BOW *SPEED* OR BOWING *POSITION*— WHICH ONE INFLUENCES SPECTRUM THE MOST?

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ABSTRACT

Raman and Schelleng analyzed waveform properties of the bowed string as function of bow speed, bow force, and bow position (the distance between bow and bridge). Schelleng also described spectral changes caused by alterations of the bow force alone. This phenomenon was further explained by Cremer, and referred to as "rounding of the Helmholtz corner". In this study it is shown that of the remaining two parameters, it is the bow's speed rather than its position that bears a potential of changing the shape of the string's spectral envelope. This contrasts to the popular belief that by bringing the bow closer to the bridge, the sound automatically becomes more brilliant.

1. INTRODUCTION

Every string player has experienced that by bringing the bow closer to the bridge, the sound becomes more brilliant. In the case of pizzicato, a similar effect is observed when the point of plucking is approaching one of the string's termination points. One might thus easily jump to the (hasty) conclusion that changing the point of excitation alone alters the spectral envelope in both cases.

In his JASA paper of 1973, Schelleng[1] utilized a diagram to describe the requirements for maintaining the Helmholtz motion in terms of the bow's force and position, provided a given speed and defined string properties. He also brought the concept of timbre variation into the picture, introducing the two terms "brilliant" and "sul tasto" in his diagram. ("Sul tasto" literarily means "by the fingerboard", but appears here, presumingly, as reference to soft tone color.) It is, however, not immediately apparent from the figure whether these timbre differences are caused by change of bowing *position* (the two expressions are marked at different bow positions within the Helmholtz area), or by change of bowing *force* (the expressions are positioned at different values with respect to the ordinate).

In the discussion that followed, Schelleng showed how the waveform of the string velocity under the bow changes with the *bow force*. Cremer [2] analyzed this more in depth, and established the theory of "the rounded corner".

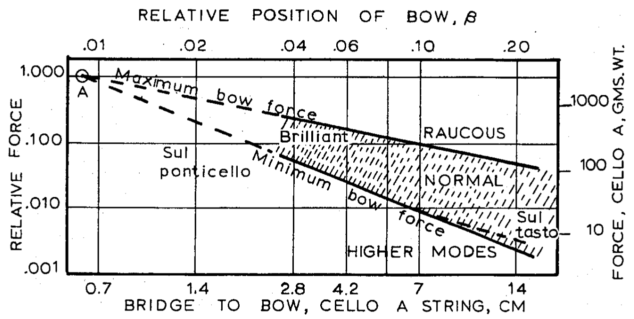

Figure 1:
Diagram from Schelleng's JASA paper. Given a fixed bow speed, the triangle sets the borders for maintaining Helmholtz motion in a bowed string. Two timbre expressions, "Brilliant" and "Sul tasto", are included in the figure, within the triangle.

2. ANALYSIS OF FORCE ON THE BRIDGE DURING PIZZICATO AND ARCO

In pizzicato, the force exerted on the bridge during each individual period is in principle an off-set square pulse with a width equal to β/f_0 (β being the relative position of excitation, and f_0 the fundamental frequency). For large β, the spectral slope is generally −6 dB/oct., corresponding to an envelope of decaying lobes. The first lobe, however—the width of which is determined by β—will provide a number of partials with amplitudes near unity (see Figure 2).

So is not the case in arco: The force signal exerted on the bridge during an ideal Helmholtz motion remains a perfect sawtooth wave, irrespectively of which β chosen. As long as the Helmholtz corner is "sharp", the deviation from the ideal saw-tooth shape are steps due to "missing partials" or "…node frequencies" i.e., frequencies having a node at the position where the bow excites the string (see Appendix). The sawtooth wave itself creates no spectral lobes, but decays smoothly at a rate −6 dB/oct. (Lobes are seen, however, in the spectrum of string velocity under the bow.)

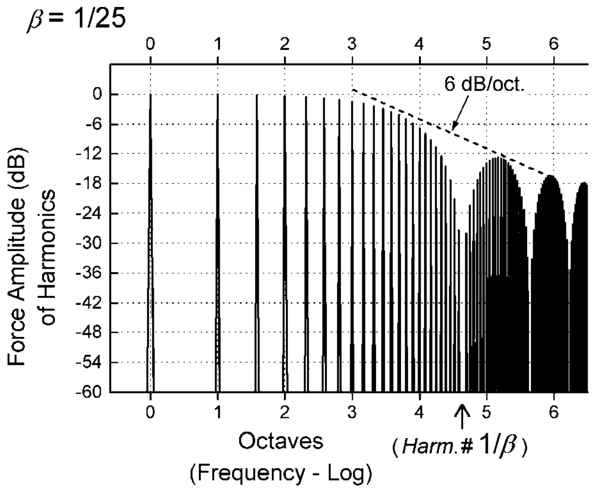

Figure 2:
Spectrum of the force acting on the bridge in pizzicato. As β *becomes smaller, an increasing number of (lower) partials will approach unity in magnitude—relative to the width of the first spectral lobe.*

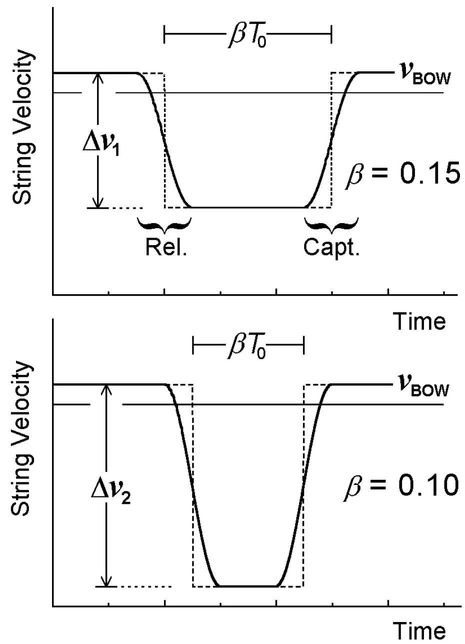

Figure 3:
Example of string velocity under the bow for two different β*, but with the same bow speed and identical transition functions from stick to slip and vice versa. (*T_0 *= the fundamental period;* $\Delta v = v_{BOW}/\beta$*, while* β *= the ratio between the bow-to-bridge distance and the total string length.)*

As was already shown by Schelleng, it is the transitions at release and capture at the bow that carry the potential of softening or sharpening the rotating corner, and thus distinctly changing the tone color. Figure 3 shows idealized examples of such transitions.

String stiffness and the frictional characteristics of the rosin—as well as previous rounding of the rotating corner—cause the string release to spread out over a small transition interval before the full negative velocity is reached at slip. Accordingly, a comparable transition takes place at capture. (In practice the transition at capture is often shorter than the one at release—see Figure 4.) It can be shown that as long as these *transition functions* are independent of the bowing position, the force signal's spectral slope, i.e., the shape of the envelope, will remain entirely unaffected by β.

3. EFFECT OF BOW SPEED ON SPECTRUM.

Figure 4 and 5 show measured string velocity during slip, and spectral content for an open violin D-string [3] bowed by a bowing machine with bow force = 400 mN, and three different bow speeds, respectively. When averaged over a large number of periods, a modest prolongation of the slipping interval was observed as bow speed was increased. But more importantly: the string's deceleration and acceleration took slightly lower values.

The effect of that is quite visible when regarding the amplitude spectrum of the string velocity under the bow. When normalizing the energy of the first harmonic to zero dB, increasing the bow speed from 3 to 5 through 10 cm/s gave average amplitude reductions of 1.3 and 5.2 dB, respectively, in the range 16th to 65th harmonic. Increasing the bow speed further, from 10 to 30 cm/s, reduced the amplitudes only slightly more: in average another reduction of 0.8 dB to 6.0 dB, for that same harmonic range. It is probably correct to say the influence of bow speed on spectrum has its greatest impact at low speeds within the Helmholtz regime.

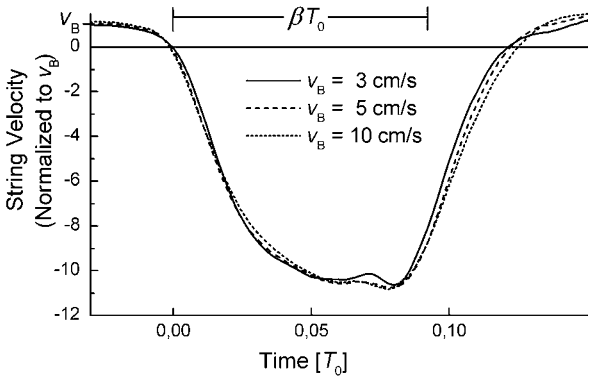

Figure 4:
Averaged string-velocity under the bow during slip for three different bow speeds. Stick/slip transitions are slowed down as the bow speed is increased. (Bow force = 400 mN; β *=1/10.833; bow-hair width = 8 mm; all strokes performed with bowing machine).*

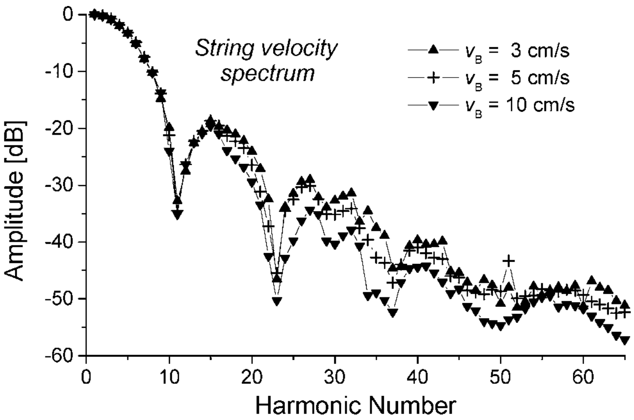

Figure 5:

Spectrum of string velocity for the three strokes referred to in Figure 4 (normalized to 0 dB for the first harmonic). It can be seen that the lowest bow speed gives the highest (relative) amplitudes for the upper partials. In each case the spectrum was averaged over several strokes with constant bowing parameters.

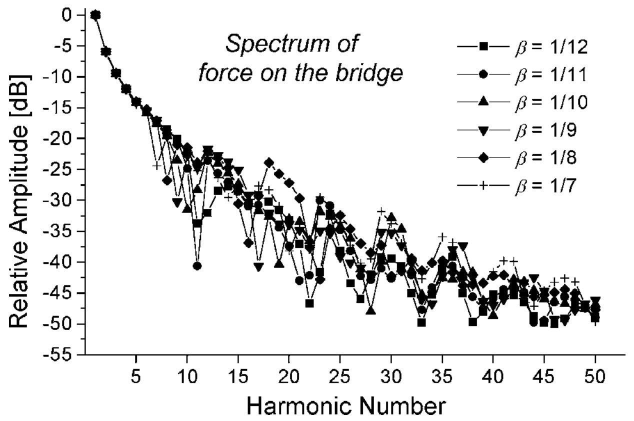

Figure 6:

Simulated spectral changes as the bow is moved from β = 1/7 to β = 1/12 while keeping other bowing parameters unaltered—the first harmonics normalized to 0 dB. (From ref. [6].)

These spectrum data were obtained by averaging the FFTs of a Bluestein [4] -filtered (the filter allowing for an arbitrary number of elements in the FFT), moving Hann window of width equal to five nominal periods of the waveform under investigation. This procedure minimizes the danger of spectral peaks of higher harmonics being reduced or "averaged" due to the small frequency fluctuations that are always present in a bowed-string signal—but less so when the bow speed is high, or the bow force low.

The string-velocity signal was recorded as the voltage induced in the (steel) D-string when moving in a fixed magnetic field provided by a permanent magnet right under the string at the point of bowing. The magnet's diameter (6 mm) was later compensated for in the calculations of spectra. Sampling frequency was 44.1 kHz (resampled to 148 kHz for Fig 4).

Apart from the "natural aperiodicity" [5] of the bowed string, no pitch flattening was observed with the bowing parameters employed in these tests. Earlier experiments and simulations have shown, however, that when pitch flattening is introduced as result of excess bow force or too low speed, higher partials tend to fade out, while mid-range partials are still emphasized.

4. EFFECT OF BOW POSITION ON SPECTRUM

To see the effect of moving the bowing point over a large range while maintaining all other parameters unchanged, a series of simulations was performed. The string model included torsion and a "quasi plastic" friction algorithm (all data similar to String I of ref. [7]). The resulting spectra of force on the bridge are shown in Figure 6. Apart from the local deviations seen for "node frequencies" or frequencies close to these, the general spectral envelope remains unchanged for all simulations. There is no trend in the direction of greater brilliance for lower β. Other string models give similar results.

APPENDIX

In a purely resistive system like the one studied by Raman [8] and Schelleng, the "sawtooth" force signal working on the bridge will consist of a number of steps rather than one ramp. This number can be found as the lowest value of n that holds for the expression below:

$$n(1-\beta) = \text{integer}, \qquad (\beta < 0.5;\ n = 1, 2, 3,\ldots). \qquad (1)$$

During the buildup of the Helmholtz motion, slip waves "rotate" on each side of the bow with frequencies β/f_0 and $(1-\beta)/f_0$, respectively (see ref [7]). In this process, the string's reflection pattern will repeat in time intervals equal to $n(1-\beta)/f_0$. Examples: for $\beta = 1/6$, $\beta = 1/6.1$, and $\beta = 1/6.5$, the force signal will consist of 6, 51 and 13 (individually sized) force steps per period, respectively. It follows that for an irrational β, the force on the bridge will take the form of a true sawtooth—after an infinitely long transient.

ACKNOWLEDGMENT

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