ingegneria sismica
International Journal of Earthquake Engineering
Anno XLIII - Num. 2 - 2026

Physical-mechanical modeling of violin bow-string interaction and computational analysis of sound output effects

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SUMMARY: *The violin sound output effect involves many aspects such as the acoustic structure of the instrument, string vibration, and so on. In this paper, based on the theoretical knowledge of vibration and Helmholtz motion, the mass-spring model of bow-string interaction is established. The physical phenomena are revealed by a non-contact optical measurement system, and the spectrogram of the bow-string interaction is obtained to analyze the sound output effect of the violin. The results show that the captured images are processed and analyzed to show that the vibration of both the G-string pulling and the E-string pulling motions are characterized by attenuation. The pulling direction is not strictly along the Y direction, and some components are in the X-Y and X-Z planes. The displacement waveforms show that the average vibration periods of the pulled G and pulled E strings are about 5 ms and 1.5 ms, respectively. The strings with average onset of vibration duration were E > A > D > G strings, and the overall amplitude of E and A strings > D and G strings, respectively.*

KEYWORDS: *Helmholtz motion; bow-string interaction; mass-spring model; optical measurement system*

1 Introduction

As an elegant and complex instrument, the beautiful sound of violin is closely related to the bowing technique. Bow handling is a crucial part of violin performance, which directly affects the tone, volume, emotional expression and other aspects [1]. Whether it is the melodious melody of classical music or the fierce rhythm of modern works, proper bow handling technique can give life to the music [2, 3]. In practice, players need to master different bow techniques, including bow speed, bow pressure, bow position and bow path, etc. Through precise wrist movements, controlling bow speed and pressure, and adjusting the center of gravity and the arc of the bow, players can create a rich variety of tonal effects, and demonstrate technical difficulty and flexibility [4-7]. The skillful use of bowing techniques can not only effectively improve the performance quality, but also make the music more expressive and infectious [8, 9]. Therefore, it is of great theoretical and practical significance to discuss the bowing technique of violin and analyze the application of bow-string interaction in actual performance.

Since the performance of musical works requires the support of technical aspects, this also makes the violin technique continuously develop in the direction of standardization and scientificization [10]. By meticulously analyzing the bow-carrying technique in violin performance in terms of physical interaction and acoustic effect, we can better understand the

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https://doi.org/10.65102/is20261006 Published: 30 April, 2026

performance and characteristics of the bow, so as to express the artistic style of the musical work freely in the performance [11-13].

This paper establishes a physical model of string vibration, the mass-spring model, based on the vibration of strings and related theories of string vibration and the Helmholtz theory of motion. The repeated occurrence of the process of sticking-sliding-re-sticking is utilized to describe the periodic motion of the string. From the perspective of physical mechanics, we analyze the interactive vibration frequency of the violin bowstring and the tension of the strings, so as to calculate the important parameters affecting the sound output effect, such as frequency response, harmonics, and vibration rise. Aiming at the problem that the traditional two-dimensional shooting method cannot prove that the focusing axis of the camera is perpendicular to the shooting plane, this paper utilizes a non-contact optical measurement system to carry out experiments on steel wire strings. The vibration displacement and period, phase change, number of harmonics, frequency response and time domain of the interaction between the G and E strings of a violin are measured and theoretically analyzed.

2 To summarize the application of mechanics to the study of the violin

2.1 Strings and Bows

The ancients measured pitch by the length of the string, and around 600 B.C. China and ancient Greece almost simultaneously recognized the law of three points of gain and loss and five degrees of phase generation. During the Renaissance, scientists proposed that the pitch of the sound is related to the frequency of vibration and verified through experiments, and finally obtained the formula (1) in the forefront of the proportionality of the empirical formula, and continue to summarize the last two equations to get the calculation method. Where f for the vibration frequency of the string, T for the string tension, ρ for the string density, l for the length of the string, μ for the mass per unit length, σ for the string when the tensile cross-section of the positive stress. For a given length of string, its maximum possible frequency depends on the tensile or yield strength of the material itself. The tension applied to the strings should be neither too tight nor too loose. The tension on a single string of a violin is generally 70 to 90N, and the wooden body is basically sufficient to support a total tension of about 300N on all four strings. After the strings are tensed, axial tensile deformation will occur, from the theoretical mechanics of static equilibrium point of view constitutes a super-static structure, the need to consider the deformation of the coordination problem. For a violin with four strings, it is not possible to tune the strings one by one in sequence, but rather the overall tension should be adjusted to about the same level before fine-tuning:

$$f \propto \frac{1}{l}\sqrt{\frac{T}{\rho}} = \frac{1}{2l}\sqrt{\frac{T}{\mu}} = \frac{1}{2l}\sqrt{\frac{\sigma}{\rho}} \tag{1}$$

Violin string materials have been gut, raw silk, nylon and steel. The first three materials have similar densities, and metal strings are about six times as dense, which works out to be about the same maximum frequency for gut, silk and metal strings, with nylon strings being about 50% higher in frequency. Violin E strings are the thinnest, and are generally made directly from bare metal wire from the standpoint of strength and durability. In the looseness and tightness is equivalent, the vibration frequency of the string is inversely proportional to the square root of the density, due to the law of the empty string low octave, its diameter to double.

In the mechanics of materials, the bending stiffness of a metal rod doubled in diameter will become eight times that of the previous one. At this point the string if continue to use bare metal strings, will greatly reduce its flexibility. Therefore, the bass strings on the violin are often wrapped with fine wire outside the bare metal wire.

In the second half of the 18th century, the shape of the bow gradually changed from a convex arc to a slight concave shape. Bamboo wood is subjected to repeated fire-roasting until it curves, but after a while its bending deformation decreases, which reduces the load-bearing capacity of the bow. The factors affecting the quality of a bow are extremely complex, but bows with high carrying capacity (strength) generally perform better. Fiberglass bows do not have warping problems, but because of their hollow mass, they are often made with metal at the ends, which makes the center of gravity more difficult to grasp. Brazilian sumac is by far the top bow maker in terms of strength, density, and warping.

2.2 Bow force application interval

In the regular Helmholtz motion due to stick-slip, there are two important characteristic force application parameters included. One is the force $F_{\max}$ that is sufficiently large to allow the bow hair to travel on the string during stick-slip, and the other is the force $F_{\min}$ that is sufficiently small to allow the Helmholtz angle to be at the point of contact of the bowstring and still continue to move on both sides, as shown in Eq. (2) proposed by Schelleng. Where v_B and β have the same physical meaning as above, Z_0 is the transverse impedance of the string, μ_d and μ_s are the coefficients of kinetic friction and static friction, respectively (the coefficient of static friction is usually greater), and R is the resistance at the end of the codpiece in the Raman string model. A violin produces a softer sound when the force exerted by the bow on the string is between $F_{\min}$ and $F_{\max}$.

When the $\beta -$ force diagram in the plane right-angle coordinate system is built according to Eq. Both $F_{\min}$ and $F_{\max}$ appear as straight lines with slopes -1 and -2. Outside of the triangular region formed by these two lines and the origin, the sound produced by the violin is harsh. When playing a piece of music, the Helmholtz motion is constant in order for the sound to be continuous and beautiful. For all players, when the musical intensity switches from pp to f and the force on the bow is increased, the bow will move closer to the saddle and the bow speed will increase. At this point the force exerted on the bow can reach 2.5N and the bow speed is 2m/s:

$$\begin{cases} F_{\max} = \dfrac{2Z_0 v_B}{(\mu_s - \mu_d)\beta} \\ F_{\min} = \dfrac{Z_0^2 v_B}{2R(\mu_s - \mu_d)\beta^2} \end{cases} \tag{2}$$

3 Vibro-mechanical modeling and acoustic properties of the violin

3.1 Helmholtz movement

The sound generation of bowed string instruments involves the process of sound wave generation and transmission, and its physical mechanism is complex. Acquiring the acoustic characteristics of bowed string instruments and revealing the physical mechanism of string movement is the theoretical basis for guiding the design, production and innovation of bowed string instruments. The string vibration driven by the bow is a complex physical process, and the “Helmholtz motion” of the string was proposed in 1862. Helmholtz motion produces the most ideal waveform, therefore, the violin sound quality is good or bad, depends on the vibration of the string can quickly reach or close to the ideal state of Helmholtz motion, and the realization of the Helmholtz motion depends on the bow speed, pressure, and bow, the string contact point and the distance between the code and other factors, which provides an entry point for the study of the vibration of the violin [14].

The Helmholtz motion properties of the string can be characterized by:

$$\frac{t_d}{T} = \frac{X_v}{L} \tag{3}$$

Description. Where: t is the return time of the string test point. T is the vibration period. X is the distance from the test point to the code.

3.2 String vibration patterns

The vibration of a violin string consists of the following four ways:

(1) Transverse vibration: By picking the string away from its equilibrium position and then releasing it, the string begins to vibrate in a flat spindle type of vibration, which is limited in amplitude to two well-defined curves. The frequency of the transverse vibration of the string can be expressed by the Taylor's formula described in the previous section, viz:

$$f = \frac{1}{2l}\sqrt{\frac{F}{\rho S}} \tag{4}$$

where f is the vibration frequency of the string, ρ, S, F, l are the density, cross-sectional area, tension and length of the string in that order. And it can be seen that the transverse vibration frequency is inversely proportional to the length of the string, proportional to the square root of the tension, and inversely proportional to the density of the string and the square root of the cross-sectional area [15].

(2) Longitudinal vibration: When the bow rubs against the string at an inclined angle, the string is subjected to an axial component force, at which point a very sharp sound is heard, several octaves higher than the fundamental of the transverse vibration, which is the longitudinal vibration. Its amplitude is so small that it is generally invisible to the naked eye. The fundamental frequency of longitudinal vibration is determined by the wave velocity of the longitudinal wave in the string $v = \sqrt{\frac{E}{\rho_1}}$ (E is the modulus of elasticity of the string), and the fundamental frequency formula is:

$$f_l = \frac{1}{2L}\sqrt{\frac{E}{\rho_1}} \tag{5}$$

It can be seen that the frequency of longitudinal vibration of a string depends only on the nature of the material and is independent of the tension of the string. Using this property, you can determine whether the string is metal or gut.

(3) Torsional vibration: if the string is glued to a small sharp-edged piece of paper, with a finger twisting the string taut between the two points, the torsional vibration of the string can be revealed. If the twisting is continuous (such as pulling the string with a bow), the fundamental is also accompanied by a harmonic series, the amplitude of which is attenuated by $1/n$ (n refers to the number of harmonics). The frequency of the torsional vibration is determined by the tangential modulus G of the string, whose fundamental frequency is given by:

$$f_r = \frac{1}{2L}\sqrt{\frac{G}{\rho_1}} \tag{6}$$

(4) Multiple-frequency vibration: This means that when a string vibrates for a full cycle, the device that holds the string vibrates twice, thus producing a sound with a pitch that is twice the transverse fundamental frequency, which is a multiple-frequency vibration. This is called octave vibration. Octave vibration exists at the same time as transverse vibration.

Treating the bow and the string as a system, the vibration produced by pulling the string with the bow is actually self-excited vibration. There are two main reasons for the energy consumption that occurs during string vibration:

1) The resistance of the air around the string during its movement.

2) The fixtures at the ends of the string also produce energy loss when the string is driven.

The second energy loss is greater than the first. When the string is in motion, when the bowstring contact point is at the same frequency as one of the nodes of the string, the part of the string between the yardstick and this contact point is almost stationary. The amplitude is greatest when the string vibrates at the same frequency as the free vibration.

3.3 Mass-spring model of string vibration

With the development of science and technology as well as the invention of advanced experimental equipment and instruments, more and more scientists have begun to study the vibration of the string with the Helmholtz motion as a breakthrough point. The main content of this subsection is to establish the physical model of string vibration by applying the relevant knowledge of vibration mechanics, and try to verify whether the Helmholtz motion is a periodic motion from the physical point of view [16].

The interaction between the bow and the string can be described by “stick-slip”: when the velocity of the string and the bow are equal, the string sticks together with the bow and moves with a uniform velocity. When the elastic restoring force of the string increases, the string slides in the opposite direction, which is the “stick-slip” motion.

When the string and the bow “stick” together in uniform motion, the amplitude of the string vibration is determined by the speed of the bow and the relative distance from the bow to the saddle: the amplitude of the vibration is directly proportional to the speed of the bow, and inversely proportional to the relative distance from the bow to the saddle (Relative Distance = Distance from the bow to the saddle / String Length).

The transverse restoring force kx of the string is proportional to the displacement and in the opposite direction. The inertial force is proportional to the acceleration, and is denoted $m\ddot{x}$ if it is plotted in the opposite direction to its reference positive direction, or should be denoted $-m\ddot{x}$ if it is plotted in the same direction as its reference positive direction.

List $\sum X = 0$ for both force diagrams:

$$-m\ddot{x} - kx = 0 \tag{7}$$

The simplification yields:

$$m\ddot{x} + kx = 0 \tag{8}$$

In fact, for any single-degree-of-freedom vibrating system that can be equated to a specific spring-mass system, the differential equations for the dynamic displacements can be expressed as:

$$m\ddot{x} + kx = 0 \tag{9}$$

Since the coefficient of elasticity and mass are both positive, you can make $\omega^2 = \frac{k}{m}$ and the equation becomes:

$$\ddot{x} + \omega^2 x = 0 \tag{10}$$

This is a second order constant coefficient chi-square differential equation whose generalized solution can be written in the form:

$$x(t) = C_1 \sin \omega t + C_2 \cos \omega t \tag{11}$$

The velocity expression is:

$$\dot{x}(t) = \omega C_1 \cos \omega t - \omega C_2 \sin \omega t \tag{12}$$

The two constants C_1, C_2 are determined by the initial conditions x_0, $\dot{x}_0$:

$$x_0 = C_2 \,, \dot{x}_0 = \omega C_1 \tag{13}$$

$$C_1 = \dot{x}_0 / \omega \,, C_2 = x_0 \tag{14}$$

Then the generalized solution for the displacement is:

$$x(t) = \frac{\dot{x}_0}{\omega} \sin \omega t + x_0 \cos \omega t \tag{15}$$

To wit:

$$x(t) = A \sin(\omega t + \alpha) \tag{16}$$

This is also the expression for the displacement of a string when it vibrates transversely under ideal conditions.

The transverse vibration of the string under ideal conditions is a periodic motion and simple harmonic vibration. And some studies have proved that there is a connection between this simple harmonic vibration of the string and the fundamental frequency [17].

4 Violin string vibration analysis and force measurement experiments

4.1 Experimental Procedures and Methods

The non-contact optical measurement system consists of panoramic and local microscopic magnification shots, which are realized by adjusting the field of view and magnification of the camera. A strobe-free light source is used, and the red calibration point on the photographed string is clearly visible by adjusting the distance of the light source. The scale of the diagram can be calibrated by sticking a scale on the test object and then calibrating it according to the length of the scale on the photo. The experiments were carried out using German Pirastro steel wire strings, whose parameters are shown in Table 1, with an effective string length of 328 mm, in which the density of G-string $\rho=3.1*10^{-3}$kgm-1, and the diameter of 0.764 mm. The position of the plane lens was adjusted before the shooting, so that a real image of the red calibration point and an imaginary image reflected by the plane mirror could appear inside the lens at the same time, and the parameters of the shooting were as follows: panoramic view, horizontal view, and horizontal view. The shooting speed is 3249 frames/sec, the resolution of the picture is 1648×284, and the local zoom shooting speed is 6650 frames/sec, the resolution of the picture is 336×480. The string pulling and plucking experiments were conducted on the strings of the violin, and the conditions of the string pulling experiments were as follows: the bowing speed was 0.25-0.5m/s, the bowing pressure was 1.5N-3N, and the bowing string contact position was 30mm away from the instrument code.

Table 1: Parameters of string

Wire string	Diameter(mm)	Tension (n)	Base frequency (hz)
G	0.764	55.42	198
D	0.678	53.94	293
A	0.492	57.94	445
E	0.263	75.29	667

In this paper, the experimental data processing selected the image when pulling the G-string, due to the G-string vibration frequency of about 196Hz, in processing data, this paper selected 600 consecutive pictures for processing, according to the periodicity of the string vibration, we can know that as long as we continuously select 600 pictures, we are able to get the situation of the string vibration. The idea of processing the pictures is as follows: from the previous description, we can see that the vibration along the direction of the string (longitudinal vibration) compared with the transverse vibration and torsional vibration, its vibration is extremely weak, in this data processing will be ignored, just consider the transverse vibration of the string and torsional vibration, in the process of processing, with the first picture in the 600 pictures selected above the point for the x-coordinate, below the point for the y-coordinate, and the coordinates of the first picture point for the y-coordinate, and the point for the y-coordinate. The coordinates of the point in the first picture are set as the origin, and after that, the difference between the coordinates of the point on top of each of the next pictures and the point on top of the first picture in the vertical direction is taken as the x-coordinate, and the difference in the distance of the point below is taken as the y-coordinate. In this way, counting the origin, we are able to get the coordinates of 600 points, and fitting these points, we are able to get the vibration of this point on the string. The whole process was done using MATLAB, and the resulting processing results are shown in Figure 1. This method can be used to correct and adjust the strings of the violin so that the violin can produce the sound that people need.

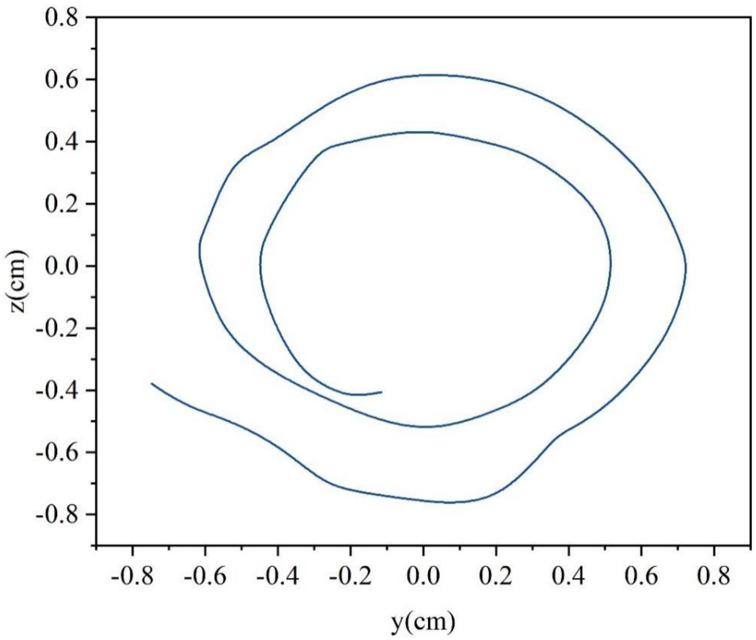
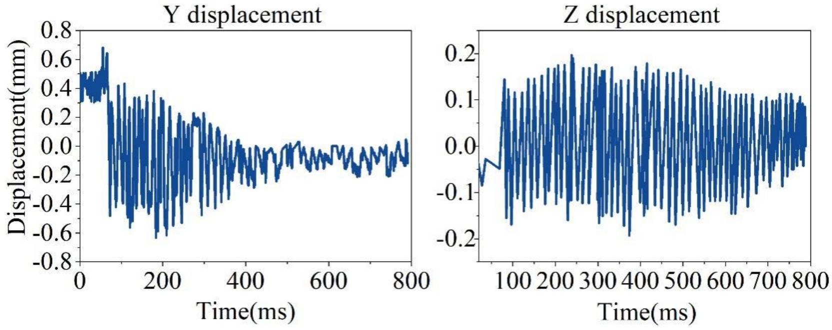


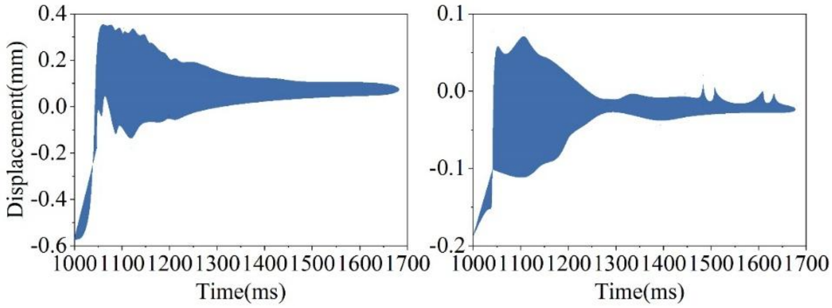
Figure 1: The trajectory of a point on the string

4.2 Analysis of the results of the bowstring interaction-pulling experiment

The experimental measurement of the calibration point when pulling the empty G string is located at 64 mm from the gauge, and the position is 130 mm from the gauge. The image data pulling the G string has 5395 consecutive images, and using the image processing algorithm described above to extract the center coordinates of the image calibration point, the panorama of the pulling of the G string and the pulling of the E string motion is shown in Fig. 2. Similarly, the plucked E string has 11430 consecutive images. From the two images of the pulled string, it can be seen that its vibrations are both characterized by decay. The initial displacement of the pulled string can be seen from the initial waveform of the figure, possessing displacement components in the X-Y plane and the X-Z plane, so the direction of the pulled string is not strictly along the Y direction. The unit of displacement extracted from the image data recorded in this experiment is the pixel, which is converted to mm by calibration, and one pixel is equal to 0.0264 mm.



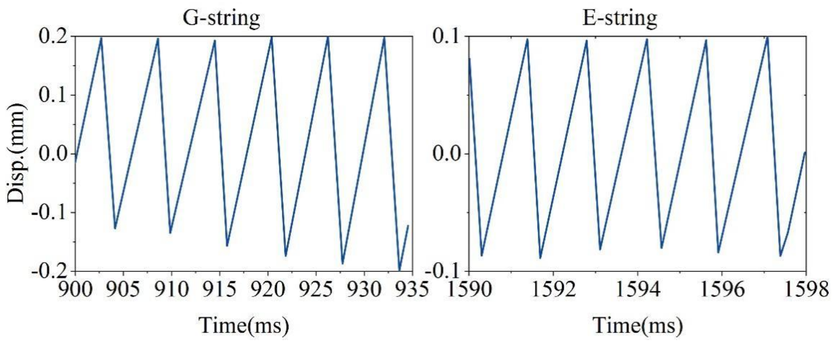
(a)G string



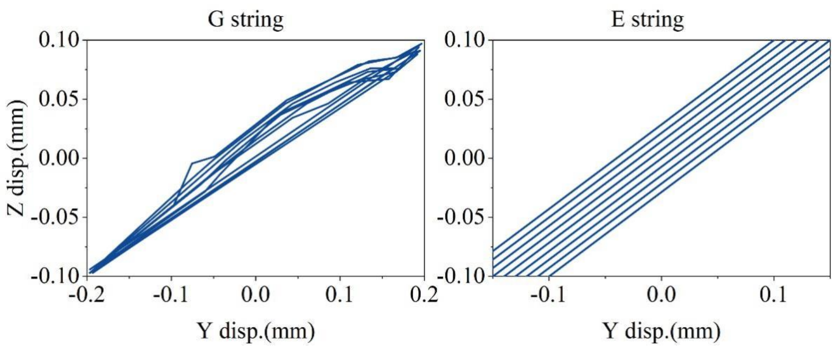
(b)E string

Figure 2: Attenuation vibration process of E string and G string

The X-Y plane of the coordinate system of the direction of the running bow when pulling the string is along the Y direction, the contact point of the bowstring is about 30 mm away from the saddle when pulling the empty string, the calibration point of the G-string is 64 mm away from the saddle, and the calibration point of the E-string is 62 mm away from the saddle.There are 7101 images recorded when pulling the G-string, and there are 12770 images when pulling the E-string, and the displacements of the X-, Y-, and Z-directions and the total displacement waveforms are obtained as shown in Fig. 3, in which the total displacement waveforms are obtained by combining the displacement components in X, Y and Z directions.



(a)Total displacement



(b)Displacement curve

Figure 3: The displacement curve and the spatial trajectory

The displacement waveforms are shown in Fig. 4, where the average period of vibration of the G-string is 5 ms and the average period of vibration of the E-string is 1.5 ms. Therefore, the vibration frequency of the G-string, 197 Hz, is very close to the excitation of the G-string predicting that the fundamental frequency is 196 Hz, and similarly the vibration frequency of the E-string is close to the fundamental frequency of 659 Hz. Furthermore, it can be seen from the figure that since the motion of an ideal string mounted on an ideal single-stringed instrument can be considered as a planar vibration, the motion of a bow-pulled string is usually considered only as an in-plane transverse vibration. In reality, the string mounted on the body of the instrument will show the effect of the coupling interaction between Y(t) and Z(t). In addition, the focusing axis of the camera in the experimental setup cannot be guaranteed to be strictly along the Y direction. Moreover, due to the slight instability of the bow when pulling the string, it cannot be guaranteed that the direction of pulling the bow is strictly along the Y-direction in all transients, and thus a small displacement in the X-direction can be observed, which displacement waveforms are obtained by a sub-pixel edge detection image processing algorithm. There are 34 sampling points per sawtooth waveform cycle as in the results presented by pulling the G string. The displacement of the string is less than 2 pixels in the X-direction and 15 pixels in the Y-direction. Without the sub-pixel edge detection capability, the sawtooth shape of the X-direction displacement waveform would not be detected. The displacement profile when pulling the string is different from plucking the string. From the displacement curve in the Y direction obtained from the experiment, it can be seen that the transverse motion of the violin string is an approximate sawtooth triangular waveform, with a longer rise time in its positive range, which is due to the fact that the string vibration is stimulated by a larger static friction force in the positive range, and the string stores elastic potential energy, and the reversal range is hindered by the bow, but due to the smaller sliding friction force, the return time is shorter, so that the system in general obtains positive energy, and the string is able to keep on maintain vibration. The displacement curves of the points on the string when the string is pulled are sawtooth waves, consistent with the motion predicted by Helmholtz. From the spatial trajectories of the calibrated points in the figure, it can be seen that the trajectory of the point on the string when pulling the string is a straight line, which belongs to the planar motion, and is different from the trajectory of plucking the string (ellipse), which is an important discovery of this paper that is photographed by the optical system.

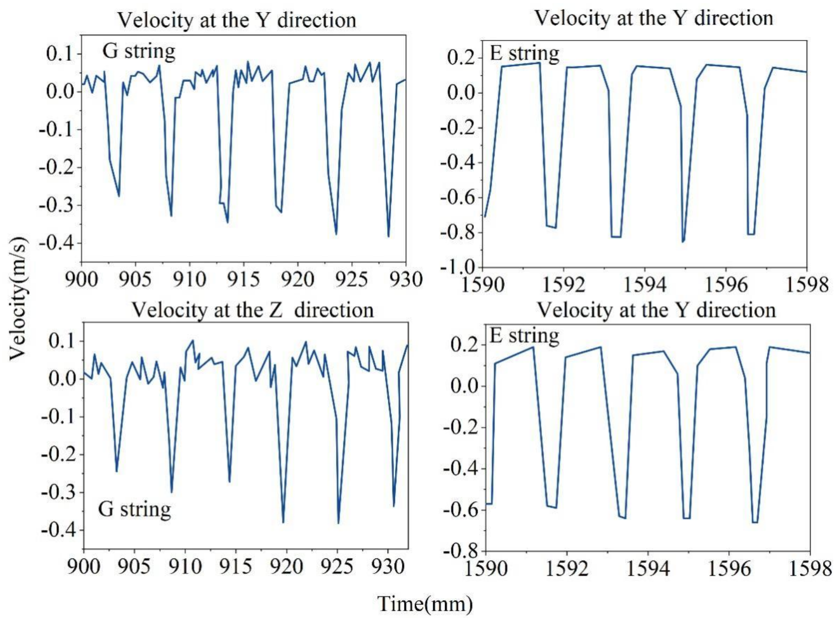


Figure 4: Vibration velocity curve

The frequency response of the bow-drawn string can be obtained by fast Fourier transform of its displacement frequency response waveform. The frequency response of the drawn E string is shown in Fig. 5, and the number of harmonics in the Z direction and Y direction when the string is drawn can be clearly observed. From the string pulling experience, it can be seen that increasing the bow speed or pulling the bow closer to the saddle requires a larger pulling force to maintain the proper string vibration. This is because if the pulling force is too small, the bow will not be able to hold the string during the forward stroke, and if the pulling force is too large, the motion of the string will malfunction during the backward sliding phase, thus failing to form the normal Helmholtz motion. This phenomenon can be well explained in this paper using the single pendulum friction model. In principle, only certain combinations of drawing parameters can produce a standard quality violin tone, although the player can change the bowing parameters alone at will.

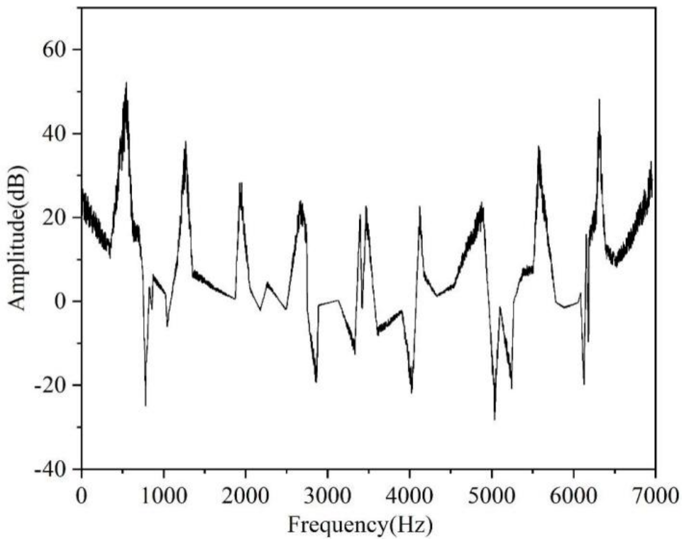


Figure 5: Frequency response when bing the open E string

4.3 Time domain analysis

Every sound has an onset phase, and the onset is an important parameter of the sound, determining the time it takes for the sound to reach its maximum amplitude. It is generally accepted that the thicker the string, the greater the mass of the string, and the longer it takes for the string to vibrate fully; longer strings vibrate more slowly than shorter ones. By analyzing the vibration stage of the violin single tone “staccato” samples, it is found that the vibration time of the violin is around 80ms, and the results are shown in Table 2, which shows that the average vibration time of the violin strings from the longest to the shortest are the E string, the A string, the D string, and the G string, respectively.

Table 2: Average duration of vibration at different strings of each tone

Monotone	Average vibration length/ms			
	E	A	D	G
E5	98	92	64	70
F#5	88	78	75	64
G5	86	80	73	72
A5	92	77	70	70

At the same time, the amplitude of the harmonic series of different strings in the time domain characteristics of the basic law, but also have their own characteristics, because the thick string tuned to the same pitch, the general players will use more tension than fine strings to play and lead to the sound of the instrument becomes louder, so this experiment requires the players to ensure that the strength of the basic consistency, the use of a strong “staccato bow” to reduce Therefore, we asked the players to make sure that the strength of the strings was almost the same, and to use a strong “staccato bow” to reduce this effect. The results of the E5 sample are shown in Fig. 6, which shows that the overall trend of the four strings is consistent, with the overall amplitude of the E and A strings being significantly higher than that of the D and G strings. The amplitude of harmonics 1-4 is significantly higher than that of harmonics 5-8, which is in line with the previous studies on the vibrational characteristics of strings. Those studies proved that the waveform area and amplitude ratio of the first five peaks (including the fundamental) in the musical spectrum would have a direct effect on the instrument's timbre. Comparing the amplitude changes of the fundamental and the first four harmonics in the vibration stage, it is easy to find out that the amplitude changes of the harmonics are not very different and not regular.

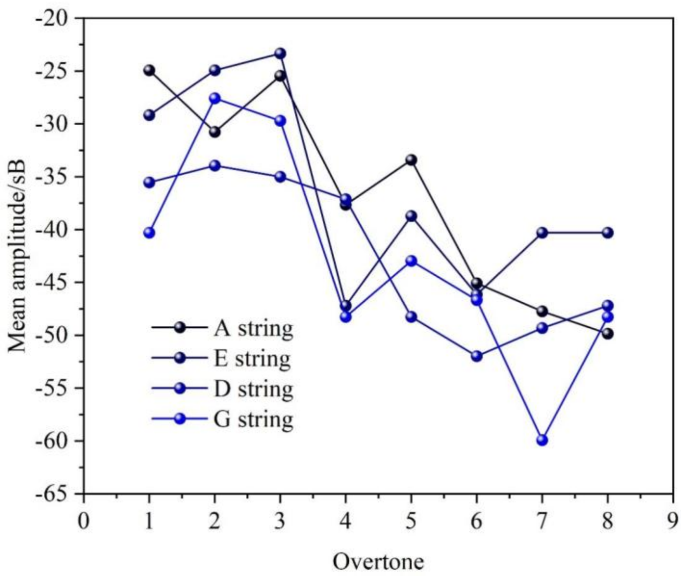


Figure 6: Mean amplitude

5 Conclusion

This paper mainly introduces the theoretical knowledge of violin bowstring vibration, and establishes the mass-spring model of bowstring interaction on the theoretical basis of the string Helmholtz motion for pulling and plucking experiments. Thereby, its vibration displacement and period, frequency response, harmonics, and starting vibration are experimentally measured and theoretically analyzed. Near the experiments, it is known that

(1) Its displacement curve when pulling the string is different from plucking the string, when pulling the bowed string interacts, the displacement component is in the X-Y plane and X-Z plane. The transverse motion of the string is a sawtooth triangular waveform, and the displacement curve of the point on the string is a sawtooth wave.

(2) Vibrato is an important parameter that affects the sound output effect, the average vibrato duration of different strings of the violin, from longest to shortest, are the E, A, D and G strings respectively, and the amplitude changes of the four different strings in the time-domain characteristics are relatively consistent in the whole, and the amplitude of the E and A strings is significantly higher than that of the D and G strings.

About the Author

Li Jiang received her Bachelor's degree in Musicology from Xiamen University and earned her Master's degree in Music and Dance from the same university, with a research focus on Cultural Industry and Arts Management. She currently serves as a Lecturer in the Department of Music Education, College of Humanities at Xiamen Huaxia University. Her academic specializations encompass Music Theory, Music Education Pedagogy, and Instrumental Performance Techniques.

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