Study on Bridge of Violin by Photoelastic Observation and Frequency Analysis

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Abstract

The stress of the bridge of a violin was observed by means of the photoelastic method, and a frequency analysis of the tones was performed. The bridge has relatively large stress at the lower part of the A-string and asymmetric triangular stress at the lower part of the "heart" hole. It was found that the stress of the bridge and the performed tones depended on the shape and the direction of force applied by bowing and so on. The stress and performed tones on baroque style bridge were also investigated. It was found that the part of "heart" of the baroque bridge corresponds to the part of stress of the modern bridge and the part of "heart" of the modern bridge corresponds to the part of stress of the baroque bridge. The spectral envelopes of performed tones using the baroque bridge were different from those of tones using modern bridge in E or A-string and were almost the same as those of tones using modern bridge in D or G-string.

The visualization method as mentioned in this paper may become a hint for design of violin bridges.

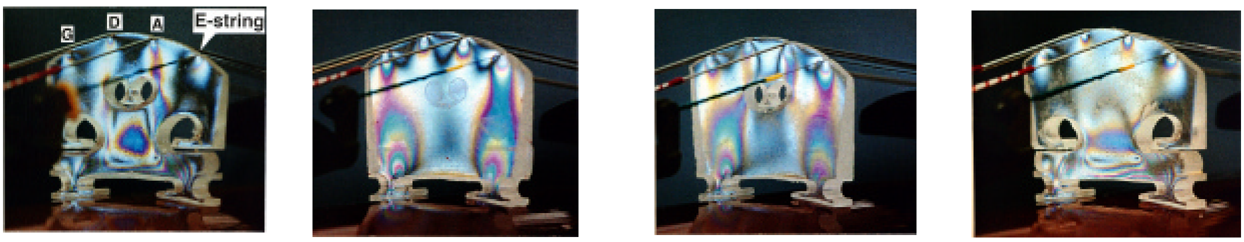
1. Introduction

The bridge is a very important part of the violin, because it transfers the vibration of the string to the violin body and influences the tone as known through experience. Many studies [1, 2] on the physics of the violin have been published. However, many aspects of violin performance such as playing skill and tone are often told through experience and feeling, and most of them are not explained scientifically, particularly to amateur players. The author thinks that this gap in knowledge is due to a shortage of scientific and practical research from the viewpoint of the player. The vibration of the bridge has been investigated by means of the finite element method and holography. [3-8] However, there are few reports taking account of the stress generated by string pressure and the force of bowing.

In this paper, the stress of the bridge is observed by means of the photoelastic method. The frequency spectra of the sound in different states of stress are also described for investigation of influences to the tones.

2. Photoelastic Experiment of Modern Bridges

Bridges made of epoxy resin were used as samples in this experiment. They were fabricated by injecting epoxy resin into molds of silicon gum resin. The photoelastic experiments were performed by observation of these bridges in orthogonal polarized light. The weight of the maple bridge was about 2.5 g and that of the epoxy bridges were about 5 g. The elastic constant of the epoxy bridge is isotropic, although that of the maple bridge is anisotropic. In the photoelastic images, isochromatic lines show differences in principal stress and high-density isochromatic lines appear in region of concentrated stress. Figure 1(a) shows a photoelastic image of the bridge correctly set up, i.e., standing perpendicular to the front plate of the violin. Four strings were adjusted to an open A-string of 440 Hz. The strings used were the nylon type (for A, D, G-strings) and steel type (for E-string). It was found that the stress was not symmetrical. The bridge has relatively large stress at the lower part of the A-string and



(a) (b) (c) (d)

Figure 1 Photoelastic images of epoxy bridges. (a) standard modern bridge, (b) solid bridge without cutout, (c) "heart" bridge, (d) "ear" bridge.

(a) (b) (c)

Figure 2
Photoelastic images of applied force by bowing.

asymmetric triangular stress at the lower part of the "heart". In addition, the stress at the lower part of the bridge was divided between the two feet. In photoelastic image of a symmetric bridge, the symmetrical state of stress was observed. Thus, it was found that the asymmetrical stress as shown in Fig. 1 (a) originated from the asymmetrical shape of the bridge.

The bridges of stringed instruments have various cutouts. Figures 1(b) - 1(d) show photoelastic images of a solid bridge without a cutout, a "heart" bridge and a pair of "ear" bridge, respectively. In the solid bridge, the force of the E-string and the G-string pushes the bridge and the stress is applied to both feet directly as shown in Fig. 1(b). It was found that the stress of both feet was different from that of the normal bridge. As shown in Fig. 1(c), it was also observed that the stress by A- and D-strings to both feet was concentrated at the "heart". In addition, it was found that the stress was divided between upper and lower parts by the presence of the "ear", as shown in Fig. 1(d). It was found that the complicated stress of the normal bridge is caused by the effect of the "heart" and the "ear" in these observations. The tone of the violin depends on the bowing skill. Therefore, the stress of the bridge with different bowing skills was observed. Figures 2(a)- 2(c) show photoelastic images obtained before bowing, and for relaxed bowing and pressed bowing. In this experiment, the four strings were tuned loosely and a larger bowing force than usual was applied to simplify the observation of the stress. This bridge stress was observed just before down bowing on the A-string. It was found that the stress in the relaxed bowing was almost the same as that before bowing and stress in pressed bowing increased in the direction of the D-string. It is considered that the force by bowing is applied in the specific direction toward which the violin is pushed perpendicular to the instrument in pressed bowing and downward in the relaxed bowing. Although the tone produced by the relaxed bowing was beautiful, that by the pressed bowing was grating.

3. Frequency Analysis

In this experiment, one stroke down bowing was performed by the author for each string. The author plays the violin and viola for long time in amateur orchestras. The bowing speed was fixed at about 50 cm/s. The frequency spectra for different types of bridges were measured. The epoxy bridges were heavier than maple bridges. It was confirmed prior to the experiments that the sound pressure level of epoxy bridges was lower than that of the wooden bridge at higher frequency. Figures 3(a) - 3(d) show differences of sound pressure levels (⊿L) between the solid bridge and the variously shaped bridges made of epoxy resin. In this experiment, two violins were used as samples. One is the author's and another is a very cheap instrument. Figures 3(a) and 3(b) show the measured ⊿L for the harmonics of the open E-string. The common characteristic to both violins was that the ⊿L was increased at 1980 Hz (corresponds to the third harmonic) due to the "ear". Figures 3(c) and 3(d) show the measured ? L for the harmonics of the open A-string. It was found that the ⊿L for the "ear" increased in frequency at 880 Hz and 2640 Hz, which correspond to the second and sixth harmonics, respectively. The effect of the "heart" for the author's violin appeared at the frequencies of 1320 Hz and 2640 Hz corresponding to the third and sixth harmonics, respectively. That for the cheap violin appeared with the increase in the second harmonic and the decrease in the sixth and the seventh harmonics. In open D-string, the effects of the "heart" and the "ear" the effect of the "ear" was similar to that of the "heart" in the author's violin. The approximate ⊿L were complicated. In the open G-string, characteristics seem to be influenced by the "ear". It is considered that the ⊿L is influenced by the "heart" at frequencies below 2000 Hz and the "ear" above 2000 Hz in the cheap violin. It is considered that this difference in the ⊿L characteristics is due to the differences in the acoustic characteristics of these violins. In other words, it is important when adjusting the bridge correctly for good violin tone to take into account the individual acoustic characteristics of the violin. Details about these experiments are described in ref. 9.

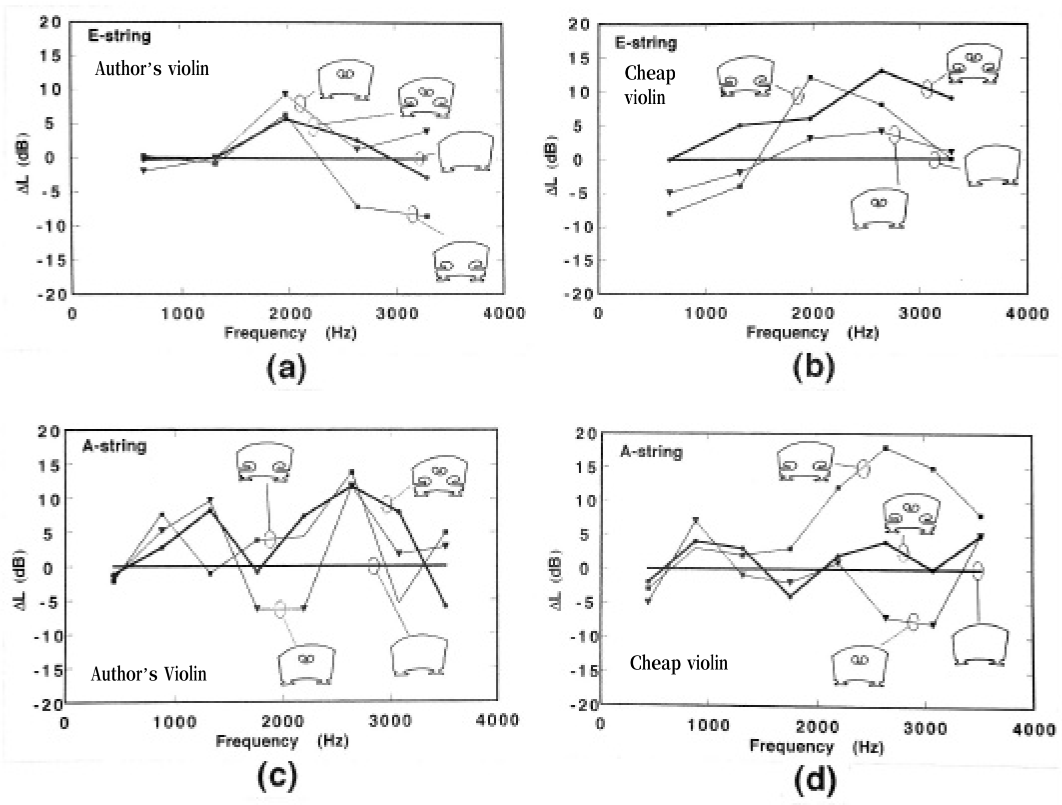


Figure 3 Differences of sound levels (⊿L) between solid bridges and variously shaped bridges.

4. Photoelastic observation of baroque bridge

In Stradivari's era, i. e. baroque violin's era, the shape of bridges was different from that of modern bridges.

Figure 4 show a photoelastic image of baroque bridge. The part of "heart" hole of the baroque bridge was corresponding to the part of triangular stress of the modern bridge. The part of "heart" hole of the modern bridge was corresponding to the part of stress of the baroque bridge. It is interested that relationship between the stress part and the hole is symmetric in the modern and baroque bridges.

Performed tones on the modern and baroque bridge were also investigated by spectral envelope analysis. In this experiments, bridges made of maple were used. In addition, a Silent Violin (YAMAHA SV-100) and two violins having different tones were used as instruments. The violin A is German and the violin B is American. These two violins were the same price and made in 2001. The bowing speed was maintained at about 50 cm/s. Four strings were tuned for an open A-string of 440Hz, 415Hz (general baroque pitch) and 390Hz (Versailles pitch). Dark colored German rosin was used. The spectral envelope was analyzed at a central part of the bowed sound. Figures 5(a)–5(i) show spectral envelopes measured in different conditions. In measurement using the Silent Violin, the spectral envelopes of E-string of modern bridge have peaks at higher frequency than those of baroque bridges. Although the spectral envelopes baroque bridges in D- or G-strings are relatively similar to those of modern bridges, the spectral envelopes of baroque bridges of A-string are different from those of modern bridges. In measurement using the two violins, it is found that the spectral envelopes of baroque bridges in E-string have peaks at higher frequency than those of modern bridges. In addition, it is found that the spectral envelopes of baroque bridges of A-string are different from those of modern bridges, except for those of the violin B at tuning pitch of 390Hz. Although the spectral envelopes baroque bridges in D- or G-strings are relatively similar to those of modern bridges, those of baroque bridges in the violin A have peaks at about 5kHz. The baroque bridge may be suitable for ensemble and the modern bridge may be for solo performance, because it is often desired to include a lot of harmonics for ensemble.

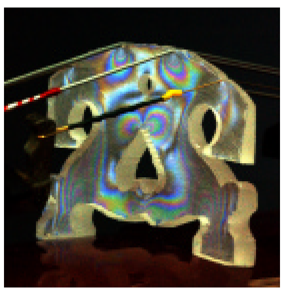


Figure 4 Photoelastic image of baroque bridge.

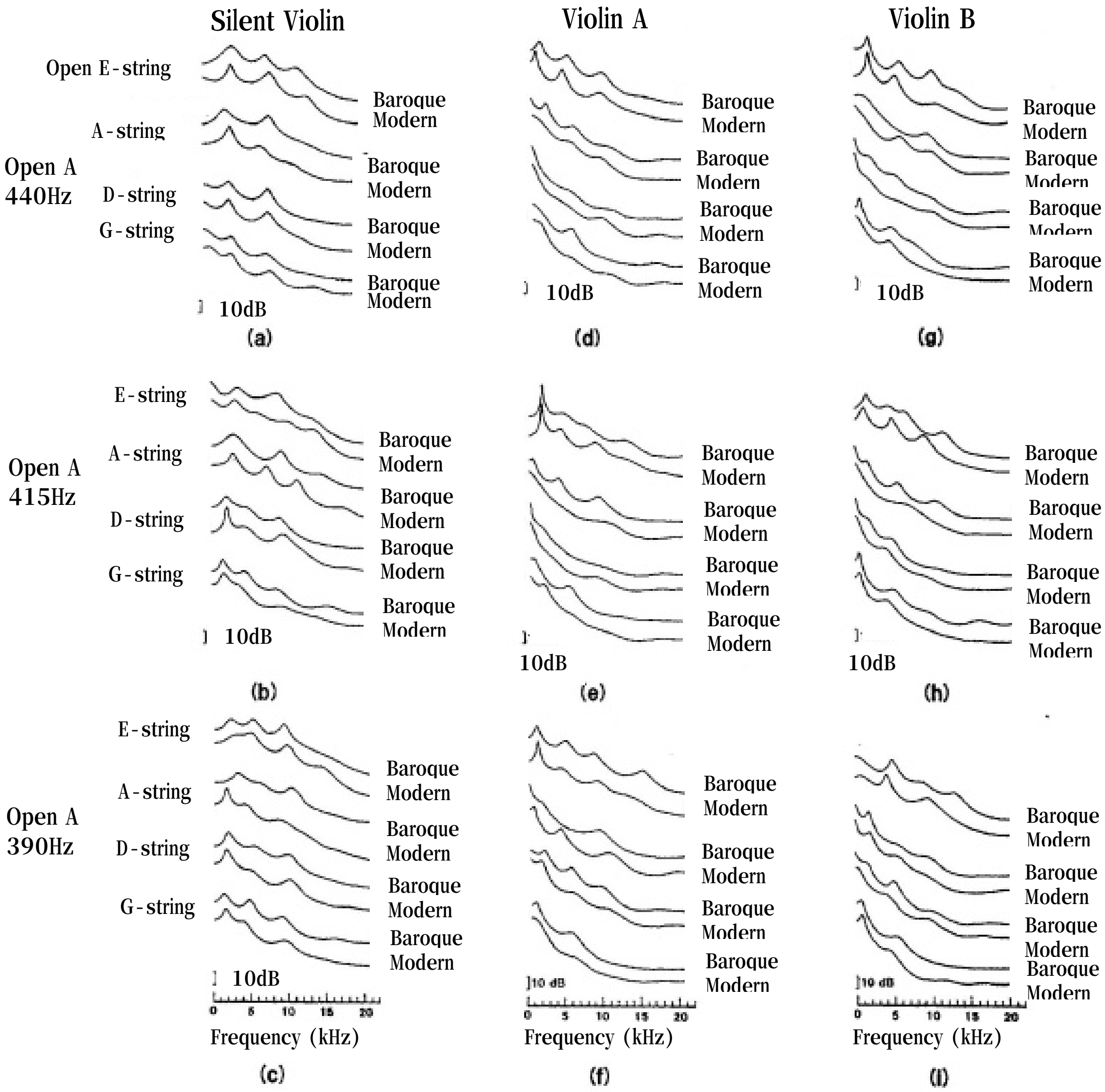


Figure 5 Spectral envelopes of performed tones in different conditions.

The shape of the violin bridge may have been changed to the modern shape by the requirement of clearer tones.

5. Acknowledgements

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6. References

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