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Askenfelt, A.

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A LOOK AT VIOLIN BOWS*

Anders Askenfelt

ABSTRACT

It is well-known that the particular choice of bow influences the tonal quality of a violin. This effect has been attributed to either a modulation of the "bow pressure," or the bow velocity at the contact point with the string, or a combination. In both cases, resonances in the bow stick, coupled to the longitudinal motion of the bow hair, can be assumed to play a central role.

Some of the dynamical properties of violin bows have been studied. From a set of bows ranging from poor to excellent, basic properties as mode frequencies and damping ratios have been collected, and an attempt to connect the data with tonal quality, as judged by professional players, has been made. Attempts of tracing the perceived tonal differences down to characteristic differences in the string motion have been made by the use of a PC-controlled bowing machine.

INTRODUCTION

Musicians seem to rate the quality of a bow in two respects, dealing with; (1) the way the bow can be controlled in playing ("playing properties"), and (2) the influence of the bow on the tone quality ("tonal qualities"). It seems reasonable to assume that both these quality aspects basically are defined by the distributions of mass and stiffness along the bow stick. However, rather than aiming at such a description on a detailed level, it would be tempting to describe the playing and tonal qualities separately by a few global measures. For example, the playing properties could possibly be summarized in a set of parameters like the position of centre of gravity, the centre of percussion (with respect to an axis through the frog), and resistance to bending for a well-defined load.

The tonal properties, which is a more surprising effect, have been assumed to have a connection with the normal modes of the bow. These include transverse vibrations of the bow stick (bending modes), and longitudinal resonances in the bow hair (Cremer, 1981; Schumacher, 1975). A model of the mechanism which accounts for the influence on the string vibrations has not been presented as yet, but a modulation of the normal bow force ("bow pressure"), as well as a variation in bow velocity during sticking, have been proposed as plausible explanations. This study focus on the normal modes of violin bows, and their possible influence on the string vibrations.

NORMAL MODES OF THE BOW

The freely suspended bow stick, without frog and bow hair, typically shows about a dozen pronounced modes up to 4 kHz. The stick vibrates basically as a free-free bar. The mode frequencies form a series starting with the typical values 60, 160, 300, 500, 750, 1000, 1300, and 1700 Hz, approximately.

The damping ratio for the modes of the free bow stick is typically in the range 0.2 - 0.6 % (percent of critical damping), slightly increasing with mode frequency. When the bow stick is held in a light finger grip as for playing (baroque style), the damping

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increases drastically (an observation with well-known parallels in the studies of the violin). The damping ratio for the lowest bow modes increased by about a factor 20 to approximately 6%.

A comparison of a set of bows ranging from "very poor" to "excellent" with respect to tonal quality as rated by two professional players, showed no clear differences in the mode frequencies between bows of good and poor quality, respectively (see Fig. 1). The damping ratios, on the other hand, suggest that good bows have lower damping below 1000 Hz. However, as evident from Fig. 1, the picture is far from clear-cut.

**Fig. 1. Comparison of mode frequencies and damping ratios (percent of critical damping) of seven bow sticks from a set of bows rated on a scale 0 - 10 ("very poor" - "excellent") in tonal quality.**

No dramatic changes occurred when the frog and bow hair were mounted to the bow stick. The mode frequencies were lowered by 1 - 7%, while the damping ratios doubled. An additional mode was found in the assembled bow, identified as the lowest transversal mode of the bow hair (resembling the fundamental resonance of the string). The frequency of this mode falls between 60 - 75 Hz for a normal tensioning of the bow hair, and consequently it couples to the lowest mode of the bow stick at about 60 Hz.

**BOW IN ACTION**

The best way of characterising a bow, in particular for the purpose of physical modeling, is probably by the impedance of the bow as seen by the string (in both the transversal and longitudinal direction). Such measurements were initiated several years ago (Schumacher, 1975). However, before undertaking such measurements again, it seemed worthwhile to try a straight-forward approach to verify that an individual influence of the bow on the string vibrations could be observed. For this purpose a PC-controlled bowing machine was used, by which any reasonable bowing pattern can be reproduced (Cronhjort, 1992). The use of the machine ensured that the bowing para-
meters (bow velocity, bow pressure, and bow-bridge distance) were the same for all bows tested.

Anticipating the results of such measurements, the conclusion is that a lot goes on in the bow itself - differently for different bows - but the influence on the string vibrations is small. The examples that follow will illustrate this characteristic behavior.

"Steady state"

As a start, a "steady state" condition was studied, obtained from a detaché stroke by the machine. The observed portion was captured as a short part of the bow hair (4 mm) at the middle of the bow passed the string (see Fig. 2).

Fig 2. String displacement and bow tip acceleration at the middle of a detaché stroke for two bows (B and K) played by a bowing machine (bow velocity 200 mm/s, bow force 800 mN). The excerpt shown in the figure corresponds to 4 mm of bow motion. Note the ringing in the bow stick triggered at each slip phase. The string displacement was measured optically about 2 mm from the bridge.
Looking at the string displacement close to the bridge and the acceleration at the bow tip, the string is seen to follow the expected Helmholtz motion, while the bow stick rings with a strong component at about 2000 Hz, triggered at each slip-phase. For certain bows this ringing can be quite strong, but it is not reflected in the string motion (cf. bow B and K).

The bow stick has resonances in the 2-kHz region as mentioned, but the vibrations in this frequency range may also be boosted by longitudinal resonances in the bow hair in the region 1500 - 3000 Hz. The pronounced ringing gives a "formant" character to the spectrum of the bow vibrations, but an influence on the string spectra from these strong bow components was, however, not possible to verify, in line with the observations on the waveform.

A comparison of the string velocity signals recorded with four bows from the set of bows in Fig. 1, showed remarkably similar waveforms, despite that the bows were of very different quality, ranging from "good" (G) to "very poor" (B) (see Fig. 3).

![String Velocity Waveforms](image)

*Fig. 3. Comparison of string velocity waveforms for four bows played by a bowing machine (detache stroke, bow velocity 200 mm/s, bow force 800 mN). The string velocity was measured electrodynamically at about 33 mm from the bridge.*
The ripple with increasing amplitude during sticking, the so-called "Schelleng's ripples," is not an effect mainly of the bow resonances, but caused by reflected secondary waves in combination with the torsional motion of the string. However, the bow admittance is completely additive to the torsional effects, so this is exactly the place where we could expect to see an influence of individual bows. A rough estimate shows that the effect of the finite bow admittance can allow for a difference of the order of 10% between the nominal bow speed and the instantaneous velocity of the bow hair (at the contact point with the string) during sticking (Schumacher, 1975, 1979).

For the four bows in Fig. 3, the observed differences during the stick-phase are small, possibly with a little more pronounced ripples for the bow of more respectable quality (bow G). A larger difference can, however, be observed in the slip velocity which reaches a slightly higher peak value for bow G, which in turn gives a somewhat steeper slope of the slip pulse. It should be mentioned that all bows in the test collection had been rehaired before the experiments, using hair from the same horse (tail).

Not surprisingly, the corresponding string velocity spectra for the four bows were also very similar, however, with some enhancement in the range 2 - 3 kHz for bow G. The same trend was observed also when measuring the motion of the bridge instead of the string velocity. It must be emphasised that these results still are tentative, but nonetheless interesting, as they refer to a frequency range which is known to be of importance for the sound of high-quality violins (Jansson, 1992; Dünnwald, 1990).

**Accented bow strokes**

Two versions of "sudden" bow strokes were tried with the bowing machine, one milder, defined as "accented up-bow," the second being a powerful martellato in a down-bow. As expected, the string amplitude grew much faster and to a higher amplitude in the martellato.

The accented up-bow was characterised by two episodes of ringing, the first at about 1700 Hz (probably the longitudinal bow hair resonances) followed by a ringing of a stick mode at about 800 Hz. Both were superimposed on a slow oscillation at about 40 - 50 Hz, which is the "trembling" of the bow after the sudden attack. The build-up of the periodic string vibrations was uncertain, and the transient state lasted for more than 100 ms.

In the bow-vibration spectra, these ringings are actually seen as resonances between the peaks corresponding to the string partials. This gives a spectral signature of the bow, as they occur at frequencies which differ from one bow to the other. However, the presence of these resonances in the string spectra is obscure.

The martellato start was usually prompt and surprisingly clean with properly spaced pulses from the very first period (see Fig. 4). In between, the bow stick is seen to ring at about 2000 Hz, as observed for the detaché stroke. Bows with a pronounced ringing (cf. Fig. 2, bow B), can give problems in the start, with spurious small slip events in between the regular slip-phases.
CONCLUSIONS

A set of violin bows of varying quality has been examined with respect to modal frequencies and damping. For the free bow stick, the damping is generally low and a trend between rated quality and mode damping could be observed, while no such dependence could be seen for the mode frequencies. With the bow assembled, the damping increased by a factor two due to the bow hair, and by an additional factor 10 due to the player’s holding.

In playing (by a bowing machine), differences in the action of different bows under identical bowing conditions could be observed, in particular for sudden bowing patterns. However, the influence from the bow on the string vibrations was small and much harder to document.

Small as it might seem, the influence of the bow on tonal quality is nevertheless an important element in professional violin playing. Continued studies with the bowing machine, using experimental bows with “unnatural” characteristics (e.g. very stiff - very weak) might be a way to get a better understanding of the influence of the bow on the string excitation.

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