Sound Generating Mechanism of the Double Bass

Filip Pantelić and Jurij Prezelj

Abstract — **This paper deals with the mechanical properties of the double bass and double bass bow. The sound of the instrument, as well as the vibrations of the bow, were recorded while playing. The sound was recorded with a microphone, while a sensor, placed on the bow's stick, registered its vibrations. By observing these signals, from double bass and bow, the correlation between them was determined in order to explain the bow-string mechanism.**

Keywords — **bow, double bass, stick-slip effect, vibrations, sound**

I. Introduction

DESPITE the fact that bowed string instruments are the target of observation in many musical acoustics studies, very little attention is paid to the bow. On the other hand, according to many musicians, the quality of the tone itself depends equally on the quality of the bow as well as on the quality of the instrument. The stick of the bow with its own mechanical properties and hair of the bow with their own frequencies form one complex vibrating system. This complex system is excited with the stick-slip effect while playing the instrument. The stick-slip effect is the one that is the basis of generating tone with the bow. The emitted bow sound, considered alone, is not of high importance since it radiates a small amount of energy to the surrounding space; however, the musician is able to feel the vibrations on his hand which gives him the feedback on the generated tone. Interaction between the bow and the strings of the double bass has a decisive influence on the tone of the instrument.

When playing using the bow in a usual way, the wire vibration is caused by wire balance displacement, generated by the bow. The position with maximum displacement of the wire is known as the Helmholtz peak. The Helmholtz peak moves along the wire, as shown in Fig. 1, reaching its end at the place of a finger pressure, and then returns back to the bow [1]. While the Helmholtz peak travels from the bow to the finger press point, the string is moving in the direction of the bow movement. When the peak of the return impulse reaches the contact point, the wire separates from the bow and moves in the opposite direction. The impulse further reflects back from the bridge, and from the moment of passing through the contact point, the wire is again moving in the direction of the bow movement. The friction produced by the interaction of the bow and wire changes from static to dynamic and vice versa every time the Helmholtz peak passes through the bow.

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The described model represents a single period in idealized conditions and applies to an ideal flexible wire only, for the case when it is attached to perfectly stiff ends and is excited by the stiff bow at only one point. In realistic conditions, the Helmholtz movement differs from the one described due to various dissipations. Final width of the bow hair is yet another parameter which causes the deviation of this model behavior compared to the one in realistic conditions. The transition from one state of friction to another (stick-slip) is not immediate for all hair strings of the bow since the point of sticking and relaxation depends on each and every hair.

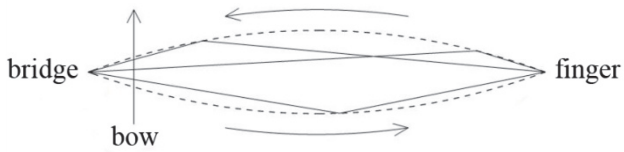

Fig. 1. Bow string interaction causing Helmholtz peak motion.

When the Helmholtz peak is moving from the bridge and passes the bow, a part of the string sticks to the hair of the bow that moves together with it and moves in a translation motion in the direction of the bow movement. The Helmholtz peak separates from the bow changing the angle between the bow hair and a part of the string attached to the hair. Partial slips occur as a result of the angle changes since the bow and string interact not only in one point but in the entire width of bow hair [2]. There is a tendency of backward sliding (away from the bow movement direction) for those hairs that are closer to bridge, in the same way as in the main Helmholtz slipping. The hair on the other side of the bow tends to slip in the direction of the bow movement. During the stick phase the peaks of force, derived from partial slips, may occur if played close to the bridge.

The first longitudinal resonance of tensed hair of the the violin bow admittance, for longitudinal hair excitation in the excitation point at hairs half length, appears at 1.5 kHz and the other at 4.5 kHz [3]. According to Gough, finite element analysis shows that longitudinal admittance in the case when the bow hair is stretched between fully stiff ends shows only those distinguished peaks. The peaks that occur under the influence of the bow stick resonances do not appear. In bow response for hair on elastic stick, finite element analysis shows the influence of stick resonances which coincide with longitudinal response of the bow hair, stretched between completely stiff ends. If there is a possibility of bow stick influencing the tone of the instrument, this influence most likely originates from its influence on the longitudinal modes of the bow hair, rather than transversal.

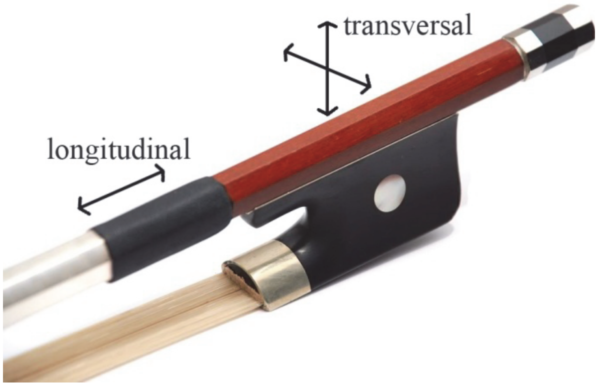

Fig. 2. Longitudinal and transversal vibrations on double bass bow.

Vibrations are present in both bow stick and bow hair, while playing. There are longitudinal and transversal vibrations as depicted in Fig. 2. The following experiment was performed in order to determine the correlation between the bow vibrations and emitted sound through the stick-slip effect. Also it will give us some additional parameters which can possibly be helpful in the evaluation of the bow quality.

II. Experiment

The contact sensor was set to the bow, close to the bow frog. It was positioned on the upper side of the bow stick as depicted in Fig. 3. The signal from the accelerometer and from a measuring microphone, placed in the double bass sound field, was recorded on two separate channels. The measuring microphone was placed in front of the double bass front panel at a distance of 1 m. The double bass was used to perform long still tones of various pitches with its frequencies in a range from of 41 Hz to 98 Hz which were then recorded. Shorter music segments such as tonal scale were also recorded. The correlation between bow vibrations and emitted double bass sound can be determined by comparing these two synchronized recordings.

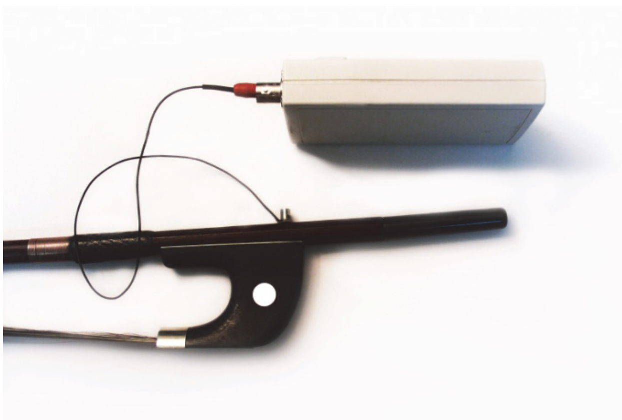

Fig. 3. A vibration sensor installed on a bow stick.

The upper signal of Fig. 4. shows the generated sound pressure of the double bass recorded with a microphone, while the bottom signal represents the vibrations on the bow. Presented signals were recorded while playing D tone with its fundamental frequency at 73 Hz.

The signal from the bow, recorded with an accelerometer, and the sound of the double bass, recorded with a microphone, are highly correlated although their frequency characteristics and envelopes differ significantly. Observing the signal, recorded with an accelerometer, it is possible to notice a certain periodicity of its envelope. The period of the envelope equals the period of the main first tone.

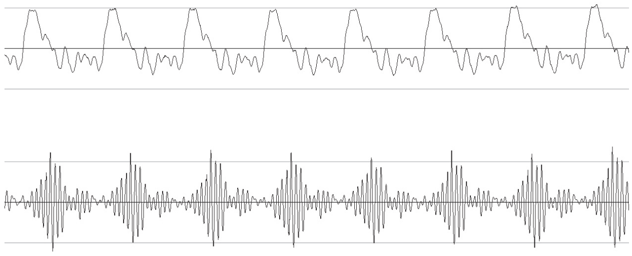

Fig. 4. Sound (above) and vibrations on a bow (below).

III. Vibration Spectrum Signal

Due to a very low fundamental frequency, and a high number of harmonics, the spectrum of double bass tones has densely arranged harmonic components. Spectrum of the lowest double bass tone is shown in Fig. 5. Because of the wide and dense coverage of spectrum this tone is suitable for observing the bow response during the stick-slip effect. Harmonic structure in Fig. 5. represents the spectrum of emitted sound recorded 1 m from double bass. This signal depends on the transfer function of double bass body too, because it was recorded in its sound field, but it's good to illustrate harmonic density of string vibrations while playing.

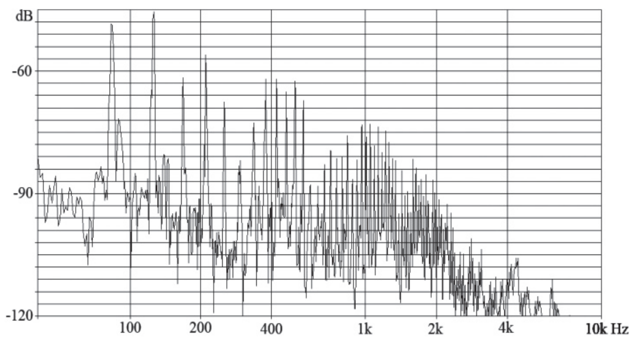

Fig. 5. Double bass sound spectrum recorded while playing tone with a frequency of 41 Hz.

Spectrum of recorded vibrations on the bow, while playing the lowest double bass tones (41 Hz), is represented by a thin gray line in Fig. 6

In order to cover the spectrum evenly, vibrations were also recorded when a musical segment was played. This musical segment was a chromatic tone scale so it contained all tones in one octave. Spectrum of vibrations, recorded on the bow while playing this tone scale, is presented by a full black line in Fig. 6.

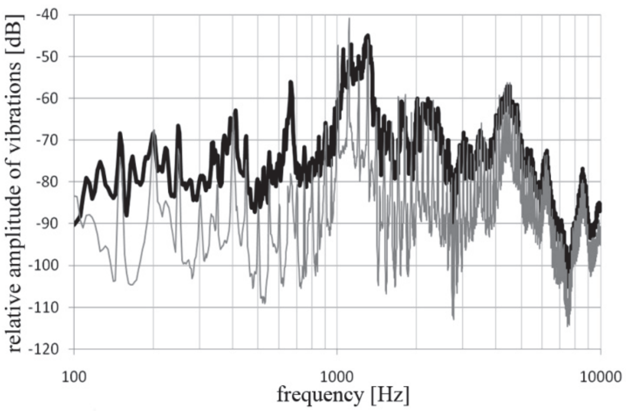

Fig. 6. Vibration spectrum recorded on the bow:
a) While playing tone with a frequency of 41 Hz - thin line
b) While playing tone scale - full line.

In order to determine the bow response it is possible to use broadband noise to excite the bow hair, though in that case we cannot talk about transmission characteristics of the bow in a stick-slip effect.

In Fig. 6, we see that the spectrum of the recorded bow vibrations has an emphasized characteristic of elevated range between 1 kHz and 1.5 kHz. Also, one peak at 4.4 kHz is noted. Such a transmission characteristic of the bow may originate from longitudinal resonances of bow hair.

Comparing the graphs in Fig. 6. with the results obtained by finite element analysis of violin bow, it can be noticed that the frequencies of the first and second longitudinal resonance of bow hair coincide with raised magnitudes in Fig. 6. Due to this it is concluded that longitudinal string resonances are the most responsible for such a transfer bow characteristic.

Peaks at frequencies below 1 kHz in Fig. 6. are mainly derived from highly expressed and rarefied harmonics of the vibrating strings. For this reason, by observing the graph, we cannot say to what extent the resonance of the bow stick affects such a frequency characteristic. Due to recording technology, there is some unwanted noise present at 50 Hz which, together with its components, corrupts the picture in the lower part of the spectrum.

IV. Time Signal Shape

The signal spectrum recorded on the bow has majority of its energy in the frequency range between 1 kHz and 1.5 kHz. Due to low frequency of the main double bass tones, this range consists of many harmonics. Such a transmission characteristic of a bow is responsible for time frame vibration signals to be as the one shown in Fig. 4. In the case of the lowest tone E, at the frequency of 41 Hz and at the range of frequency from 1 kHz to 1.5 kHz, there are no less than eleven harmonics (1025 Hz, 1066 Hz, 1107 Hz, etc.). Due to their close frequencies and similar intensities, time shape of the bow stick vibration signals has a characteristic envelope that tracks the frequency of the first harmonic.

As an example, Fig. 7. shows how, from the sinusoidal signal with the frequency of 1025 Hz and by successive addition of sinusoidal signal with a frequency increased by adding of 41 Hz, we get the envelope whose period equals the period of the additional frequency (41 Hz).

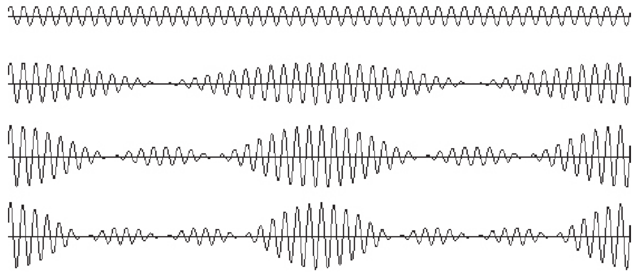

Fig. 7. Graphics obtained by successive summing of sinusoidal signals (from top to bottom: 1025 Hz + 1066 Hz + 1107 Hz + 1148 Hz).

Fig. 8. shows two by two periods of recorded sound and bow vibration signals when playing the tone D (73 Hz). The figure shows that the vibration signal has a shape similar to the one presented in Fig. 7. It can be concluded that the dominant component of vibration signal consists of harmonic tone components whose frequencies lie in the range of the first longitudinal bow hair resonance. In addition, when the amplitude of vibration signals is in its maximum, there are some artifacts whose frequencies lie in the range of higher frequencies.

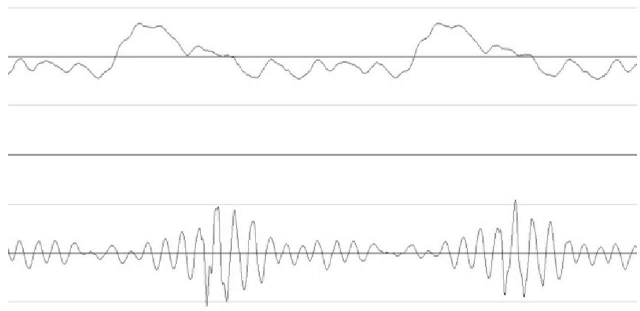

Fig. 8. Sound (above) and vibration (below) - a form of time when playing the tone D (73 Hz).

In order to observe the bow vibrations, the components are parsed according to frequency ranges derived from a total sum of vibration signals recorded while playing the tone G (98 Hz). Specifically, by digital processing, from a total sum of bow vibration signals, partial components of the frequency bands are derived [4] - [6].

In order to analyze the signal, a nonuniform complementary filter bank data is used. The bank parameters are interactive inflicted according to the spectrum of the input signal. The audio signal is divided into several channels. The filter bank for signal analysing is designed on the basis of marginal frequencies which depend on the particular signal, and are not predefined. The designed bank is all-pass complementary, the signals obtained at individual outputs can be added up in order to get the signal equal to the one that occurs by filtrating an input signal through an all-pass filter. The filter bank enables to single out the essential components of the signal, so that each component can then be individually analyzed.

Frequency ranges, according to which this signal divides to separate audio signals, are 0-800 Hz, 800-2350 Hz, 2350-7300 Hz, and 7300-28000 Hz. The sum of these four signals forms the signal of bow vibrations. Their relative effective values are -38 dB, -16 dB, -30 dB and -47 dB respectively. Fig. 9. shows components with the highest amplitude signals; ranges of 800 – 2350 Hz and 2350-7300 Hz. Within the limits of these frequency ranges, there are the first and the second longitudinal resonance of bow hair.

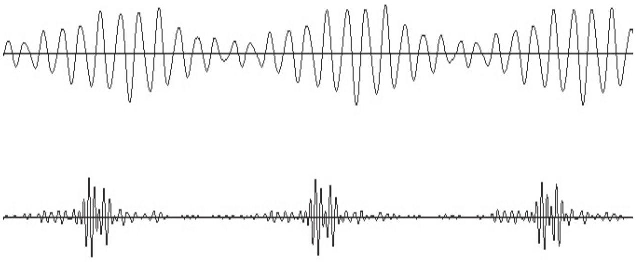

Fig. 9. Components of bow vibration while playing the tone G (98 Hz) - up: 800-2350 Hz, bottom: 2350-7300 Hz.

V. Vibration Signal Spectra for Various Bow Types

In this experiment, by using the various types of bows to play the lowest tone, the vibrations on a bow stick are recorded. The first bow is a double bass bow with black hair and the German bow frog. The second bow is a double bass bow, with white hair and the French frog. The third bow is a violin bow with white hair.

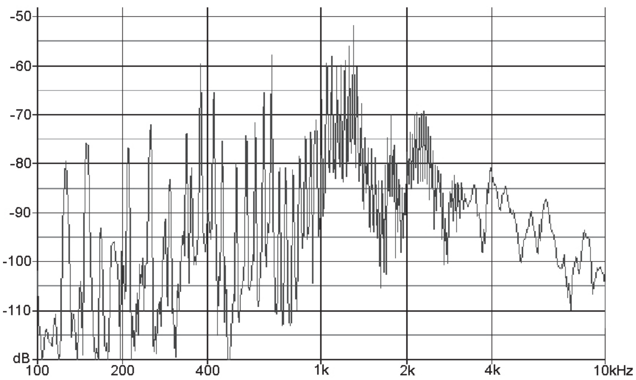

Fig. 10. Vibration spectrum recorded on the German bow while playing the tone with a frequency of 41 Hz.

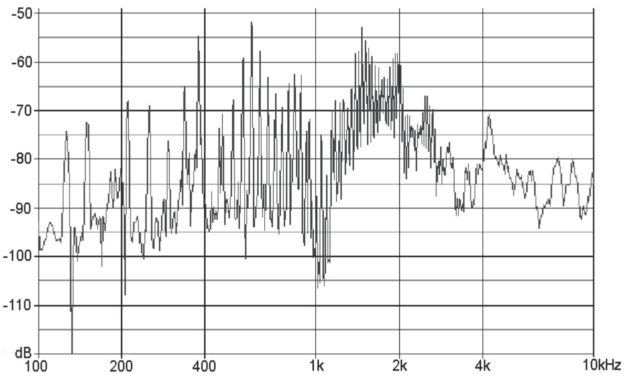

Fig. 11. Vibration spectrum recorded on the French bow while playing the tone with a frequency of 41 Hz.

Figs. 10., 11. and 12. present the vibration spectra recorded on the German, the French and a violin bow. By observing the first longitudinal string resonance zone, the graph displays that the German bow reaches its maximum at a frequency of 1300 Hz. The French bow has its highest value at 1475 Hz. These values depend on the tension and elastic characteristics of bow hair. With the violin bow characteristics, as presented in Fig. 12, compared to the other pair of bows, there are notions of more defined peaks, at the frequencies of 2.7 kHz and 4.8 kHz.

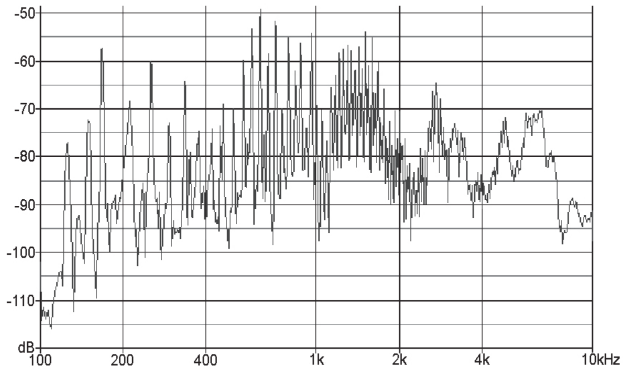

Fig. 12. Vibration spectrum recorded on a violin bow while playing the tone with a frequency of 41 Hz.

During tone generation, vibrations occur during the interacting of strings and bow. Vibrations are transmitted to the bow stick through bow hair. In this case, longitudinal bow hair resonances play a major role.

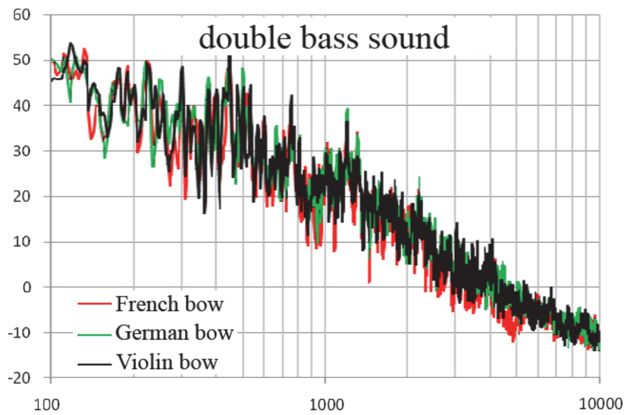

Fig. 13. Comparative review of the double bass sound spectrum for all three types of bows while playing a tone with a frequency of 41 Hz.

The resonances of a bow stick changes the admittance of a bow for longitudinal hair impulse. Considering that, it can be concluded that the appearance of presented bow vibration spectra, Figs. 10, 11. and 12, also depends on the resonant characteristics of the bow stick itself. To what extent does the influence of bow characteristics on the string exist, is the question that is still open. It is expected that the bow stick resonances, elastic characteristics of bow hair as well as their tension affect the stick-slip effect which is the main mechanism of tone generation for a bowed string instrument.

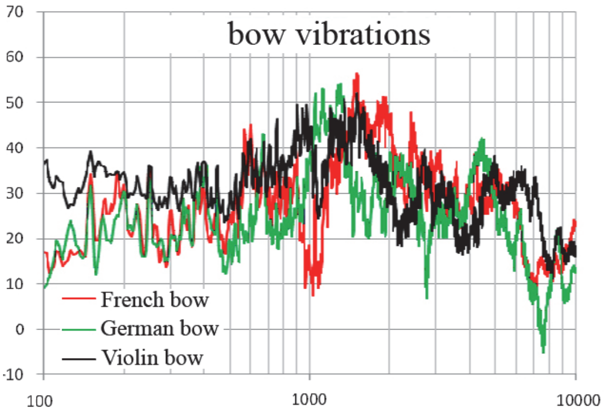

Fig. 14. Comparative review of the bow vibration spectrum for all three types of bows while playing a tone with a frequency of 41 Hz.

VI. Conclusion

This paper opens up many new topics because a double bass' bows are very rarely analyzed. Low frequencies and a dense harmonic structure, in contrast to the violin, provide the possibility of a different approach to this issue.

As shown in Figs. 13. and 14, besides the big differences in bow vibration spectrum, the differences within a sound spectrum are not that significant. That is way the signal of bow vibrations while playing could be a source of information in order to find some new parameters to evaluate bow characteristics.

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