Behavior Of Real Violin Strings, Mechanically Bowed

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Abstract: Traditional methods of evaluating various types of strings for bowed instruments have relied almost exclusively on subjective impressions of expert players. In the real world, busy professionals rarely have time enough or objectivity enough to provide string designers and manufacturers with precise information. The use of a well-designed bowing machine makes it possible to amass quantities of data on specific strings, enabling string makers to discover the characteristics that are favored by professional artists. This work has led to new string designs, incorporating new materials and manufacturing processes.

As the mechanical source of whatever sound emanates from a string instrument, motion of the string itself is what aspiring players spend their lives trying to control. Although much of what such a musician has to learn can be expressed as logical physical principles in mechanics, those are rarely, if ever, used by even the greatest teachers. Years of guided practice slowly reveal to the student the boundaries of useful string vibration within which one must operate to produce acceptable music.

When a taut string is plucked or struck it will vibrate after release no matter where or how much it was displaced. The details of its motion will vary, but while returning to rest it will oscillate at a definite frequency determined by its mass, length, tension and mode (whether fundamental or harmonic).

Exciting a string with a rosined bow is a different proposition altogether. It may or may not produce a musically useful vibration, depending on a number of variables: Under control of the player are the bowing point (distance from the bridge), bow velocity and force against the string (what musicians call “bow pressure”). Not under immediate control are the mechanical properties of the particular string being played and the effect of mechanical resonances in the instrument reflected to the string through the bridge.

In 1973 John C. Schelleng clearly explained the physics of bowing in a paper entitled “The Bowed String and the Player” (1). It explains the reasons for restrictions and limitations on bowing parameters in a form that might be somewhat difficult to understand for musicians without mathematical skill. The following material reveals the teaching of Schelleng, the data having been obtained by actual bowing of real strings. The bowing was done on a machine developed over many years to provide controlled excitation of bowed string to a degree of uniformity far in excess of what even the most skillful player can achieve.

The mechanics of string excitation through adhesion of rosin particles is explained in some detail in Chapter VII of “The Bowed String” (2). For the player, the important things to remember are: (a) There is a limit to the frictional force the rosin interface can exert before breaking loose, (b) The force is applied at the circumference of the string, and not in the plane of the center of mass, (c) With limited applied force more massive (lower) strings are inherently slower to respond, and (d) The closer to the bridge, the more resistant the string is to lateral displacement.

Each series of these tests requires approximately 150 measurements on a single string. Bow weight against the string was varied from 10 to 120 grams in steps of 10 grams for each combination of bow velocity and distance from the bridge. Velocities were 10, 15, 20 and 25 centimeters per second at 1.5, 3.0, and 4.5 centimeters between the bridge and the nearer edge of the ribbon of bowhair which had a constant width of 7 millimeters (narrower than usual) for this work.

It takes rather a long time (tenths of seconds) for a steady tone to develop under light bow pressure, especially when the bow is close to the bridge and moving quickly. Elevated temperature at the bowing point is what makes rosin “sticky”, and it increases with bow pressure. Furthermore, a fast-moving bow conducts heat away from the contact area more quickly, and more lateral force is required to displace a string close to the bridge. For these reasons, when the bow machine operates under these conditions, the stroke is started with reduced velocity and increased pressure for the first few centimeters, after which test conditions are established and measurements made.
A few seconds of the waveform amplitude (optically observed) are digitally captured in computer memory and transferred to hard disk. Resolution is 10 microseconds between readings, or 10,000 points per second. The computer calculates average amplitude and average frequency for each bow stroke.

Amplitude or sound intensity can be directly controlled by bow speed if the bowing point is held constant. It is essential for players to note that amplitude is not appreciably affected by bow pressure! The belief that pressing harder with the bow makes a louder sound is prevalent among players and teachers alike, but is not really true if the bowing point is unchanged. Higher pressures do increase noise and production of high partials, both of which may give an impression of increased power, but the usual effect, to a listener, is degraded tone quality and pitch flattening with negligible change in sound intensity.

There are strict limits on bow pressure, as every player knows, depending on how far from the bridge a given string is bowed. Once a steady tone is established it can be maintained over a wide range of bow speeds and pressures, the tonal breakdown occurring at low velocity and heavy pressure. As the bowing point moves away from the bridge that breakdown comes earlier, in terms of allowable pressure at a given velocity.

Interesting relationships among bow speed, pressure and distance from the bridge can be observed in this testing. For instance, bowing at 15 cm/sec 1.5 cm from the bridge produces almost exactly the same string amplitude as does 25 cm/sec at twice the distance, regardless of bow pressure. This indicates how good players extend the length of phrases on a single bow stroke.

One might reasonably expect a more exact relationship between distance from bridge and bow velocity required for the same string amplitude, but the rather wide ribbon of hair compared with the bowing distances involved makes determination of the latter somewhat imprecise.

Mistuning of more than about 5 cents is readily audible to musicians, so the amounts found in testing show that some conditions of bowing can exceed acceptable intonation criteria, even when producing a tone of good quality. Much of the pitch change is compensated for by the string player’s ability to change finger position.

The reason for the drop in pitch as bow weight is increased is the delay in release from the “sticking” portion of the cycle. This lengthens the period of the individual cycles. The further from the bridge and the slower the bow, the more reluctant is the string to break loose from the rosin bond once it is formed. Inasmuch as the breakaway force is fairly constant for a given bow weight and velocity, the string will adhere longer as its lateral compliance increases with distance from the bridge.

Three violin D strings of different core materials were bowed at 15 centimeters per second 1.5 centimeters from the bridge at varying bow weights. Waveform was recorded on disk and short segments, randomly selected, examined for frequency stability. Time between zero crossings was converted into cents deviation from average frequency and plotted for groups of ten consecutive cycles. Variation increases gradually as bow pressure increases and becomes quite wild at the extreme, even though a continuous tone (of poor quality) is being produced.

Work continues along these lines with the testing of all brands of strings for violin, viola and cello. Other physical characteristics such as torsional stiffness and damping, mass per unit length, lateral damping and diameter uniformity are recorded. From correlation with the opinions of fine performers, desirable attributes of bowed strings are revealed and incorporated into new designs.

REFERENCES