Proceedings of the Institute of Acoustics

MEASURING THE PHYSICAL PROPERTIES OF VIOLIN BOWS

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ABSTRACT

The violin bow is a critical and often-neglected element in the production of good violin tone. The bow maker makes critical decisions in selecting the wood, graduating and bending the stick. These decisions determine the static and dynamic properties of the bow. These physical properties determine the complex interaction between the bow hair and the string and give each bow its own "signature" sound and feel. This paper addresses the measurement of static characteristics of violin bows and their correlation to player's impressions of playing quality. Methods for measuring stiffness and its distribution along the length of the bow are developed to emulate the tactile tests performed by makers and dealers when they evaluate bows. Measurements of ten violin bows of varying quality are presented.

1. INTRODUCTION

The violin has been extensively studied for centuries to an attempt to discover the "secrets of Stradivari". Hundreds of books and technical papers have been written on all aspects of construction, varnish, wood, as well as the scientific testing and analysis of the violin. However, few of those papers even mention the violin bow. As any bow maker will gladly tell you (admittedly, not an impartial source), that the bow is just as important as the violin in the production of high quality sound.

The bow maker makes several decisions in crafting a fine bow. The first decision is to select the wood, (universally pernambuco for top quality bows). The important properties of wood are its aesthetics (grain, color, etc) as well as density, elastic modulus, and internal damping. The bow maker then tapers or "graduates" the stick, and adds the camber, based on experience, feel, and the study of other great bows. In addition to using their hands to feel, some makers will measure the flexibility of the bow by suspending it between supports at the frog and tip. A known weight (typically 1 pound) is hung from the center of the stick and the deflection at that point is measured. This provides a single measure of the overall flexibility of the bow, but provides no information as to how that flexibility is distributed from frog to tip.

The decisions made by the maker and embodied into the final work dictate all its physical properties. These physical properties uniquely determine the complex interactions between the bow hair and the string that give each bow its "signature" sound and feel. The physical properties of bows can be divided into two categories - static and dynamic. The static properties include weight, location of the center of gravity, moment of inertia, and stiffness distribution. Dynamic properties describe the vibrational behavior and include the natural frequencies, mode shapes and damping values for each mode.

2. QUALITATIVE EVALUATION OF BOWS

How does a bow maker judge the quality of a bow? At a recent meeting of the Violin Society of America several makers, as well as dealers, were observed evaluating bows without playing them. Some of the observed tactile assessment techniques used were:

a) Hold bow at frog and assess its overall balance and feel
b) Tighten hair to playing tension, hold the frog in the right hand and tap the tip against the left palm. A "good bow" will feel lively in the right hand, i.e. the vibrations felt in the frog will "ring" longer in a good bow. The frequency of the vibration can also be informative.
c) With bow at playing tension, holding the tip in the left hand and the frog in the right, flex the stick toward the hair. A bow of lower quality will appear to bend only at the center. Good bows will appear to bend more uniformly over a wide area of the stick.
d) Tighten the bow hair until all the camber is taken out of the bow. As bow is tightened, observe the stick. A good bow will straighten out uniformly and all parts will arrive at straight condition at the same time.

These actions qualitatively measure:
a) moment of inertia, location of center of gravity, mass
b) internal damping, natural frequency
c) stiffness distribution
d) stiffness distribution and camber

3. LITERATURE

Important research on bows has been undertaken by Pickering[1], who attempted to discriminate between violin bows of various degrees of quality by means of physical measurements. He measured the moment of inertia, thickness distribution and deflection of ten violin bows, and found a promising correlation between bow quality and the ratio of moment inertia to weight. Vibrational characteristics of bows (mode shapes and natural frequencies) were measured by Askenfelt[2], and Bissinger[3]. The complex action of the bowed string (but with no mention of the bow itself) is described by many papers and is well summarized by Cremer[4].

4. OBJECTIVE

This study builds on the work of Pickering and attempts to quantify the playing quality of violin bows by physical measurements of static properties. Specifically, physical measurement procedures are developed to emulate the observed actions of makers and dealers when they evaluate bows. The objective of this study is to develop procedures to gather physical data on bows for later comparison to professional players' evaluations of the playing qualities of bows. A future study will address dynamic characteristics.

5. TEST DESCRIPTION

1) A test fixture was built as shown in Figure 1 to measure bow deflections under prescribed loading conditions. The bow is suspended on two 3/8" diameter steel dowels which are spaced 24.87" (63.2cm) apart. The right support is located at the end of the frog where the thumb grip begins. Loads are applied by hanging weights at any desired position along the bow. Deflections are measured by five equally spaced dial indicators with resolution of .001 inches. The dial indicators measured the deflection caused by the applied load relative to the unloaded position of the bow. The camber was not measured. The indicators were located 10.8 cm apart with the center unit located at the midpoint between the two supports. The frog was removed from the stick to eliminate any hair tension.

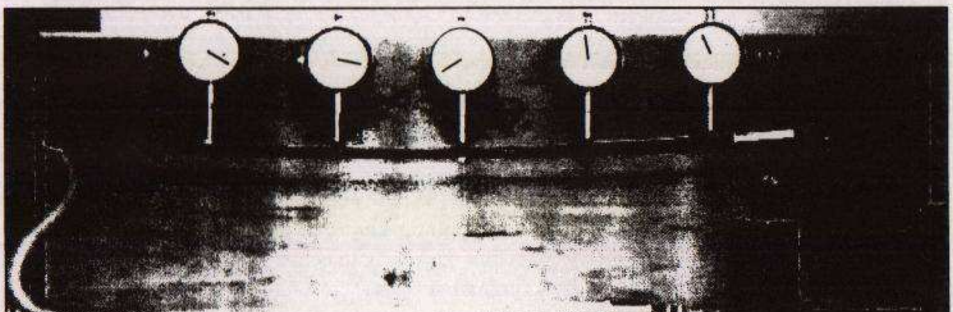


Figure 1. Test apparatus for determining bow deflection to known static loads, here shown is a 1 kg weight applied 5 cm from the support at the frog end.

Two different tests were performed with this fixture:

1) Measure deflection at the center (δ_{1lb}) to a 1 pound load at the same position (to compare with the traditional bow maker measurement)
2) Measure deflections at five positions along the bow to a 1 kg load applied 5 cm from the support at the frog (to measure how a bow deflects when loaded in a pseudo-playing condition)

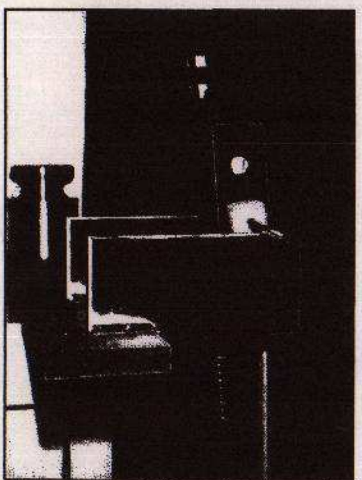
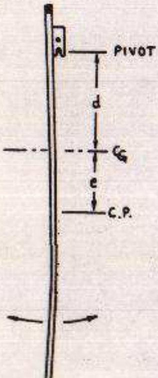


Figure 2. Test fixture for measuring the time for a bow to swing as a pendulum

Bow mass was measured with a digital balance (Ohaus model LS200) with 0.1 gram resolution. The center of gravity was determined by balancing the bow on a support and measuring the distance from the balance point to the end of the screw barrel with a millimeter scale.

The moment of inertia (I_G) was found by first measuring the time it takes the bow to swing as a pendulum when supported by a pivot at the frog as shown in Figure 2. The thumb notch of the frog was suspended by a 3mm diameter hollow brass rod which freely rolled on polished edges. The time to complete twenty oscillation cycles was measured by a stop watch.



The moment of inertia is calculated by:

$$\tau = \text{measured period of one oscillation (seconds)} = 2\pi\sqrt{\frac{d+e}{g}}$$

where: g = gravitational constant (981 $\mathrm{cm/sec^2}$)
d = distance from pivot point to center of gravity (cm)
e = distance from center of gravity to center of percussion (cm)
m = mass of bow (grams)

$$e = \frac{\tau^2 g}{4\pi^2} - d \quad \text{(cm)}$$

$$I_G = \text{moment of inertia about center of gravity} = m \cdot d \cdot e \qquad (\mathrm{g \cdot cm^2})$$

6. RESULTS AND ANALYSIS

Ten bows of various quality were tested, including a Sartorie, a fine handmade bow by a modern maker (Rodney Mohr), a nice playing bow by Carlo Michaeli,), a modern Chinese bow of very good quality (Eastman), German bows of good quality (Sturm, Raum, Meisel) and lesser quality (Seifert, Schmidt) and for comparison purposes, a Glasser figerglas bow. The moment of inertia was determined for each bow, except the Sartorie, which was without hair at the time. Deflection tests were performed on each bow. The deflection data from the five dial indicators was further processed using a spreadsheet program (Microsoft Excel). A fourth order polynomial of the form: $\delta(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4$ was fitted to the experimental data (where $\delta(x)$ = vertical deflection at position x, x = horizontal distance from support at frog).

A typical data set is shown in Figure 3 for the Sartorie bow, showing the experimental data points as well as the fitted curve. Excellent agreement between the fitted curve and experimental data can be seen. This fitted curve was then used to determine the position of the maximum deflection from the end of the bow (x_{max}), and its amplitude (δ_{max}). In order to emulate the tactile test (c), the fitted curve was next used to calculate the length of the bow stick which experienced at least 90% of the maximum amplitude ($x_{90\%}$). The deflections for the higher quality bows are shown in Figure 4. A summary of all test results is shown in Table 1. The bows are listed in order of author's preference (most preferred at top of table).

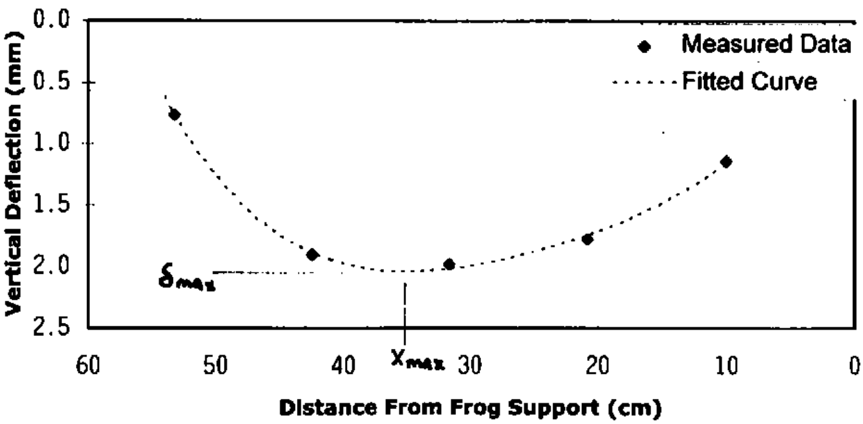


Figure 3. Comparison of the measured deflection to a fourth order polynomial curve fit for Sartorie bow. A 1 kg load was applied 5 cm from the support at the frog.

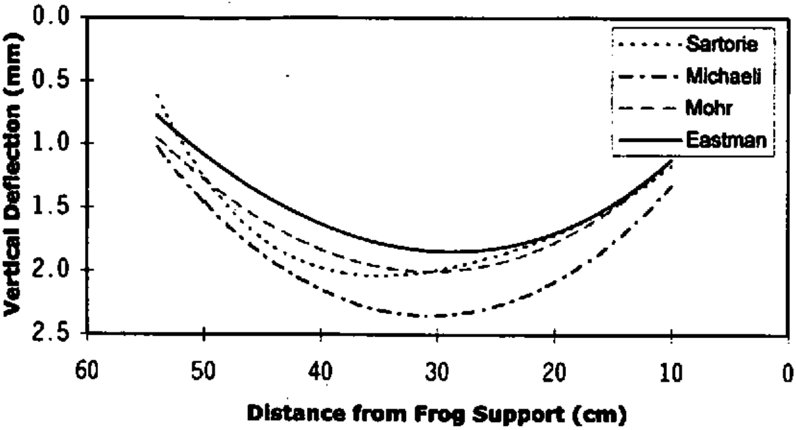


Figure 4. Deflections caused by 1 kg load applied 5 cm from frog support for higher quality bows

Table 1. Summary of Test Results

Bow	mass grams	CG cm	d cm	τ sec	δ_{1lb} inch	δ_{max} mm	x_{max} cm	$x_{90\%}$ cm	I_G g cm^2
Sartorie	58.2				.175	2.04	34.9	20.1	
Michaeli	57.0	25.5	19.5	1.34	.212	2.35	30.6	20.1	27700
Mohr	60.5	25.7	19.7	1.35	.180	2.00	30.6	19.9	30300
Eastman	58.9	25.2	18.5	1.34	.173	1.85	28.7	20.0	28300
Sturm	61.6	25.5	19.5	1.34	.153	1.82	28.7	19.4	30000
Meisel	60.1	26.9	20.5	1.34	.151	1.77	28.1	18.7	30300
Raum	61.7	26.8	21.0	1.36	.206	2.40	29.6	19.5	32000
Schmidt	57.1	25.6	19.3	1.34	.174	2.14	26.9	19.0	27700
Seifert	61.7	27.0	20.2	1.36	.194	2.28	29.4	18.7	31800
Glasser (	63.1	28.0	21.2	1.38	.163	1.91	30.5	19.6	34700

7. CONCLUSIONS

An examination of Table 1 seems to indicate a correlation between quality and high values of x_{max}, and $x_{90\%}$. Bows that felt "heavy" had high moment of inertia I_G. A more complete study with more bows and player's evaluations is planned.

References

[1] N.C. Pickering, Physical Characteristics of Violin Bows, Journal of the Violin Society of America.
[2] A. Askenfelt, A Look at Violin Bows, Proceedings Stockholm Musical Acoustics Conference, 1993.
[3] G. Bissinger, Merging Microphone and Accelerometer Modal Analysis Measurements- Violin Bow Example, Proceedings of 11th International Modal Analysis Conference, 1993, pp 850-854.
[4] L. Cremer, The Physics of the Violin, MIT Press 1984.