ACOUSTICAL MEASUREMENT OF VIOLINS

Why are some violins better than others? Studies with modern electroacoustical techniques yield at least part of the answer and give us information that helps build good fiddles.

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ACOUSTICAL EXAMINATIONS of the violin family extend over 200 of its more than 300 years but the instruments still defy analysis and complete understanding. The apparent simplicity of the problem is misleading; although the violin can be represented as merely a resonant air cavity in a wooden enclosure, driven by vibrating strings, the number of parameters to be determined for full analysis is very great.

The long-searched-for test is one to divulge and isolate the unique physical characteristics that distinguish the relatively few superb violins from the large number of good ones. Researchers can measure the differences between good instruments and poor ones, but the subtle differences that make up a magnificent instrument are still the realm of the expert player and listener.

Of the many directions that violin analysis has taken we have selected one, namely to study resonant vibrations of individual top and back plates during construction, driving them sinusoidally and determining their response electronically. These tests proceed side by side with traditional methods (illustrated by the juxtaposition in figure 1), giving analytic justification for some of the skills that makers learned by experience. These same methods extrapolate to the construction of new instruments for which experience is lacking.

VIOLIN AND VIOLAS (top). This collection includes a German "standard violin" (center) currently on loan to Carleen Hutchins for comparison. Below, left and right: Workbench and electronic equipment are adjacent so that testing and adjustment can proceed alternately during construction. —FIG. 1

What should be measured?

Any attempt to define the properties of a violin by physical measurement must start with a decision of what is to be measured; the possibilities are so varied and complex that each experimenter must make his own selection. The most immediate and obvious approach, either to absolute measurements or to comparisons between instruments, has been to study the complete violin under playing conditions. Some parameters that can then be investigated are harmonic content,[1] transients,[2] loudness,[3] ease of response[4] and directional effects.[5] Automatic bowing[6] removes the effect of the player on the instrument and allows objective study of sound output as a function of bow position, speed and pressure.

Modern techniques make possible other ways to excite the complete instrument; violins have been driven by sine waves[7] and wide-band white noise or pulses[8] to provide spectral response curves.[9] The trouble with these vibration methods is that they do not provide an input with the unique stick-and-slip sawtooth action of a bowed violin string.[10]

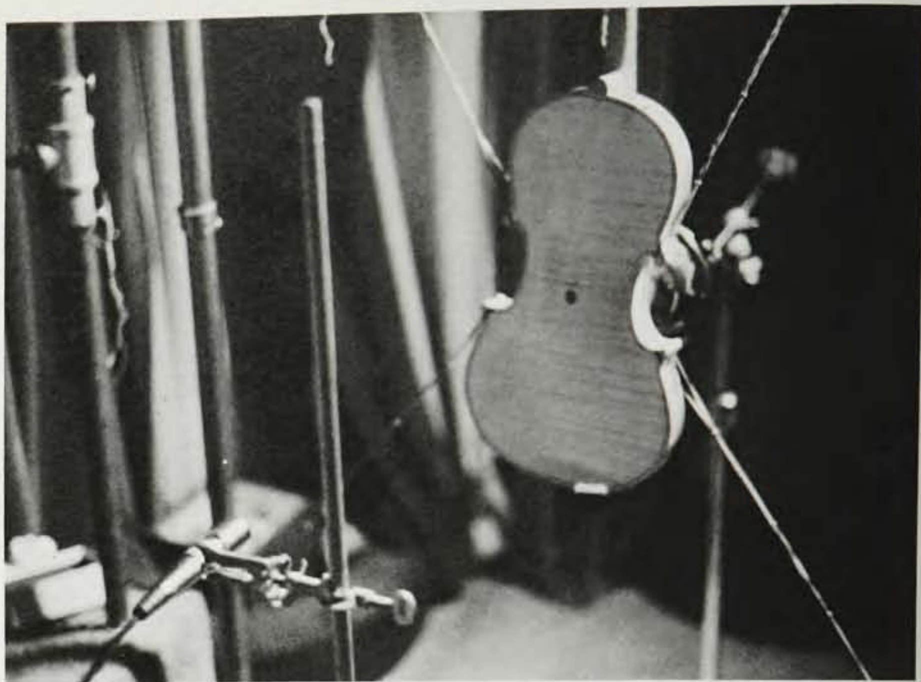
Another approach is to measure the characteristics of its component parts separately, eventually relating these characteristics to the performance of the instrument as a whole. Much detailed work has been done on violin strings[11] and their interaction with the bow,[12] on the bridge,[13] on the internal parts (soundpost[14] and bass bar[15]) and on the air vibrations in the enclosed volume.[16] The violin can be taken apart and the free resonances[17] and Chladni patterns[18] of the separated top and back plates determined. Wood for violin making[19] has been tested for its elasticity and vibration-damping characteristics, and even the varnish has been studied[20] to see how it affects the violin tone.

Our own approach

We concentrate mainly on observing plate resonances and their effect on final tone quality. We test top and back plates of violins and the larger instruments in the course of construction, thus observing changing resonances as wood is progressively removed. The completed ,instrument is then evaluated by the response curve, the loudness curve and performance tests to correlate results with the characteristics of its free-plate resonances.

A moving-coil electromagnetic transducer fixed either to an individual plate or to a complete instrument drives it at a frequency variable between 20 Hz and 20 000 Hz. A microphone picks up acoustic power radiating from the vibrating plate, and the power spectrum, recorded on a strip chart, shows resonances. Figure 2 shows a complete violin suspended on rubber bands from our test rack. In this picture the transducer is behind the instrument and the microphone in front. The transducer itself, a light 0.8-gram modified speaker coil clipped to the bridge of this instrument, is shown in closeup in figure 3; the extended center pole of the speaker magnet projects into the coil but does not touch it; the air gap is 2–3 mm wide. In the alternative case of an individual plate the coil is fixed to its center with sealing wax (figures 4 and 5).

A ceramic microphone picks up radiated sound at a position opposite the center of the plate or instrument, and for consistency between measurements on instruments of different sizes the plate–microphone distance is set at one plate length. Several layers of thick curtains cover the concrete walls and ceiling of the test area to reduce standing-wave patterns within the room.



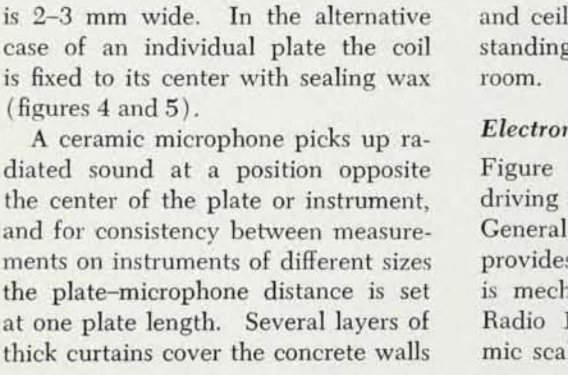
VIOLIN ON TEST RACK. Microphone is in clamp at left forground; coil that couples audio-oscillator output to instrument is hidden in this view. —FIG. 2

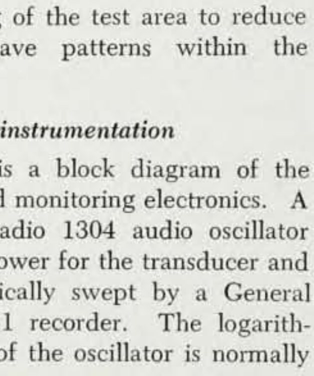
Electronic instrumentation

Figure 6 is a block diagram of the driving and monitoring electronics. A General Radio 1304 audio oscillator provides power for the transducer and is mechanically swept by a General Radio 1521 recorder. The logarithmic scale of the oscillator is normally driven at a chart speed of 0.5 in./min, or 18 minutes for a 9-in. chart. Reduction gear reduces sweep speed by a factor of ten, when necessary, to expand the scale for detailed measurements. If needed, we can make a 20–20 000-Hz spectrum 90 in. long.

A General Radio 1551 Sound Level Meter amplifies the signal from the microphone; the amplifier output is monitored on an oscilloscope and simultaneously fed to the spectrum analyzer. This instrument, a Spectral Dynamics Corporation SD 101A analyzer, is used by us as a tracking narrow-band filter to reduce the noise level in the comparatively weak airborne acoustic signal. This filter is locked to the input frequency by a reference signal obtained from the same oscillator output that drives the transducer. We use a filter bandwidth of 5 Hz at 3 dB down and 18 Hz at 50 dB down. At present we determine the frequency by comparing it with the 60-Hz line frequency as a Lissajous figure on the oscilloscope screen, but there are plans to add a digital frequency meter.

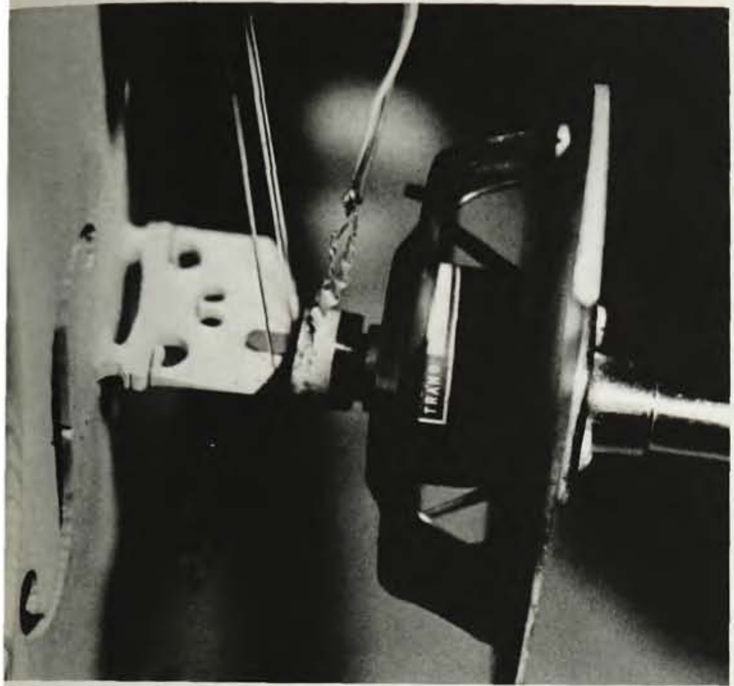
The spectrum analyzer has three alternative outputs: analog dc, the fundamental audio at 20–20 000 Hz and filtered 100 kHz. We use 100 kHz to drive the recorder, to avoid dc drift error and detector frequency-



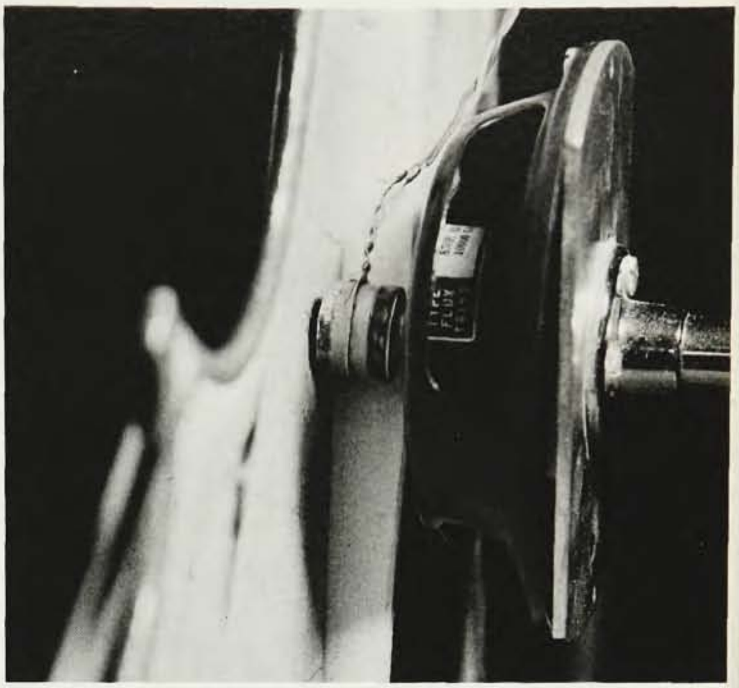


Carleen M. Hutchins graduated from Cornell and took an MA at NYU during her career as a science teacher. She started making stringed instruments (a viola was the first) when the arrival of the first of her two children interrupted that career. An interest in the acoustics of the violin family soon followed; Mrs. Hutchins was a founder member of the Catgut Acoustical Society in 1963.

Francis L. Fielding, who was born in New Zealand, attended the Battersea Polytechnic in London, where he received graduate membership of The Institution of Electrical Engineers in 1957. He heads a design group at ITT Avionics and has been involved with violin-family acoustic measurements since 1965.



COIL CLIPPED TO BRIDGE of complete violin. Speaker magnet has extended pole piece within the coil. —FIG. 3



VIOLIN TOP PLATE with the transducer coil (without clip seen in figure 3) fixed on with sealing wax. —FIG. 4

response variations. With the 40-dB potentiometer on the recorder we obtain an amplitude scale of 0.25 cm/dB on the chart.

"Tap-tone" resonances

With this equipment we can draw the frequency-response curve of a top plate, back plate or complete instrument when driven electrically by sinusoidal oscillations. How do these curves help us make better violins?

Let us look at a typical result. In figure 7 we see a complete 60–20 000-Hz frequency scan with the 300–480-Hz segment on a 10× expanded scale. It is in this small frequency range (for violin free plates) that the first strong resonance appears when the frequency is scanned from low to high—the resonance known as the "tap tone." A traditional violin maker can approximate this resonance by tapping the wood with his finger and listening for pitch and quality of the sound. By experience he works by careful removal of wood to achieve a certain "ring" in each completed plate. An experienced violin maker once said to us: "Of course you have to live with the wood, especially in the final stages."

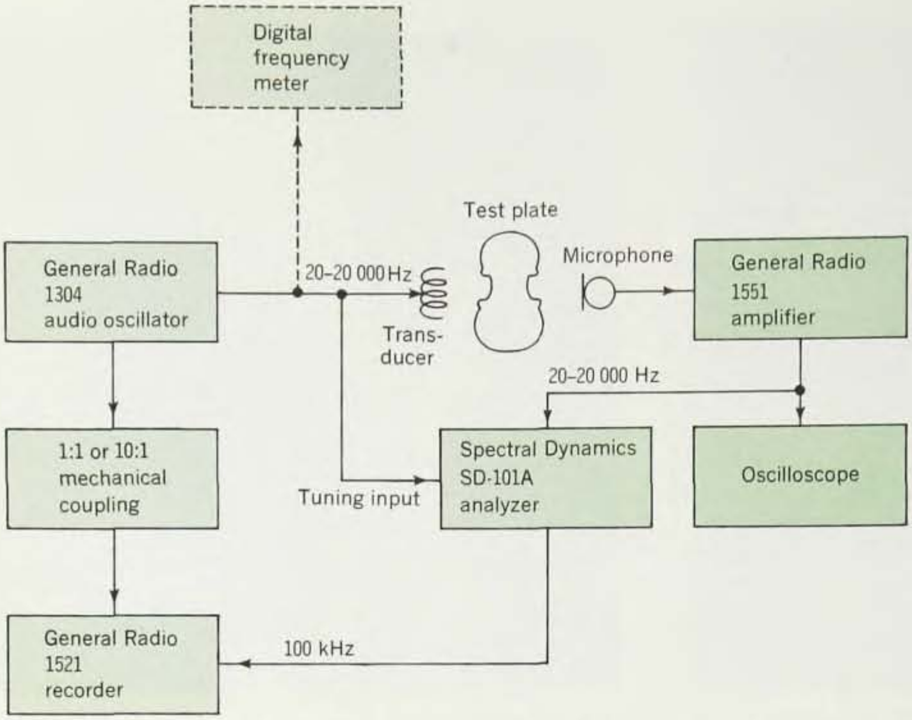
In our work with electronic recording we have tried to correlate these tapping and listening methods with the measured frequencies and amplitudes of free plates and the resultant resonances and tone qualities of each completed instrument.

First results, gleaned from 400 tests on 35 instruments in process of construction over a seven-year period, were reported by Frederick A. Saunders, Alvin S. Hopping and Carleen M. Hutchins in 1960.[21] They found that tone quality can be controlled to a large degree before an instrument is assembled by the placement of the strong resonances of the free top with respect to those of the back.

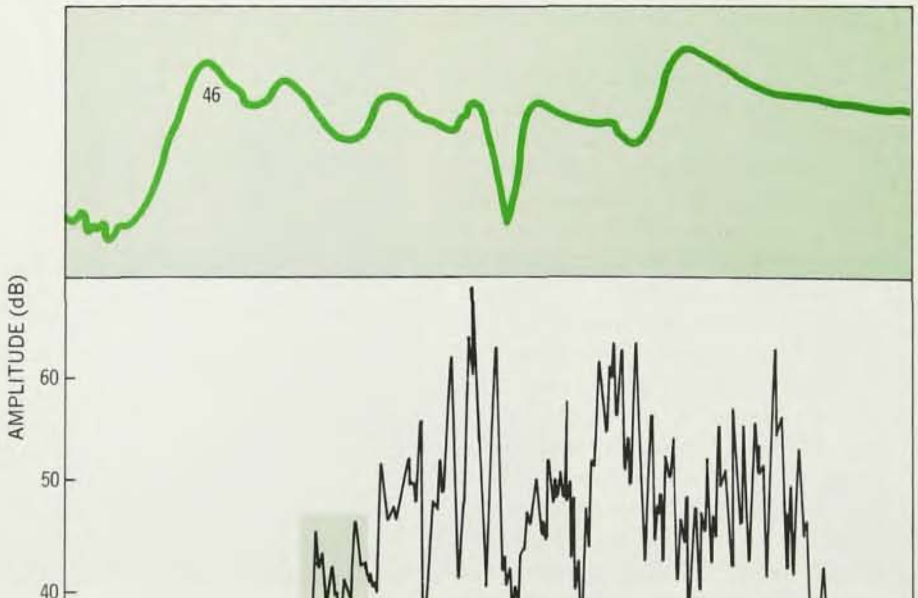
When the frequencies of the top-plate resonances alternate with those of the back plate, and the separation between tap tones of top and back plates is more than a semitone and less than a full tone, the resultant instrument was judged good by three evaluation methods—response curves, loudness curves, and musician judgement. When the top- and back-plate resonances match, or when the separation is greater than a full tone, the instrument was judged poor. Later they found a correlation of this work with Felix Savart's findings in 1830.[22] Savart had opened and examined the plates of several Stradivari and Guarnerius violins.

Since the death of Saunders in 1963, John C. Schelleng, A. Stuart Hegeman

UNDERSIDE VIEW of a violin top plate. The blob of sealing wax at the exact center marks the position that the transducer coil would occupy during a test. The bass bar, a strip of wood glued to the plate, runs under the string of lowest pitch and is therefore off-center. It acts as a stiffening member for the plate and its final shaping is very important in determining the tone of the completed instrument. —FIG. 5



DRIVING AND MONITORING electronics. The audio oscillator drives the transducer on the test plate and simultaneously provides a tuning signal that locks the analyzer to the instantaneous frequency of the 20-20 000 Hz sweep. A mechanical coupling with two alternative ratios links the oscillator output to the x-coördinate drive of the chart recorder. The analyzer operates as a narrow-band tracking filter with 5-Hz bandwidth at -3 dB. Oscillator frequency is compared with line frequency on the oscilloscope screen; frequency meter is planned. —FIG. 6



FREQUENCY RESPONSE CURVE of violin SUS 36 from 60 to 20 000 Hz. "Tap tone" is defined as the first strong resonance from the low-frequency end of the spectrum; in this case it lies just above 300 Hz. Colored line is a 10:1 expansion of the tap-tone area, from 300 to 480 Hz, showing 46 dB resonance. —FIG. 7

and ourselves have developed a second area of investigation. This new work, more difficult than the earlier studies, involves the relationship of stiffnesses in the several areas of each plate as they contribute to the vibrational modes of the whole.

Effect of humidity

The encouraging development is that for the first time we can measure the large effects of véry small physical changes that markedly alter the tonal characteristics of the violin. For example, practically all string players are bothered by variations in humidity; some instruments sound best in moist conditions, and others respond better in a dry atmosphere. Also some violins have a greater sensitivity to humidity than others.

Figure 8 shows the effect of less than one gram of moisture on the tap-tone resonance of the top plate of Hutchins violin No. 44 at two stages in its fine tuning (the process whereby the wood is carefully scraped thinner in certain areas to achieve the best subjective tap tone and high-amplitude smooth resonances). In the top pair of curves the plate was not well tuned and gave a truncated waveform with added moisture. In the bottom pair the same plate had been carefully tuned so that when tapped it gave out an overall clear ring. Note the smooth narrow shape and near symmetry of the upper part of the 50-dB resonance in the well tuned plate. The wider, more rounded, resonance peak shown by the colored line indicates increased vibrational damping with moisture. More noticeable, however, is the difference between the two sets of curves, which shows that the poorly tuned top plate is far more susceptible to moisture than the well tuned one.

Discussions with John C. Schelleng, Arthur H. Benade, Robert Scanlan and ourselves developed the idea that the main tap-tone resonance is compound; it has components contributed by the interrelation of two active modes of the vibration. These components are related to stiffnesses in the upper and lower areas of each plate coupled by the narrower "waist" between them. In the top plate this coupling consists of the bass bar and the area of wood between the f holes. Figure 9 shows the changes in shape of the tap-tone resonance caused by progressive removal of a few shaves of wood from the height of a bass bar. Total wood removed weighed 0.5 gram. As the bass bar is essentially a supporting beam under the top plate, parallel to the string of lowest tuning, its stiffness (proportional to the cube of its height) is very sensitive to slight changes in height. Every good violin maker knows only too well that the tone of an instrument is greatly affected by the final shaping of the bass bar.

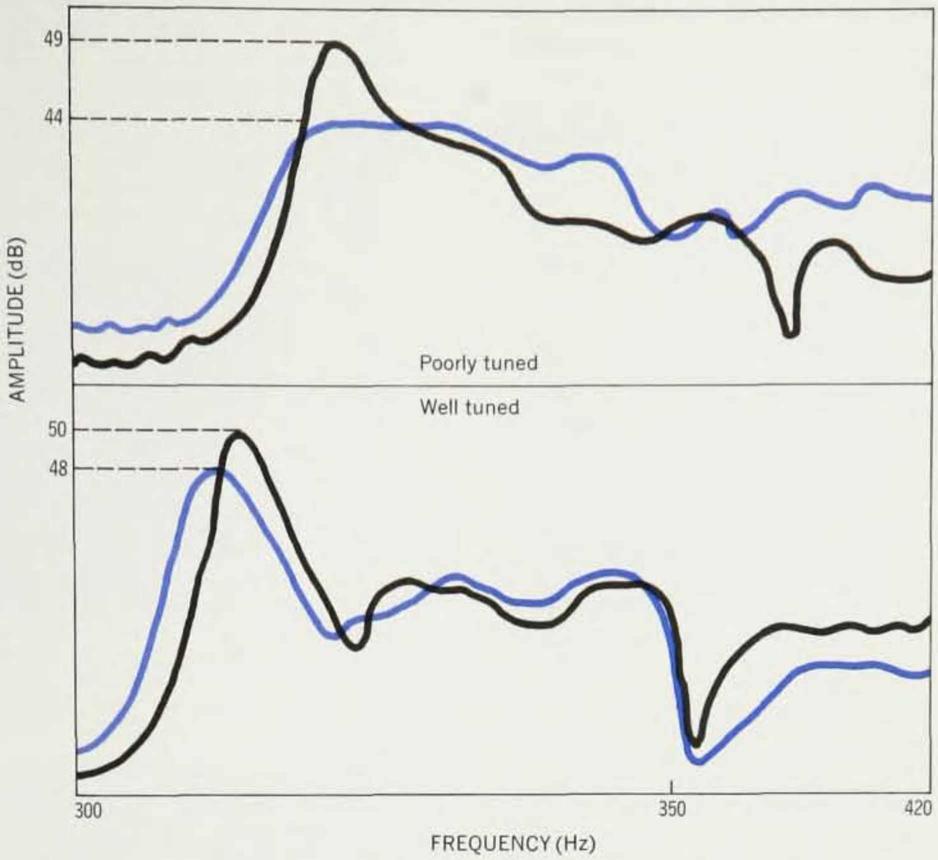
Holographic method suggested

Current methods of locating and identifying the Chladni or nodal patterns of the vibrating plate areas are slow and cumbersome. The most promising new method is hologram interferometry[23] applied to both free and coupled plates.

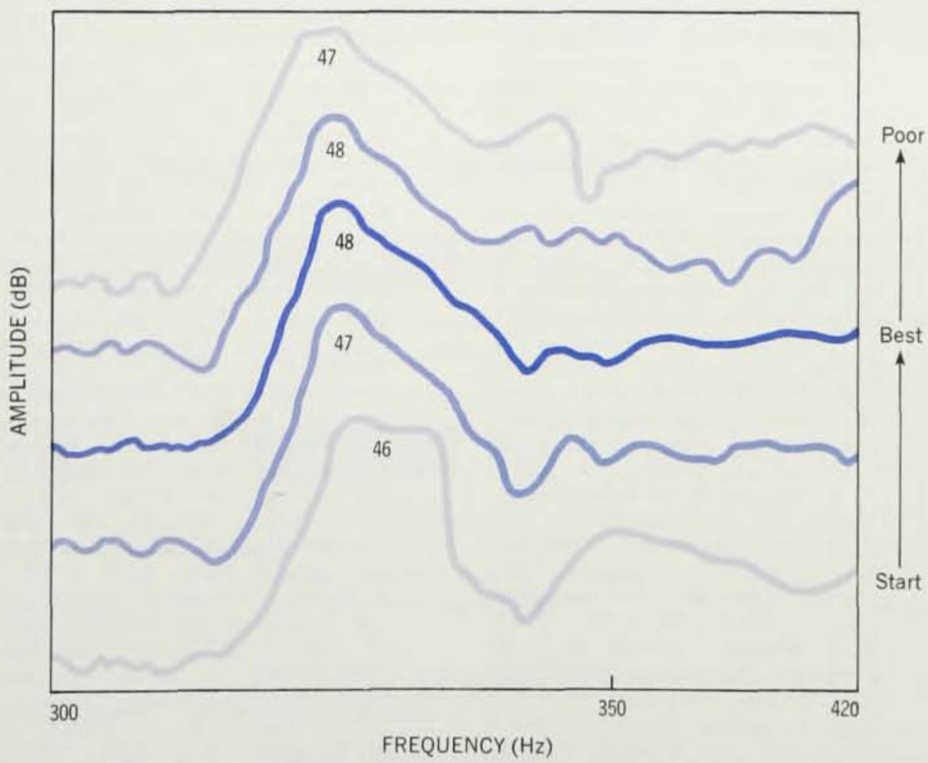
The method, suggested by Karl Stetson, is similar to the applications of holography that Robert Collier discusses in his article on page 54 of this issue. A hologram of a vibrating violin plate would show not only the vibration nodes but also a set of contours in the antinodes that would measure the vibration amplitude in the plate. We could watch the patterns changing with variations in driving frequency and power. This method would also show the effect on the overall vibration of removing wood from particular areas. With our current technique we know the response of the entire plate but have only experience and intuition to help us decide where wood should be shaved.

Expert violin makers meet this problem by listening to the sound of the wood when it is tapped at various positions; experience enables them to recognize the sound local to that particular area in spite of the complex of sounds from the whole plate. Eventually, if thicknesses are properly adjusted, the whole plate gives a clear bell-like tone. One success of our method of electronic testing is the confirmation, from over 100 observations, of a high correlation between this full ring and large-amplitude, well shaped, tap-tone resonance.

This process of tuning plates by tap-tone resonance is still incompletely documented since alterations in the wood are reflected by changes in many resonances in the spectrum. By combining the proper relation of tap-tone frequencies in free top and back plates



EFFECT OF MOISTURE on frequency response of a violin top plate. Colored lines show tap-tone resonances for plates containing about 0.6 gm more water than "dry" plates (black lines). The poorly tuned plate (top) is much more affected by humidity than the well tuned one (bottom). —FIG. 8



CHANGE IN TAP TONE during the progressive removal of 0.5 gm of wood from a bass bar. Five stages show improvement from initial condition (light tone at bottom) to the best (dark tone) and then to a poorer peak shape. —FIG. 9

with this method of fine tuning in each plate we have not only made conventional violins, violas and cellos that are eagerly sought by professional musicians, but have also developed eight new violin-family instruments.[24]

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