THE STRAD PAPERS

► An impact hammer and microphone identify a violin's sound output at each frequency

Frequency response in the 'Vieuxtemps' Guarneri 'del Gesù'

The chance to examine the acoustics of a great late Guarneri 'del Gesù' violin was too good for a team of maker–researchers to pass up. In the first of a two-part investigation of the 'Vieuxtemps', JOSEPH CURTIN sets to work with his impact hammer

One of the last manually operated elevators in Chicago is tended by a Polish man called Joe, who pulls shut the cage-like doors, asks which floor, and then throws a brass lever, setting the whole apparatus into motion. All this made my ride up to violin dealers Bein & Fushi seem like a journey back in time – back to when men wore hats and everyone smoked, and Milstein and Stern could still be heard at Chicago's Orchestra Hall. Nothing inside the violin shop breaks the illusion. Signed photographs of famous players cover the walls. A painting of Heifetz presides over the Great Room like some frowning deity. In a smoky office with a spectacular view of Lake Michigan, Geoffrey Fushi sat behind a large mahogany desk, holding the 'Vieuxtemps' Guarneri 'del Gesù'. Which is why I was there.

About a year earlier, I was asking around about great-sounding violins to study. Russian soloist Ilya Kaler told me his friend Vadim Gluzman had tried the 'Vieuxtemps' and said, 'If that's a violin, what do we call all the others?' Later, Kaler played the instrument and pronounced it 'unbelievable'. When next in Chicago, I went with Kaler to Bein & Fushi, and got to try it for a few minutes myself. My first impression was that it was the best violin I'd ever had under my chin. The sound is huge, the response preternaturally quick, the bowing point surprisingly close to the bridge. Laser-sharp high overtones help explain the instrument's reportedly superb projection.

THE 'VIEUXTEMPS' IS ONE OF TWO 1741 Guarneri 'del Gesù' violins associated with the celebrated violinist and composer Henry Vieuxtemps. It is well documented in all the usual ways, most notably in Peter Biddulph's two-volume *Giuseppe Guarneri del Gesù*. In the decade since that work was published, new measurement technologies have become increasingly available to researchers, among them a handful of technically minded violin makers. In the 1980s German maker Martin Schleske pioneered modal analysis and sound radiation measurements as workshop tools. In 1989 American maker John Waddle teamed up with radiologist Steven Sirr to CT-scan old Italian instruments. Everything began accelerating in 2002, when the VSA Oberlin acoustics workshop started bringing makers and researchers together every summer. By 2007 British maker George Stoppani was distributing modal analysis software that he himself had written – a mind-boggling feat for someone with no formal training in science or programming.

Following Schleske's lead, I got interested in measuring violin sound using an impact hammer. Colleagues have since suggested that the words 'impact' and 'hammer' should never be used in the same sentence as 'old Italian violin'. Still, the tool itself is disarmingly small – a hollow plastic handle, several inches long, with a soft-tipped head no bigger than a peanut. Tapping a violin's bridge with it applies roughly the force of a mezzoforte pizzicato, setting the instrument into vibration across a wide range of frequencies. By comparing the signal from the hammer's internal force sensor with that from a suitably placed microphone, a computer calculates the sound output at each frequency, for a given force at the bridge.

There's a complication – you can tap a bridge at any number of places, from any number of directions, and each gives different results. Capturing all the ways the strings might act on the bridge means measuring in three directions at each string notch – a total of twelve separate measurement cycles.

PHOTO JOSEPH CURTIN

► The 1741 'Vieuxtemps' Guarneri 'del Gesù': a huge sound and a quick response

MATTHEW TOLZMANN/COURTESY BEIN & FUSHI INC

In practice, researchers usually pick a single driving point, such as one corner of the bridge, and apply a sideways force, emulating the roughly side-to-side direction of the violin bow.

Using this 'horizontal excitation', researchers have mapped out a number of acoustical features that show up in any normally built violin (see figure 1). The three prominent low-frequency peaks are the so-called signature modes: A0, B1- and B1+ (see 'Scent of a Violin', June 2009). One or more peaks near 1kHz form the 'transition hill', a feature first named at the Oberlin acoustics workshop. A cluster of peaks from roughly 2.5kHz–4kHz make up the 'bridge hill' (see 'Bridging the divide', August 2005), above which the output tends to decline with frequency.

BUT HOW COMPLETE A DESCRIPTION of violin sound does this unidirectional excitation provide? After all, when a violinist moves from bottom string to top, the bowing angle changes by almost 90 degrees. On the E string, it can reach 45 degrees with respect to the plane of the top, meaning that the forces at the string notch are evenly divided between horizontal and vertical. What, then, do vertical forces add to the tonal mix?

For a quick answer, tap the corner of a violin's bridge sideways with your fingernail, then tap it downwards from above, between the A and D strings. The downward (vertical) tap sounds brighter, suggesting greater high-frequency content. I tried measuring this about a year ago, my assumption being that horizontal and vertical hammer taps would elicit the same acoustical features, though in a somewhat different balance. The overall slope of the response curve did indeed shift, with the low modes only weakly excited. But there was now a significant peak at about 720Hz – a peak that had barely shown with horizontal excitation. More surprisingly, the bridge hill had become a valley, while a broad range of peaks had sprung up in the 3.5kHz–6.5kHz range.

I was particularly interested in this 'upper hill'. Was it associated with a vertical 'bouncing' motion of the bridge, the way the bridge hill is with a horizontal rocking motion? If so, could makers control it by 'tuning' the bridge? The bridge hill is considered profoundly important to an instrument's brilliance and projection. What, then, does the upper hill contribute? Could it explain why the outer strings are more soloistic than the middle strings, where bowing is constrained to the near horizontal? Physicist Gabriel Weinreich once warned me that before building theories around some particular phenomenon, it is best to make sure that the phenomenon actually exists. Finding an unusual acoustical feature on one of my own instruments would convince no one. I needed to measure old Italian violins of indisputable quality. I needed to measure the 'Vieuxtemps'.

AS LUCK WOULD HAVE IT, Fushi was agreeable, so I returned to Chicago one icy December morning, lugging a suitcase full of equipment. The 'Vieuxtemps' wasn't available until the afternoon, so I got started with a Vincenzo Rugeri, which I put though a horizontal and then vertical measurement cycle – each involving eight taps at twelve different microphone positions. I was also able to measure a Giuseppe 'filius Andreae' Guarneri, the 'Nachez' Stradivari, and a Guarneri 'del Gesù' that once belonged to Ruggiero Ricci.

Rush hour comes early in Chicago. Even ten floors above Michigan Avenue, traffic noise was jiggling the sound levels as I tapped and re-tapped the 'Vieuxtemps'. Every five minutes the 'El' train would thunder by, bringing measurements to a dead stop, so it was after closing time when I finally packed up my gear. Outside, a snowstorm was blanketing the city. There was only just time to get to the station in time for my train, but once safely onboard, I began processing the data.

All the violins showed a prominent upper hill, none more so than the 'Vieuxtemps'. For two out of twelve microphone positions, its upper hill was higher in amplitude than any other peak in either response curve (see **figure 1**). If the measurements were credible, the 'Vieuxtemps' was a startling counter-example to the idea that horizontal bridge excitation provides a reasonably complete description of a violin's sound output.

Fortunately I got the go-ahead to redo the measurements, and then to expand the project to include modal analysis and CT scans. I called Terry Borman, an Arkansas-based maker who learnt modal analysis from Stoppani. Borman had also done important research with Dutch computer imaging expert Berend Stoel, using CT scans to study wood density in old Italian violins. I spoke with Stoppani, who agreed to modify his software to streamline the testing. Scientists Gabriel Weinreich, Jim Woodhouse and Evan ▹

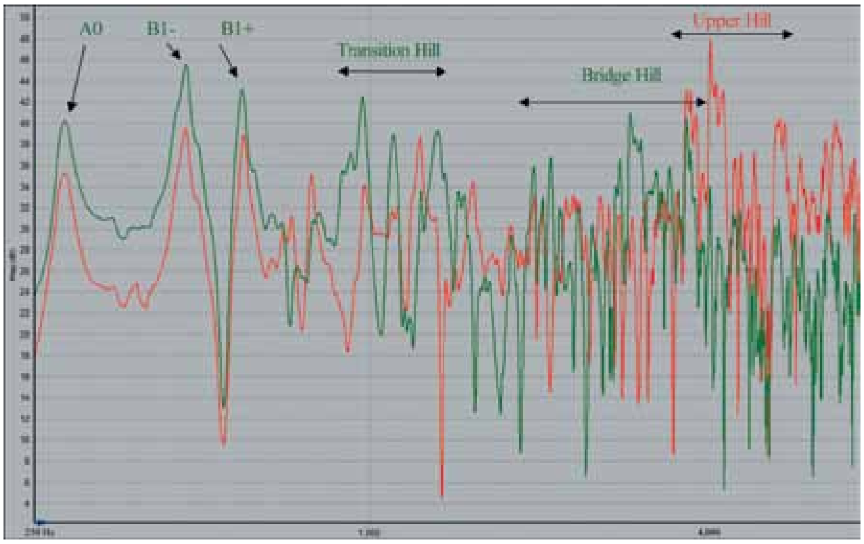

FIGURE 1 Horizontal (green) and vertical (red) spectra for the 'Vieuxtemps', measured at a single microphone position, 20cm from the violin's central axis, directly in front of the bridge. Vertical scale: relative amplitude in decibels. Horizontal scale: logarithmic frequency, 250Hz–8,000Hz.

FIGURE 2 Horizontal (top) and vertical (bottom) spectra for the 'Vieuxtemps' (white), 'Jarnowich' (yellow), Guadagnini (green), 'Cathedral' (red) and 'Nachez' (blue). Each line represents the real average of twelve microphone positions, evenly spaced around the instrument, in plane with the bridge, 20cm from the instrument's central axis. Vertical scale: relative amplitude in decibels. Horizontal scale: logarithmic frequency, 250Hz–8,000Hz.

Davis offered to help with interpreting data. D'Addario string designer Fan Tao suggested using binaural recording techniques to document the instruments: tiny mics placed in or near a violinist's ears would give a driver's-seat impression of what it's like to play a great instrument. This became feasible when Ilya Kaler agreed to record musical excerpts, and then a full recital, on five violins – a 1752 G. B. Guadagnini, the 1707 'Cathedral' Stradivari, the 'Nachez' Stradivari (labelled 1709 but whose back, sides and scroll have been dated to 1703, and the top much later to 1727), the 1741 'Jarnowich' Guarneri 'del Gesù' and the 'Vieuxtemps'.

IN MID-MARCH the team assembled in Chicago for a few days of intense work. In early April, Kaler played an inspired recital to a packed house (to hear him playing Wagner's *Albumblatt* on the 'Vieuxtemps', visit www.thestrad.com). All this left us with mountains of data and hours of audio recordings. **Figure 2** shows the horizontal and vertical response curves for the five violins. For all but one, the upper hill is higher in amplitude than the horizontally excited bridge hill. For the 'Vieuxtemps' and 'Jarnowich', it is both higher in amplitude and narrower in bandwidth than the other violins – or any violins I've measured since. Is this a characteristic of late Guarneri 'del Gesù' violins? If so, why? More research is needed.

Players often cite a greater depth of sound for 'del Gesù' violins compared with Stradivaris. As shown in figure 3, the 'Vieuxtemps' puts out conspicuously more sound below 500Hz than the 'Cathedral', especially for the A0 mode. Researchers have correlated relatively high A0 amplitudes with old Italian instruments (Duennwald), and with high-quality instruments in general (Bissinger), suggesting that A0 levels are an indicator of overall quality. In my experience, Stradivari violins confound this notion. Their A0 levels tend to be low – and this is certainly true for the Stradivaris in this study. Looking at figure 3, they fall some 5dB below the other three violins.

The B1 frequencies for the 'Vieuxtemps' are high, at about 468Hz and 590Hz (average values are around 440Hz and 530Hz – see 'Good Vibrations', July 2009). This means that the body is stiff ▹

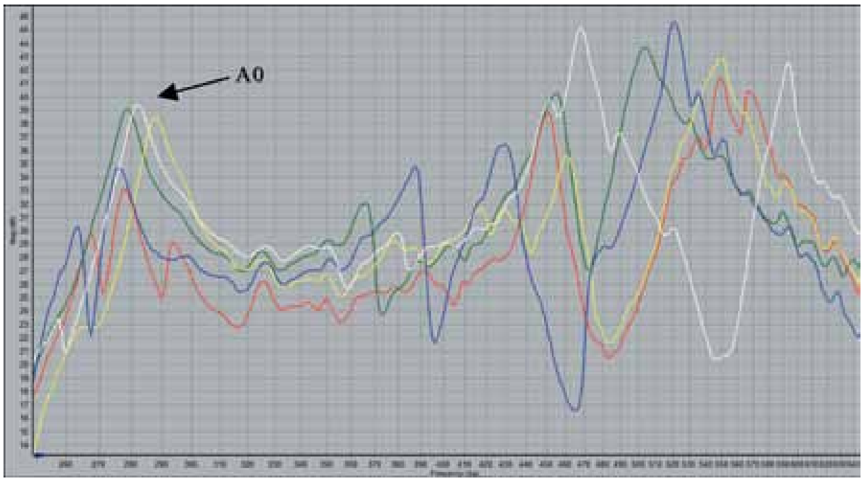

FIGURE 3 Below 500Hz, the 'Vieuxtemps' (white) puts out conspicuously more sound than the 'Cathedral' (red). Both the 'Cathedral' and 'Nachez' (blue) have significantly lower A0 levels than the 'Vieuxtemps', 'Jarnowich' (yellow) and Guadagnini (green). Vertical scale: relative amplitude in decibels. Horizontal scale: logarithmic frequency in Hertz (Hz).

► The laser-sharp high overtones of the 'Vieuxtemps' help explain its superb projection

MATTHEW TOLZMANN/COURTESY BEIN & FUSHI INC

in relation to its mass, which is no great surprise given the rather full graduations. Still, it raises an interesting question: when copying a violin, how closely should a maker follow the original graduations? The question becomes urgent when considering the 'Cannon' or 'Ole Bull'. Did Guarneri 'del Gesù' leave their plates so thick because he used low-density wood and wanted to compensate for its inherently lower stiffness? Or did he use 'normal' wood, but feel a little added mass and stiffness would benefit the sound or playability? It's hard to guess without knowing the wood densities or the plate weights. Fortunately, CT scans provide both, as Terry Borman will show. ■

Read Terry Borman's results from CT scanning and modal analysis of the 'Vieuxtemps' in the January 2011 issue

KEY POINTS

- Tapping the bridge vertically elicits an 'upper hill' – a cluster of high-frequency peaks in the response curve. For the 'Vieuxtemps' and the 'Jarnowich', the upper hill is higher and narrower than that of the other old Italians measured. More research is needed to see if this is a characteristic of late 'del Gesù' instruments.

- The 'Vieuxtemps' puts out considerably more sound below 500Hz than the 'Cathedral' Stradivari, especially for the lowest signature mode, A0. The difference in A0 levels holds true for other Stradivari and 'del Gesù' instruments tested, supporting players' observations that 'del Gesù' violins offer a greater depth of sound.

- The high B1 frequencies observed for the 'Vieuxtemps' mean that the body is stiff in relation to its mass – not unexpected given the violin's rather full graduations. Before using those same graduations for a copy, makers may want to take into account the wood density and plate weights of the original.