Violin Bridge Vibrations – FEM

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Abstract

Violin bridge transmits vibration of the strings on the violin body. In numerous publications, the feet of the bridge are often glued to a rigid surface. In this paper the authors present a model of the bridge based on springs. The movement of the top of the bridge is partially limited by the violin strings. This movement limitation is modelled as an additional spring. Furthermore, it is possible to introduce a model of sound post. The material of the bridge (maple) is modelled as anisotropic.

Keywords: violin bridge, measure of the bridge, sound post, anisotropy of wood, FEM

1. Introduction

The analysis of the role of the violin bridge in transferring the vibrations of the strings to the resonant body and further influence on the sound of the instrument requires the necessity of considering the dynamics of the entire instrument, taking into account the mutual coupling between the thin-walled structure of the instrument and the volume of ambient air. In the case of FE simulation in such investigations, building a discrete model of a structure of the entire instrument coupled with the surrounding air volume requires a lot of work and is associated with many difficulties.

This publication presents a simplified version of the model taking into account the elastic support of the violin bridge with the resonant body. The elasticity of the violin body (belly and back) was replaced with static models of translational and rotary springs – their elasticity. An important disadvantage of the presented model is the inclusion of only the static elasticity of the bottom and top plates of the violin, omitting the vibrations of the plates. However, the results of the presented model can be used in further studies. An advantage of the tested model is the ability to determine the forces and moments in the bridge feet. This forces and moments impact on the resonance body of the violin – they generate vibrations of the violin plates. The forces and moments change their values according to the signal enforcing vibrations of the bridge.

2. Violin bridge

The violin bridge is one of a few structural elements that is not connected to the resonant body permanently. In a properly constructed instrument, the bridge supports the strings (325 mm from the upper cone), sets the strings' distance from the fretboard as well as the mutual distances between adjacent strings. One of the bridge planes is perpendicular to the soundboard.

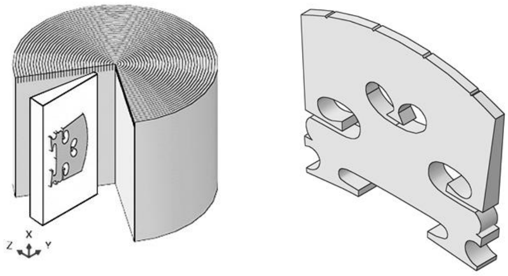


Figure 1. Violin bridge material orientation:
X – 1 - tree growth direction, Y – 2 - radial, Z – 3 - tangential

A good quality bridge is made of a seasoned plane tree with very dense growths maintaining the direction of the grain parallel in relation to the sternum planes (Figure 1). The feet of the bridge legs should be perfectly alined to the profile of the soundboard and positioned in the central part of the top plate between the inner notches of resonance holes. The choice of material, fit, shape and mass of the bridge has a significant impact on the sound of the instrument, because it is the part that directly transmits the vibrations of the strings onto the resonance body.

a) b)

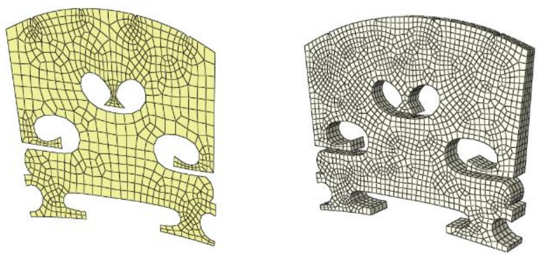


Figure 2. The violin bridge 3D models:
a - the shell model and b - the solid model

Geometry of the violin bridge. The outline of the actual bridge was specified in the metrology laboratory of the Poznan University of Technology. The outline of the bridge allowed us to build FE 3D models: the shell model and the solid model (Figure 2). The shell model was used in this basic study due to a lower number of elements.

3. FEM simulation

In all FE violin bridge models the following properties were used:

Basic dimensionsof the bridge: height (feet to top) = 36.8 [mm], width (between bridge corners) = 47.1 [mm], thickness = 4.5 (feet) – 1.5 (top) [mm]. Additionally, in some cases, the bridge thickness is 4.0 [mm] – here a uniform thickness was applied.

Material property. For the bridge (maple) – material property was applied (7).

Bridge maple	Young's modulus: $E1 = Ex = 10.2$ GPa, $E2 = Ey = 1.55$ GPa, $E3 = Ez = 0.89$ GPa Kirchhoff mod.: $G_{12} = G_{xy} = 1.158$ GPa, $G_{13} = G_{xz} = 1.132$ GPa, $G_{23} = G_{yz} = 0.287$ GPa Poisson's ratio $\nu_{12} = \nu_{xy} = 0.46$, $\nu_{13} = \nu_{xz} = 0.5$, $\nu_{23} = \nu_{yz} = 0.82$ Density $\rho = 590$ kg/m^3. Material orientation is shown in Figure 1.

Load. Harmonic load of 1 [N] toward X axis direction was applied in the *Steady-state, dynamic* procedure. The force *F* acts on the bridge (in point – Figure 3a).

Boundary conditions are shown in Figure 3a,b. The violin feet are based on springs – each foot on 6 springs (3 translational and 3 rotary). The translational spring connects two points – one to RP (foot) and the second point is fixed to ground. Rotary spring connects RP (foot) to the ground directly. Additionally, translational spring presents reactions (resistances due to the strings tensions) of the strings G and E.
Four points of the bridge in contact with the strings are blocked in direction perpendicular to the bridge plane – Z axis direction. Translational displacements $Tz = T3 = 0$ (Figure 3b).

Mesh. The bridge is modelled as a 3D shell – see Figure 3. The FE mesh consist of 718 elements type shell S4R.

Procedure. Steady-state dynamic, Direct procedure of Abaqus/Standard was used for all analysed cases. Frequency range 100 – 5000 [Hz] (increment 1 Hz). Output field – every unit 1 [Hz].

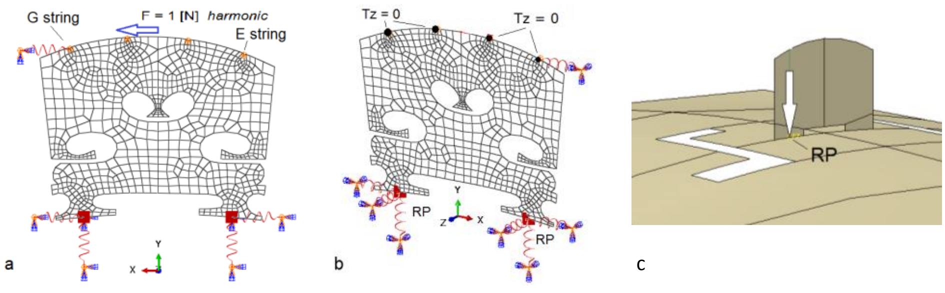


Figure 3. The violin bridge FE model - shell elements S4R, springs, load and boundary conditions

Table 1. String stiffness

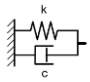
Foot string G	Foot string E	Direction (*local coordinate systems in RP*)	Spring stiffness
T1$_G$	T1$_E$	Translation *X*	k_x = 1.81E6 [N/m]
T2$_G$	T2$_E$	Translation *Y*	k_y = 0.104E6 [N/m]
T3$_G$	T3$_E$	Translation *Z*	k_z =7.65E6 [N/m]
R4$_G$	R4$_E$	Rotation *X*	kr_x = 30.27 [Nm/rad]
R5$_G$	R5$_E$	Rotation *Y*	kr_y = 10.76 [Nm/rad]
R6$_G$	R6$_E$	Rotation *Z*	kr_x = 9.21 [Nm/rad]

3.1. *Violin bridge with various boundary condition*

The purpose of the presented simulations was to show the influence of boundary conditions on reaction forces in the bridge feet. The following cases of boundary conditions have been taken into account:

– violin bridge with fixed feet 

– violin bridge based on springs – no dashpot 

– violin bridge based on springs and dashpots 

All models are divided by the same FE mesh (see Figure 3a,b). The reference points RP (Figure 3) of the bridge with fixed feet are blocked (the springs of the feet are deactivated). In the other cases of boundary conditions RP are connected with springs. The second ends of the springs are blocked (fixed to ground).

The stiffness of the springs (spring constant) was determined by introducing loads (forces or moments) in the reference point RP of the arched shell with "f" holes. The load location is shown in Figure 3c. The springs stiffness are shown in Table 1. The shell thickness is 4.5 mm. The bridge in Figure 3c does not participate in the shell reactions on the loads of the shell because it has Young's modulus (in the case of spring stiffness determinations) as a symbol 1 Pa – the bridge stiffness is neglected.

3.2. *Results of FEM simulations*

The following symbols are used in the description of diagrams and text: NTh - nodal bridge thickness (defined in the input file * .inp), Th4 - uniform thickness 4 mm, Spr - springs (bc), Dash0-1 - Dashpot value 0.1, Fix - fixed feet.

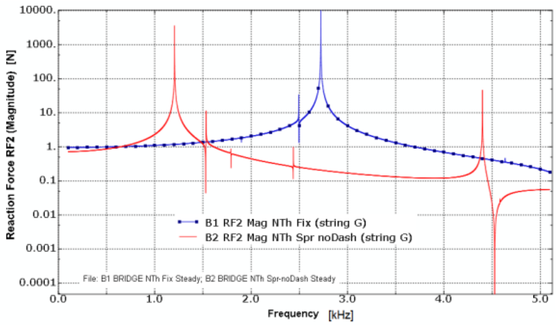


Figure 4. Comparison of RF2 (reaction forces) in foot (G string); B1 – bridge with fixed feet, B2 – bridge based on springs. Nodal thickness of the bridge - 1.5 – 4.5 mm

The reaction force RF2 (y axis direction) in bridge feet was used to study loads of the resonant body. The influences of the frequency (harmonic load Figure 3a) on the reaction force are shown in Figure 4 and Figure 5. Two cases of boundary conditions were considered: fixed feet and feet based on springs.

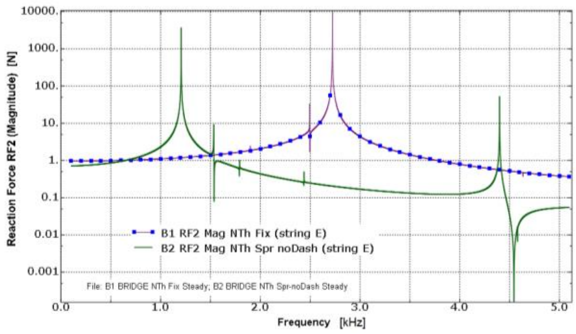


Figure 5. Comparison of RF (reaction forces) in foot (E string); B1 - bridge (th. 1.5 – 4.5 mm) with fixed feet, B2 - bridge (th. 1.5 – 4.5 mm) based on springs

The diagrams in Figure 4 and Figure 5 show similarities of the reaction force magnitudes in the bridge feet.

For the bridge with fixed feet, the reaction force significantly increases for the frequency about 2700 [Hz]. In the case of feet based on springs there are two frequencies with a significant increase in the reaction force – 1200 [Hz] and 4400 [Hz]. For the frequency about 4550 [Hz] there is a local decrease in the reaction force. Differences in reaction forces between a fixed bridge and a bridge based on springs are very clear. The question arises whether a bridge with fixed feet can be used to study the relationship between the bridge and the resonant body?

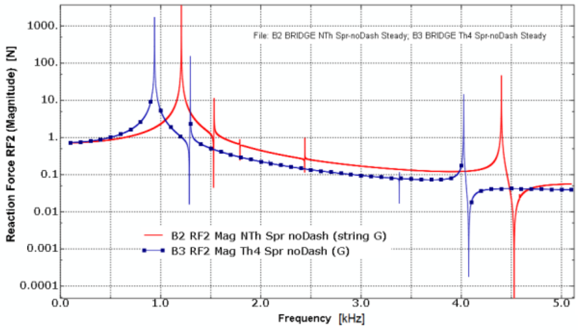


Figure 6. Comparison of RF (reaction forces) in foot (G string); B2 – the bridge (variable nodal thickness 1.5 – 4.5 mm), B3 – the bridge (uniform thickness of 4 mm); in the both cases the feet are based on springs

Figure 6 shows simulation results for two bridge thicknesses. Both bridges are based on springs. One bridge has a uniform thickness of 4 mm and the other has a variable thickness of 4.5 to 1.5 mm - as in violin bridge. The plots show that the bridge with uniform thickness of 4 mm has lower resonant frequencies. Apart from this the diagrams are similar.

3.3. *Dashpot damping*

Material damping of the resonant body and the bridge was modeled by dashpots connected parallel to the springs. Results of this modeling are shown in Figure 7.

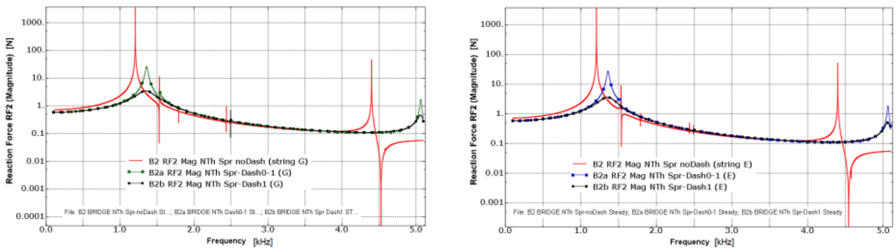


Figure 7. Comparison of RF (reaction forces) in feet;
B2 – no Dashpot, B2a Dashpot (0.1), B2b Dashpot (1.0)

4. Conclusion

Transferring the strings vibrations on the resonant body through the violin bridge feet depends greatly on boundary conditions.

Magnitude of RF2 (reaction force) of the foot below G string is very similar to the reaction force of foot below E string - see Figure 4 and Figure 5.

Figure 7 clearly shows the influence of damping for the reaction force amplitude.

As already mentioned in the introduction, in order to fully understand the mutual coupling of the bridge with the strings and the resonant body, it is necessary to simulate and analyze the entire complex violin FE model.

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