Study on the Spatial Radiation Characteristic by Adjusting the Violin Sound Post

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Abstract—Violins were invented in the 16th century in Italy, many methods of manufacturing and adjusting have been developed. Certain violins are highly valued from a cultural perspective as well as for their high sound quality. However, Violin repairers have carried on techniques that have largely been transmitted verbally from generation to generation, so there is a little detailed documentation. Much research has been done to elucidate manufacturing technology and materials used for these valuable violins. This study aims to support the passing down of certain techniques from an acoustic engineering perspective. Many elements defining the timbre, but this study will be focusing on the sound post and the bridge. By clarifying the relationship of adjusting the sound post to the Spatial Radiation Characteristic, we will estimate the ideal position of the sound post and attempt to present the results in the form of a graph.

Index Terms—Violin, Spatial Radiation Characteristic, Tone Color, Timbre, CT Scanning.

I. INTRODUCTION

Previous study [1] relating to this is “A Consideration on the Sound Radiation Pattern of Violin” by Yuya Nishimura. An analysis of sound post adjustment and spatial radiation characteristic was made to estimate the ideal position of the sound post. This study as well as sound post analysis, we aim to prepare a suitable environment for editing CAD data.

The violin is a string instrument. Amongst the string family, it has the highest pitch. The violin body constitute by a large number of parts. Fig. 1 shows the detail of violin parts [2] and quote given below is from previous study [1].

Violin body consists of the top plate also called the belly, back plate, ribs, which connect the top and bottom plate at the side and the neck. The back plate, ribs and neck are made of maple or sycamore whereas spruce is generally used for the belly. Added to this, the violin typically has four strings tuned in perfect fifths. The pitches of open strings (without any finger stopping) on a violin G3-D4-A4-E5 is used for most violin music.

A. Bridge

The bridge supports the strings above the fingerboard from the nut, over the bridge to the tailpiece. Bridges are usually made of maple as they have the ability to withstand the pressure caused due to tightening of the strings. Some bridges have an insert of ebony where the E-string will go to prevent its digging into the bridge.

B. Finger Board

The fingerboard is the piece of wood that is laminated on top of the neck of violin and above which the strings run. A violin’s fingerboard is traditionally made of ebony. The player presses string down to it in order to change their vibrating lengths, causing changes in pitch.

C. Bass bar

Bass bar is a thin, about 265 mm long wooden strip attached to the interior of the belly underneath bass side of the bridge. It is almost parallel to the strings. The bass bar helps it to transfer the sound vibrations to a larger area of the belly.

D. Sound Post

The sound post is a cylindrical piece of wood, which is fitted to the interior of the instrument underneath the treble side of the bridge between the back plate and front of violin. It is made of spruce. Tight violin strings which push the bridge down provide a pressure from the top to the bottom plate, and the sound post is held on this pressure. The main function of sound plate is to transfer the sound energy from the top plate to the back plate of the instrument. The accurate positioning of the sound post is very important as it critically affects the quality and timbre of sound and the playability of violin.

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II. OUTLINE OF EXPERIMENT

A. Sound Quality by Sound Post

The sound post is a dowel placed between the top and back plates of a violin. Its role is to convey the vibration of the strings created by the bow, to the back plate. Since a small change of the angle or position of the sound post can make a big difference to the sound quality, the sound post is a determining factor. A violin is assembled using varnish and adhesive, meaning it cannot be reassembled in exactly the same way once it is taken apart. That also means that the sound quality will differ too. However, it is not necessary to disassemble the violin in order to adjust the sound post, so research can be done accurately.

The sound post adjustments will be undertaken by Mr. Kitazawa from Kitazawa Stringed Instrument Workshop who was engaged in violin manufacturing in Cremona, Italy, for 6 years. He is also experienced in adjusting the Stradivarius which is said to be one of the most valuable violins in the world. In this research, we will not request a certain timbre, but entrust that to Mr. Kitazawa.

B. Method of Data Acquisition and Evaluation

Although there are several ways of evaluating the sound quality, previous research has found that fine violins have a sharp Spatial Radiation Characteristic of sound. Therefore, our evaluation of sound will conform to it [3], [4]. Violins used in this experiment are shown in Table I.

| TABLE I: DETAILS OF THE VIOLIN |
|--------------------------------|
| Violin | Maker | Year | Place |
|-------|-------|------|-------|
| A     | Mario Gadda | 1993 | Mantova, Italy |
| B     | Bernardel Augustine | 1840-45 | Mirecourt, France |

By setting up a spherical microphone array with 42 channels in an anechoic chamber around a violinist, the sound radiation pattern can be recorded and analyzed. The distance from the center of the icosahedron to each microphone is 80 cm. Needless to say, the icosahedron is a polyhedron. Polyhedrons are consisting of flat polygonal faces, straight edges, and sharp vertices. There are two types of icosahedrons, the convex regular icosahedron, and the great icosahedron. The icosahedron has 20 flat polygonal faces, thus making 30 straight edges and 12 sharp vertices. We set up the 42 channels microphone around icosahedron to the 12 apexes and 30 edges, located to become the equal density. We will record the sound using 42 Omni-directional condenser microphones “CX-500”. The microphones are attached to a three-dimensional icosahedron frame, which is similar to a sphere and also spread evenly to identify the sound effect. The frame is made of thin aluminum pipes (φ=8 mm) to prevent sound reflection. Fig. 2 shows the recording. The violinist stands inside the frame and the red marker are positions each microphone. The microphone specifications are shown in Table II.

| TABLE II: THE MICROPHONE SPECIFICATIONS |
|-----------------------------------------|
| Microphone type | Omni-directional condenser |
| Frequency Response | 20 to 20,000 Hz |
| Max.SPL for 1% T.H.D. | 130dB |
| Signal-to-Noise Ratio | 68dB |
| Weight | 6.5 grams(including cable) |
| Dimensions | (φ6mm(W)*13mm(H)) |

Throughout this experiment, the violinist is required to play uniformly. Previous research has found that professional violinists have absolute and relative pitch, also the tone of the sound is reproducible if the player, the violin and the bow are the same.

It is impossible to analyze all scales since any scale can be played with a violin. Therefore, in this experiment, 8 scales are played as shown in Table III. These are all C major scales including open strings such as G, D, A, E. In these 8 scales, there are sounds that resonate well and sounds which don’t. The violinist paid close attention equally to play and without vibrato.

| TABLE III: NOTES |
|------------------|
| PITCH | G3 | C4 | D4 | G4 | A4 | D5 | E5 | A5 |
| FREQUENCY[Hz] | 196 | 262 | 294 | 392 | 440 | 587 | 659 | 880 |

After all of the recordings, each sample data was input into a real-time analyzer. It generates the values of the A-weighted sound pressure level and stores it into a CSV file. After that, we create a function to find out the average sound pressure level of the recorded data on a new CSV file. Then, each average data is normalized by using the formula

\[ x = \frac{(n - \min n)}{(\max n - \min n)} \quad (1) \]

where \( n \) represents a data on any column, and \( \min n \) and \( \max n \) represents the minimum and maximum values of the same column. We will normalize each sound pressure recorded on 42 microphones by sound pressure level “1 “, and create a color model showing Spatial Radiation Characteristics to represent the sound radiation pattern and direction.

C. CT Scanning

The violin will be CT scanned before and after adjustment to measure the change in the position of the bridge and sound post. The measurement is carried out by a company specialized in object analysis through CT scanning (Fig. 3). Considering the accuracy of the CT scan, a minimum range of the violin will be CT scanned. The tube voltage is 140 kV and the tube current is 110 μA.

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III. EXPERIMENT

A. Procedure

Perform the experiment according to the procedure shown in Fig. 4.

1) 3D CT scan.

2) Record and create figures showing spatial radiation characteristics.

3) Sound Post adjustment by craftsman.

The above procedure is performed twice before and after adjustment.

Fig. 3. CT Scanning

Fig. 5. Sound Post

Fig. 6. View of the Top Plate

Fig. 7. View of the Cross-Section

IV. RESULTS

[Subjective Opinion of the Violinist and Repairer]

Impressions after the adjustment are as shown below. It can be said that the repairer’s purpose in adjusting the sound post was successfully conveyed and resulted in:

- Better sound balance
- Less noise
- A lighter tone is and more open sound

A. Violin A

1) CAD images made from CT

Fig. 5 to 7 are CAD images made from CT scan data. Fig. 5 shows the cross-section of the sound post, Fig. 6 shows the view from the top plate, Fig. 7 shows the cross-section of the violin. Fig. 5 is a close-up of the sound post from Fig. 6. The object with the green shows the violin before adjusting and the orange line shows the violin after adjusting. As seen in Fig. 7, the sound post is placed to the bottom right of the bridge. In Fig. 5 we can see that the sound post has been moved away from the bridge by 0.65mm. Also in Fig. 7, we can see that the angle of the sound post has been changed from $93.87^\circ$ to $91.37^\circ$. Although the angle of the sound post has been moved closer to $90^\circ$, the sound post is not placed vertically between the top and back plates.

2) Spatial Radiation Characteristics

We will normalize each sound pressure recorded on 42 microphones by sound pressure level “1", and create a color model showing Spatial Radiation Characteristics. Relative sound pressure levels are shown in the figure and places with high sound pressure are colored red, places with low sound pressure are colored blue. 2 notes out of 8 showed a dominant result. Fig. 8 and 9 are images of Spatial Radiation Characteristics while playing C4 on violin A. Before adjustment, the directivity is seen front and front right, but after adjustment, it is seen more strongly in front looking from the violinist. Fig. 10 and 11 are images of Spatial Radiation Characteristics while playing D4 on violin A. Before adjustment, the directivity is also seen front and front right, but after adjustment, it is seen more strongly in front looking from the violinist.
B. Violin B

1) CAD images made from CT

Fig. 12 to 14 are CAD images made from CT scan data. Fig. 12 shows the cross-section of the sound post, Fig. 13 shows the view from the top plate, Fig. 14 shows the cross-section of the violin. Fig. 12 is a close-up of the sound post from Fig. 13. As seen in Fig. 13 the sound post is placed to the bottom right of the bridge. In Fig. 13 we can see that the sound post has been moved towards the bridge by 5.49mm. Also, in Fig. 14 we can see that the angle of the sound post has been changed from 95.42° to 92.11°. Again, although the angle of the sound post has been moved closer to 90°, the sound post is not placed vertically between the top and back plates.
2) **Spatial Radiation Characteristics**

We will normalize each sound pressure recorded on 42 microphones by sound pressure level “1”, and create a color model showing Spatial Radiation Characteristics. Relative sound pressure levels are shown in the figure and places with high sound pressure are colored red, places with low sound pressure are colored blue. We also 2 notes out of 8 showed a dominant result. Fig. 15 and 16 are images of Spatial Radiation Characteristics while playing G4 on violin B. Before the adjustment the directivity is seen to the front right, but after adjustment, it is seen more strongly in front looking from the violinist. Fig. 17 and 18 are images of Spatial Radiation Characteristics while playing E5 on violin B. Before the adjustment the directivity is seen in front but spread out. After adjustment, it is seen more strongly in front and the directivity behind has weakened.

![3D diagram showing spatial radiation characteristics before and after adjustment](image1.png)

**Fig. 15. Spatial Radiation Characteristic (Before Adj., G4)**

**Fig. 16. Spatial Radiation Characteristic (After Adj., G4)**

**Fig. 17. Spatial Radiation Characteristic (Before Adj., E5)**

**Fig. 18. Spatial Radiation Characteristic (After Adj., E5)**

**V. DISCUSSION**

Firstly, adjustments by the repairer improved the timbre. Both the violinist and the repairer gave similar reviews regarding sound quality and ease of playing.

As seen in Fig. 6 and 13 the sound post is placed to the bottom right of the bridge. From Fig. 7 and 14 we can see that the angle of the sound post has moved closer to 90°. In Fig. 5 the sound post was moved away from the bridge, while in Fig. 12 it has been moved towards it. Thus, patterns were not found relating to the method of adjustment.

Secondly, comparing directivity before and after adjustment. Before adjusting, the directivity is seen into the front right (colored red). However, after adjustment, every note is seen more strongly to the front looking from the violinist. In violin A, notes which improved in particular were C4, D4, A4 and A5. In violin B they were D4, G4 and E5.

The reason for this may be because the sound post was placed almost vertically, the contact area between the sound post and the top/bottom plates and the contact pressure had increased. With the overall effect that vibrations enhanced performance. We couldn’t ascertain the ideal location of the sound post accurately, but it can be assumed that it’s in the area to the lower right of the bridge.
VI. CONCLUSION

In this experiment, it is apparent that increasing the contact area between the sound post and top/back plates by adjusting the sound post vertically, improved the timbre. However, no pattern was found. Although we can assume that the ideal location of the sound post will be in the area to the lower right of the bridge, there are many places where the contact area increases. Therefore, it is necessary to experiment with more violins and procure a larger amount of data.

There are big differences between the various makes of violin meaning that the adjustment method will vary too. For example, the two makes of the violin we used in this experiment were of different thicknesses and lengths. Furthermore, each violin has its own characteristics, so no two violins are completely the same. Usually, violins from the same maker are also the same shape, so it may be more appropriate to compare violins of the same make. Also, it is necessary to consider a suitable graph format. Although we weren’t able to accomplish the final goal, which is to quantify the relationship between the sound post and the bridge, an important foothold was gained. In addition, the software environment for editing CAD data has been prepared, so smooth experiment and analysis is expected from now on.

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