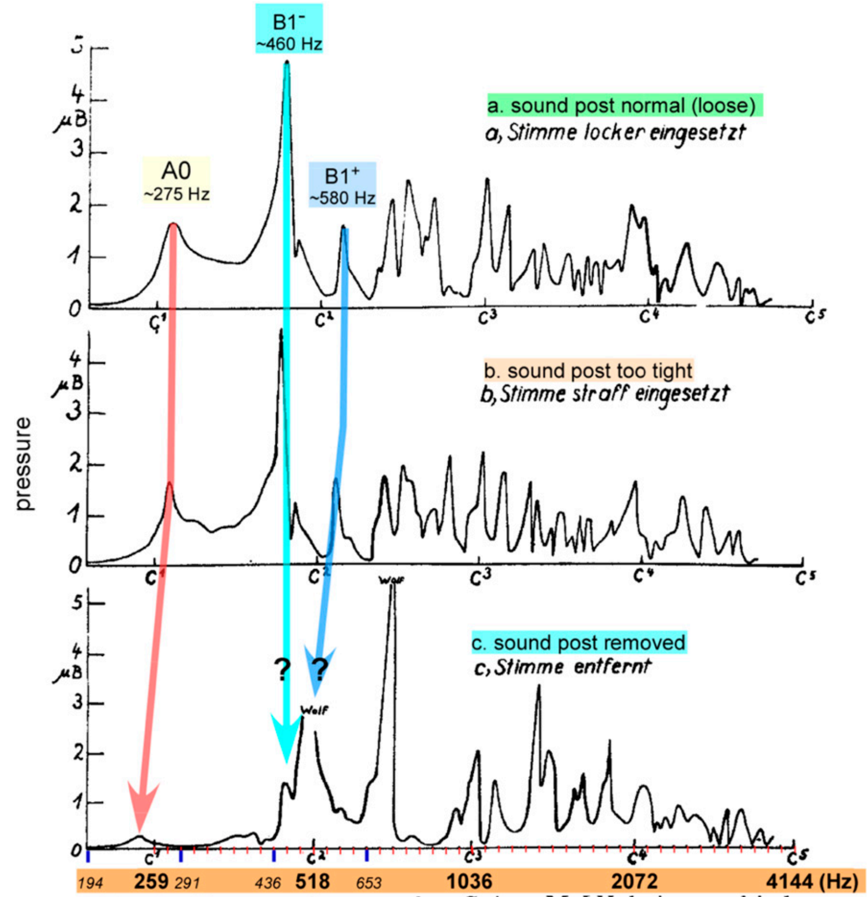

Abb. 5. Frequenzkurven der Geige *M IX* bei verschieden s eingesetzter und entfernter Stimme

Figure 5. Frequency response of violin M IX with varied inserted and removed sound posts [(a) normal (loose), (b) too tight, and (c) removed; note damping decrease for the too-tight sound post].

violin *M XII*, and a flat violin *M XV* were recorded (see Fig. 7a–c). All three violins had the same rib form and height. One can see that all three violins kept the main features of the frequency response. Thus, comparing the earlier found frequency responses with each other, one finds extraordinarily small amplitudes at deeper sounds of the *g*-string. Then, an increase follows through the development of the [A0] cavity resonance, already known by Savart (about 100 yr ago), which lies between $c\sharp^1$ and d^1 [~280 Hz] with normal violins. Until the a^1, nothing special occurs, except of one maximum that appears often but not always with normal violins close to $f\sharp^1$ and g^1 [~390 Hz]. Then, all violins showed the most distinctive area of resonance, which consists of the low sounds of the a^1-string [~440 Hz] and which is mostly split into several maxima.[14] This is followed by a deep minimum close to e^2 [~660 Hz] and the increase to the mostly big amplitudes for the lower sounds on the e^2-string. Multiple split areas of resonance can be found there. Another quite distinctive area of resonance, which is not always beneficial for good sound because it is sometimes a little twanging, covers some generally smaller areas of resonance mostly until the frequencies of c^4–$e\flat^4$.[15] These main features of a violin's frequency response can also be found in the three differently arched violins.

Considering the influence of the thickness of wood on the three frequency responses

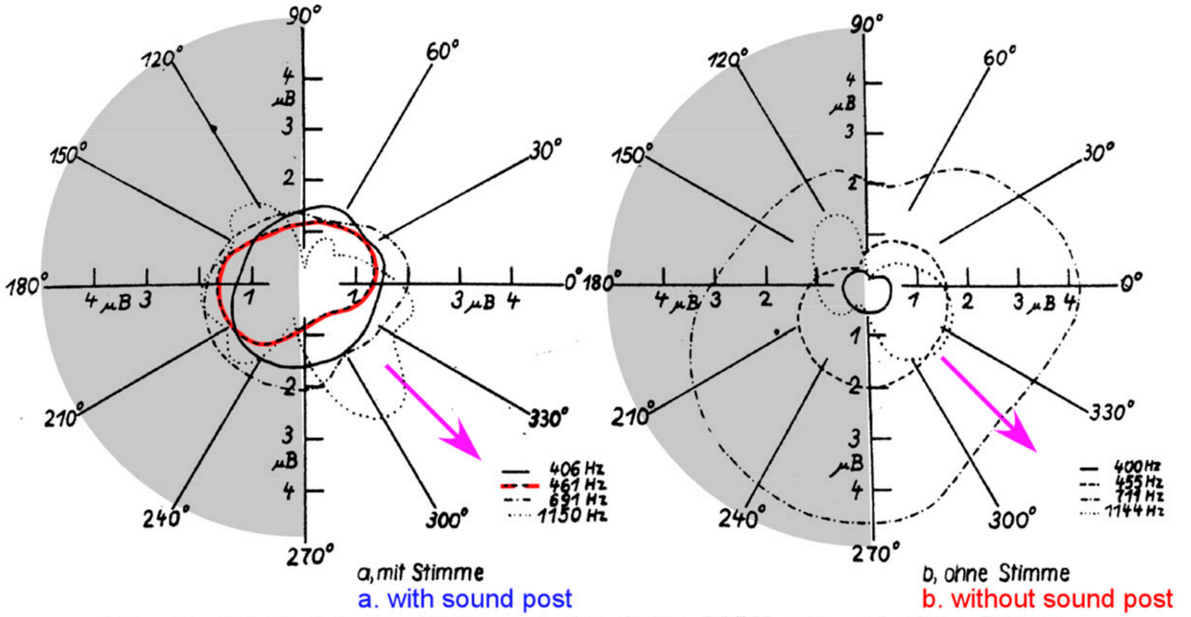

Abb. 6. Richtwirkungsdiagramme der Geige $M\,IX$ mit und ohne Stimme

Figure 6. Radiation patterns for violin M IX with and without a sound post. [B1⁻ in red; back hemisphere shaded; arrow at 315° in the direction of audience].

(see Fig. 3a–c) for comparison, one recognizes clearly that the influence of the arching is inferior to the influence of the thickness of wood. In detail, one can state the following about the influence of the arching on the resulting frequency responses: the frequency location of the cavity resonance area is not considerably influenced by the arching, which supports the perception that the lowest eigenfrequency of the cavity [A0] lies there.

In the area of lower frequencies of the a^1-string, the splitting of the areas of resonance seems to decrease with decreasing arching; the single maxima are only indicated for the nonarched violin. It is remarkable that with decreasing arching, the differences between the modulus of elasticity of the different parts of violin corpus decline.

Furthermore, notice the increase of amplitudes with decreasing arching at lower frequencies until about d^3, which can be explained with the smaller stiffness of the less arched violins. Summing up the amplitudes of acoustic pressure in the area of g–d^3 (from nearly 1/8 to 1/8 of a whole tone) and dividing the sum by the number of measurements, the result is the average amplitude of acoustic pressure of this area of frequency. It is 1.19 μB for the nonarched violin, 1.09 μB for the slightly arched violin, and 0.89 μB for the normal arched violin. The radiation of high frequencies is better on the arched violin, as the experimental results also show. Proceeding similarly in the area of $f\sharp^3$–c^6 to the lower frequencies, the average amplitude of acoustic pressure will be 0.44 μB for the nonarched violin, 0.52 μB for the slightly arched violin, and 0.63 μB for the normal violin, which is the opposite way as with the lower frequencies. With decreasing arching, the violin's sound color is overall perceived softer, darker, and also weaker. The nonarched violin possesses a timbre, which is too charmless and too characterless for our taste.

These results also reveal the reasons for a long-standing experience of the violinmakers. Highly arched violins (for example, built according to Jac. Stainer's archetype) are thinner in wood than shallow arched violins. Physically considered, the lower wood thickness suppresses high partial tones that are favored by high arching, as we saw earlier.

2.5 About the influence of the violin's ribs

The ribs connect the violin's top plate with the back plate. Violinmakers are generally not interested in the elastic properties and rib thickness.

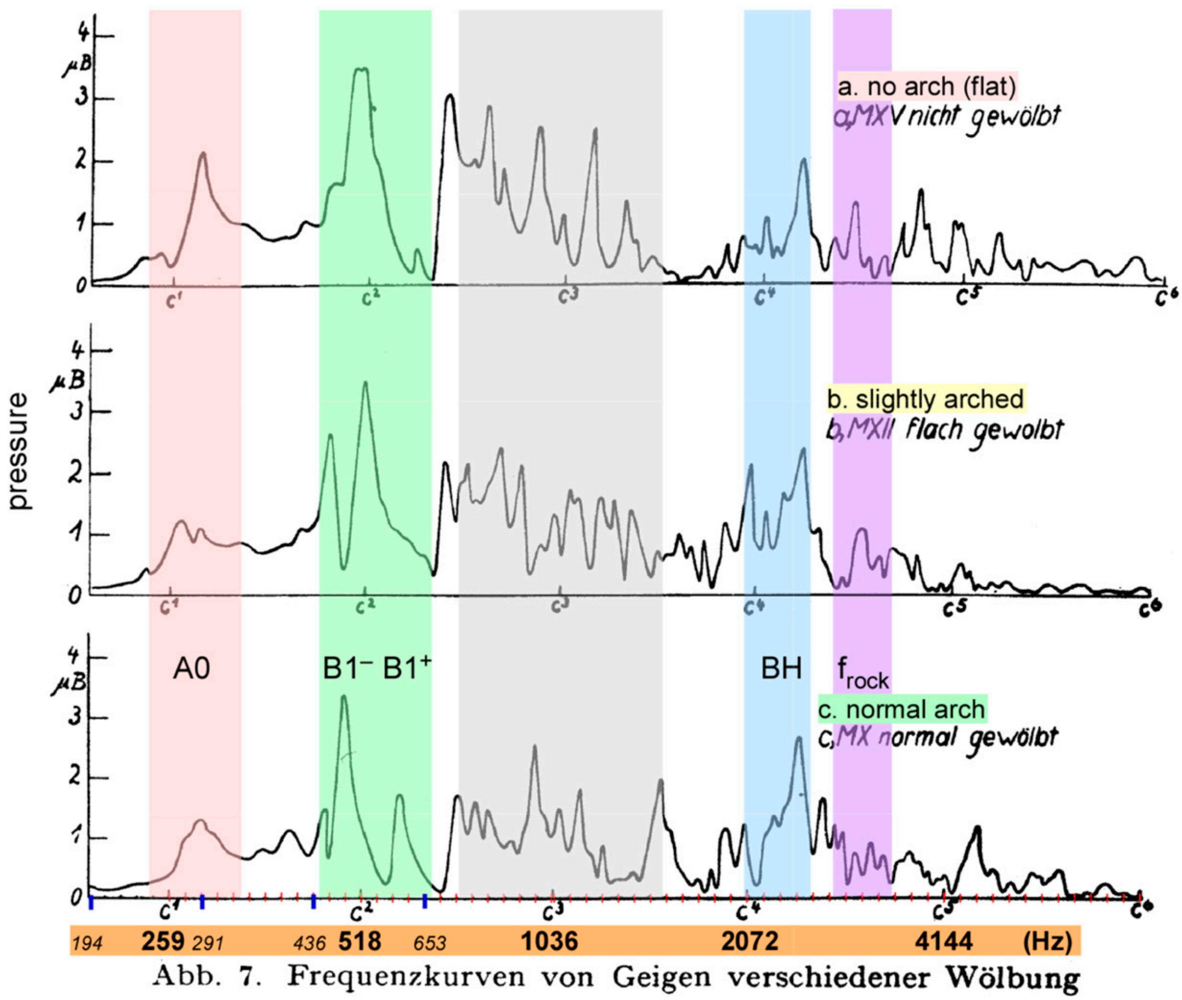

Figure 7. Frequency response of violins with varied arching [none (flat) to slightly arched to normal arch; curves in Fig. 7 all suggest the presence of a sound post; BH and f_{rock} regions shown shaded, but not sure about bridge properties.]

They primarily look for an aesthetically matching rib wood (as regards, the "flames," the charming cross-grains of the maple wood) to the wood of the back plate. However, the violinmaker bestows an extraordinary importance for the sound on the form of the ribs (as to the form of the violin generally). The attempts to establish satisfactory rules for the construction of first-class violins based on a purely geometric basis range to the end of the 18th century. They were repeated doggedly until today[16] (with the same disappointment), but they are a priori doomed to failure. The existing problems are less of geometric nature, as indicated by the relatively small influence of large changes in arching and—as we will soon see—also by the relatively small influence of bigger alterations in the ribs' form. But even without paying any attention to the experimental results, one acquires similar views about purely geometrical rules. Just imagine that every violin, constructed according to the Golden Section, would sound extremely well, for example (to realize the true meaning of those rules), even if it was built with a material that should only suffice for static reasons (for example, iron). If one wants to reason the form of a violin, one ought to discover the relationship between the violin's form, material, and frequency response.

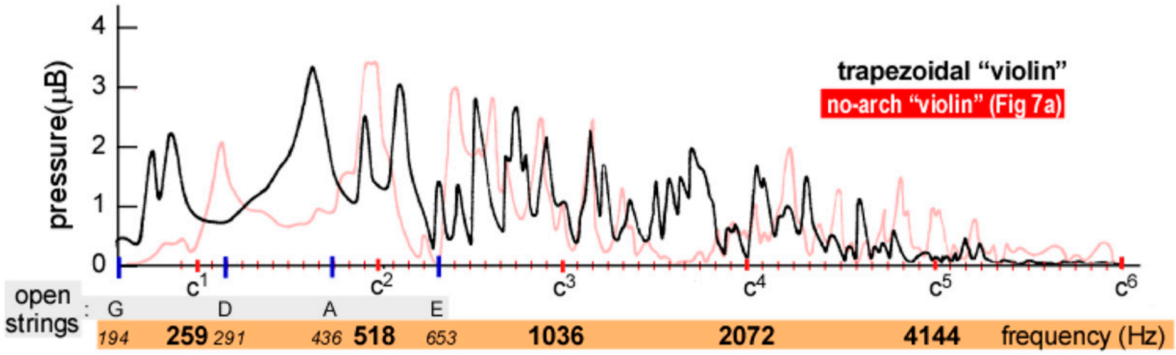

Abb. 8. Frequenzkurve einer trapezförmigen Geige *M XVI*

Figure 8. Frequency response of trapezoidal violin M XVI [with superimposed no-arch "violin" from Fig 7a.]

The frequency response of violin *M XVI* (Fig. 8) (similar to Savart's trapezoid [flat arch] violin analogue[17]), which was recorded for an initial orientation, makes the limitations of the change in frequency response because of the ribs' form apparent through comparison with a normal frequency response [closest *violin-shaped* rib form was the flat-arch violin from Fig. 7a, shown superimposed in Fig. 8.] Comparing the frequency responses to those of the influence of thickness of wood, it clearly shows that the influence of ribs' form is inferior to the influence of thickness of wood.

Along general lines, the main form of the violin's frequency response can also be seen in the trapezoid violin *M XVI*. Its frequency response also starts at small amplitudes with low frequencies of the *g*-string, followed by an area of cavity resonance with a strong enhancement of the amplitudes, which is just slightly shifted to lower frequencies. Above this follows the multiply-split main area of resonance in the range of the lowest frequencies of the a^1-string, which is only slightly shifted downward, about two whole steps, for the violin *M XVI*. Furthermore, we find the smaller amplitudes near e^2 and the big amplitudes near to the low frequencies of the e^2-string. There is also the strong area of resonance close to c^4 again. According to this is also the subjective impression on the sounds. The externally very different violins *M VII* and *M XVI* vary in their sound significantly less than the externally resembling violins *M VII* and *M II*. Of course, the violin *M XVI* sounds too soft and weak, here and there too dull and hollow, because of its generally too-big amplitudes of low partial tones.

Remarkable also are the relatively big amplitudes of the low sounds on the *g*-string of the trapezoid violin *M XVI*. With the usual [violin] form, no success was possible to achieve amplitudes of sound pressure larger than 0.2 µB for *g* and *g*♯, but mostly it was even smaller. The violin *M XVI*, however, delivers 0.5 µB under the same excitation and recording conditions at the same frequencies. It would be necessary to consider whether the relatively high sound pressure amplitudes are due to particularly large corpus amplitudes or mainly due to particularly simple, and for the radiation, beneficial nodal line images.

Furthermore, the first cavity resonance [A0] of the trapezoid violin *M XVI* lying significantly closer to the low frequencies than normal violins deserves mention. Because the flat arching does not influence the position of the [A0] cavity resonance significantly [Fig. 7], its adjustment to lower frequencies has to be due to the simple rib form of violin *M XVI*. [Presumably eliminating the C-bout draw-in for the trapezoid violin increases the total volume of the cavity and thus drops A0.]

Continuation in the next booklet:

6. About the influence of eigenfrequencies of the cavity

7. About the influence of the damper

8. Frequency response at electrodynamic excitation of the violin

III. About directivity measurements on violins

NOTES

*This would nowadays be labeled "frequency response."

1. A major part of this work together with the PhD dissertation of 1935, published in the *Elec. News Technique* in 1937, contains fundamental results of the work that was submitted for the 1936 contest at the Prussian Academy of Sciences on December 31, 1935, and received the prize.

2. Meanwhile, H. Backhaus has published a paper about resonance properties of violins [see *Akusl. Z.*, I(3), 1936.]

3. PhD dissertation, Leipzig 1935 (look at introductory comment). I found two turnable circular discs for the bowing strap that were adjusted for the violin research in former times.

4. These bowing straps are more durable than the formerly used, which were made of metal wires (see PhD dissertation). Similar threads can be found for music strings and fishing lines.

5. After former work with other constructions, I went over to this bolt to change the frequencies effortlessly under preferably natural circumstances. The bowing strap pressure lowers with the bolt's sliding toward the bridge in this arrangement because the string is displaced from the bowing strap by the movement on the neck finger board. By readjusting the bowing strap, this problem was easily solved. But bolt movement affects the bowing position by only fractions of millimeters. Furthermore, exceptional changes of the pressure are necessary to achieve noticeable changes of the sound spectrum [see similar results of R.B. Abotts, *J. Acoust. Soc. Am.* **7**(2) (1935), p. lll ff]. The errors that occur when one does not readjust the bowing strap are well within the other error limits.

6. M. Grützmacher, *Elect. News-Techn.* **4** (1927), p. 534.

7. See dissertation, Leipzig 1935 (introductory comment). As a recent result of continued examinations, I would like to add that certain distributions of thickness of wood can emphasize some maxima or even combine several maxima into one.

8. See Helmholtz, Tonempfindungen (tone sensation) 1913, p. 193 and 310.

9. Kohlrausch, Praktische Physik zum Gebrauch fur Unterricht, Forschung und Technik (Applied Physics for School, Research, and Technique), 17th edition, 1935.

10. This is presumably confirmation of empirical results of violinmakers. Physically speaking, the violinmakers mostly put the eigenfrequencies of the violin corpus as low as possible. They seem to have achieved it by the way of joining the top plate which consists of two pieces (narrow annual rings in the center of the top plate at the joint) and, thus, among other things, no waste of wood of low elastic modulus from sawing of the violin form.

11. It seemed to be right in this case to tightly attach the sound post by moving it about 3 mm toward the ribs to avoid the influence of the material for a slightly longer sound post. After recent experiences, such an alteration of the position of the sound post does not cause any noticeable errors.

12. Be careful at executions of similar experiments because not every violin tolerates a removal of the sound post for a longer time; even the inappropriate removal can cause serious damage to the violin.

13. See C.V. Raman, Springers Handbuch der Physik 8 (Springer's Manual of Physics 8), 1927 p. 381.

14. The splittings of the resonance areas are due to asymmetry and inhomogeneity of the violin corpus. [Nowadays we would describe each peak as signaling a separate mode of vibration.]

15. These results confirm those that were received earlier [see dissertation, Leipzig 1935 (introductory comment)] about the frequency location of the main areas of resonance of normally built violins. They even reach beyond because in this present work, it was possible to carry on the examinations in small-frequency intervals and, thus, determine the splitting of the areas of resonance, due to the elimination of time consuming nodal line examinations.

16. Max Möckel, The construction secret of the old masters (Golden Section).

17. In this violin, the ribs' indentation close to the *f*-holes is missing, the ribs' form resembles a trapezoid with rounded edges. The violin is not arched.