Design and testing of a novel audio transducer to train string musical instrument

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ABSTRACT

Stringed wooden instruments, like violins or double basses, experience a decrease in performance if they are not played for a long time. For this reason, top class instruments are usually given to musicians and played every day to preserve sound quality. The paper deals with the design, construction and testing of a device to be inserted in the bridge of a stringed wooden instrument to simulate the stresses experienced by the instrument during normal playing. The device could provide a simple, fast and inexpensive way to recover the sound of an instrument that has not been played for a period of time, or even to enhance the instrument's sound. The device is based on two magnetostrictive actuators that can exert suitable forces on the body of the violin. The device has been designed and tested to exert forces as constant as possible in the range of frequency between 10 Hz and 15kHz. Experimental tests are carried out to evaluate the effect of the device on the sound produced by the violin during a 3 weeks hours training. Two hi-quality microphones have been used to measure principal harmonics and changes during the test. Results show that in the first part of the test (approximately 100 hours) amplitudes of main harmonics widely change, while in the following their values remain constant. This behavior demonstrates the violin has reached its "nominal" status.

Keywords:.

1. INTRODUCTION

There is widespread belief among players of stringed musical instruments, and experienced listeners, that these instruments improve with age and/or playing. A previous study has reported some measurable changes associated with regular playing of a violin [1]. The intrinsic mechanical properties could change with age or with exposure to different environments. Woods used in string instruments often have a high ratio of longitudinal Young modulus to density, and drying of wood over time would lower the density. However, there is no simple reason to expect that age-related changes in general would necessarily improve an instrument.

A violin (and its components) undergoes considerable mechanical vibration during playing and this could alter the intrinsic mechanical properties. There is usually a strong correlation between the age of a violin and the total amount of excitation it has undergone. A study has shown a decrease in internal damping as a consequence of mechanical excitation in isolated samples of violin wood [2]. Extended mechanical vibration of violins has produced improvements as judged by listeners and players [3, 4] as well as measurable changes in the vibro-acoustic properties that are associated with improved tone and playing qualities [2, 5]. However, not all studies have shown a measurable mechanical change of violin wood upon extensive mechanical excitation [6], and there is again no simple a priori reason to suggest that these changes will improve the instrument. However it might be argued that mechanisms that produce mechanical loss could be affected by sufficiently vigorous excitation.

As a matter of fact, several devices have been patented over years, to automatically play violins to improve their sound. These early methods had the great disadvantage that long periods of time were needed in order to obtain any noticeable result. The best examples arrived in 1923 [7], 1926 [8] and 1959 [9].
U. S. Patent 5031501 [10] describes a Method for attaching an audio transducer to a string musical instrument. It discloses the first attempt of introducing an electrical signal, via an audio transducer, producing vibrations on an electrical device which are then transmitted to the body of a string instrument. When an electrical sound signal is applied to transducer, the resulting vibrations will be transferred to sounding board. In [11], inventors suggest to shake the entire instrument with high amplitude vibrations in the range of audible. This method, provides a faster change in sound produced by instruments, but requires a huge apparatus.
A more recent patent [12] describes a method for artificially aging an acoustic instrument by placing it in an enclosure in front of one or two electromechanical transducers, typically speakers. The theory is that when a broadband audio signal is played through the speakers, the vibrations produced by the sound waves would age the wood. The most promising solution, however, can be found in [13,14]. An electric vibration generator is attached to a bridge cradle. This should be configured to be placed upon the bridge in sufficient contact so as to permit the transfer of the vibrations generated to the bridge of the instrument.
This paper relates to the design and testing of an innovative device that can be used to age a violin. Section 2 introduces the concept of the device explaining the functioning principle, while section 3 describes the prototype. Experimental tests on a violin are described in section 4 and results are commented in section 5. Finally conclusions are drawn in section 6.

2. CONCEPT DESIGN

A vibrating string can produce a motion that is rich in harmonics (different frequencies of vibration). However, the string on its own is capable of producing only little sound. This is the reason why the body of the violin serves to transmit the vibrational energy of the string into the air as sound. The bridge stands on the top plate, between the *f* holes. As already mentioned, it is the piece that transfers the vibration of the strings to the body. The treble foot is quite near the sound post, which connects the relatively flexible top plate (partly due to the *f* holes) to the much stiffer back plate. This post prevents the top plate from collapsing under the vertical tension of the strings and it also couples the vibration of the plates. The other side of the bridge, the bass foot, is much easier to move up and down, and as a result, the bridge tends to pivot around the treble foot when the string is driven from side to side by the action of a bow.

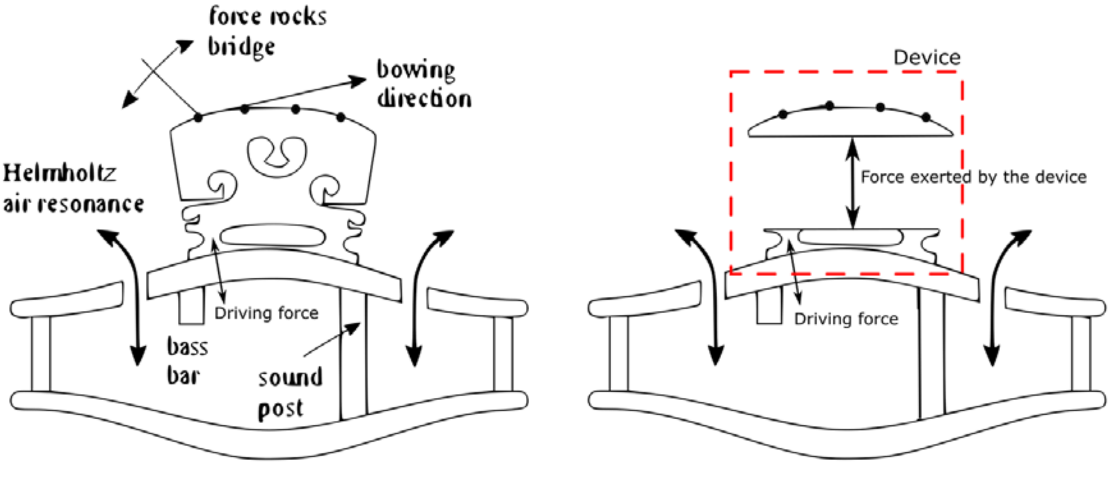

Figure 1 – a) Working principle of a string instrument, b) layout of the proposed solution

The top and back plates are shaped so that they can easily vibrate up and down. The plates have a number of resonances, i.e., there are certain frequencies at which they vibrate most easily (Fig.1a).
The idea of developing a device that is able to make a violin sound autonomously arises in accordance with the working principle of stringed instruments. Commonly, a violin sounds because the belly, driven by the forces that the bridge transmits when the strings are made to ring, vibrates.
It is therefore possible to reproduce the same effect simply by replacing the bridge with a device of the same shape, capable of generating itself the forces it should transmit when the strings are played (Fig. 1b).

This can be profitably obtained by using a custom magnetostrictive actuator [15]. The active element is a giant magnetostrictive rod which is surrounded by a coil and is subjected to a magnetic field generated by permanent magnets placed at the ends of the bar. When the supplied current flows in the coil, a variation of the electric field that passes through the magnetostrictive material produces a change in the magnetic field opposing this variation. This leads to the subsequent alignment of the magnetic domains of the material and thus to the lengthening/shortening of the magnetostrictive rod and to the generation of a high force. Magnetostrictive rod are prestressed by the tension of the four strings that guarantee the actuator always works under compression.

3. THE PROTOTYPE

The device developed in this work is depicted in figures 2, 3. It consists of magnetostrictive bars (1), coils (2), transversal bars (3), transversal support pieces (4), violin bridge pieces (5), permanent magnets (6).

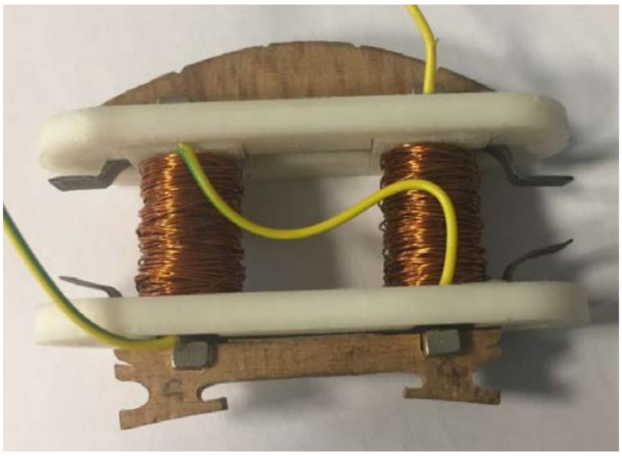

Fig. 2 Prototype

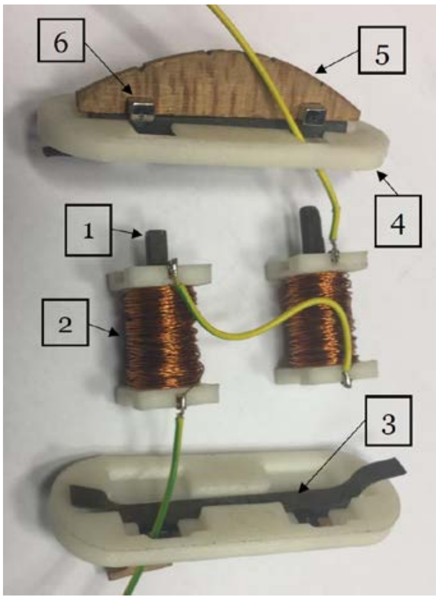

Fig. 3 – Main parts of the prototype

The magnetostrictive bars are the core of the device, as they have the function of converting the oscillations in the magnetic field in which they are immersed to mechanical vibrations. They are made out of Terfenol-D, and their size is 20 x 3 x 3 mm. The coils are wounded around a tailor built part and create a variable magnetic field according to the current flowing. For the prototype, this part has been built in ABS plastic by a 3D printer. It has a squared vertical hole through which the magnetostrictive bar passes, so that it is in the center of the magnetic field created by the coil. It has two grooves, both on the top side and on the bottom, to allow the transversal bars to rest on the magnetostrictive bars. The total height of the squared hole is 19 mm,

while the length of the magnetostrictive bars is 20 mm. This ensures that these bars are the ones in contact with the transversal ones and not the plastic parts, so that the magnetostrictive bars are compressed with the tension of the strings of the violin. The transversal or horizontal bars are the two metallic bars between which the magnetostrictive rods are compressed. Their function is to transfer the compression of the strings of the violin to the magnetostrictive bar (top transversal bar) and from the magnetostrictive bar to the lower violin bridge (lower transversal bar).
Violin bridge pieces have been cut from an original violin bridge. As the device is inserted in the bridge between the body of the violin and the strings, to obtain a perfect fit the best option is to modify an original bridge and keep same dimensions. The upper part serves the purpose of keeping the strings in the same position they would have with a non-modified bridge. The lower part allows the device to rest on the body of the violin with a correct fit, as the body is not flat but has a slight curvature. The total height of the device is slightly higher than the original bridge, but it is not a relevant aspect as long as the device has the adequate tension from the strings that ensures the correct transmission of the vibrations.
The magnets used for the magnetic field biasing are made of neodymium and have the following dimensions: 8 x 4 x 3 mm. They are positioned at both ends (superior and inferior) of each of the coils, in order to maximize the magnetic field that passes through the magnetostrictive bars.

4. EXPERIMENTAL TESTS

Experimental tests are carried out with the double scope of evaluating the ability of the device to reproduce sound and estimate the ability of the system to train a violin. As it is difficult to define whether the sound is better or worse after the training, it would be enough to know that it changed and that it reached a stationary regime. Once this is acknowledged, further studies should be performed to determine the quality of the sound.

The layout of the experimental setup is shown in figure 4. A suitable electric signal, having the same frequencies of the sound to reproduce, is generated and amplified to reach the adequate amplitude. The current flows into the coils and changes the magnetic field of the two magnetostrictive rods, thus exerting the corresponding driving forces to the body of the violin.

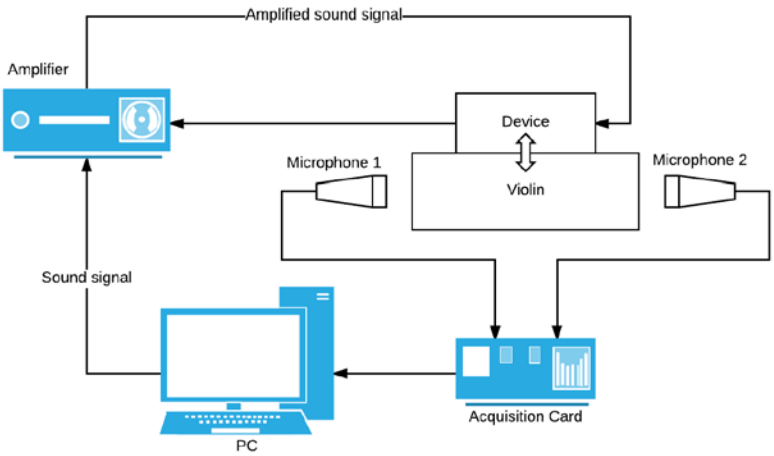

Fig. 4 – layout of the experimental setup

The instrument is suspended through an elastic rope and resonates driven by the actuator, sounding as if it was being played. One of the strongest points of this method becomes clear here: virtually any vibration can be replicated on the violin as the input is simply an audio signal. Therefore, any frequency can be excited or accentuated, if so desired, in order to obtain a certain behavior of the violin. Either lower or higher frequencies can be emphasized, as well as certain songs or music styles. Two 130D20 microphones manufactured by PCB Piezotronics are used to record the sound. They are placed close to the *f* holes to have the best measurements (Fig.5, Fig.6).

Fig. 5 – The prototype installed on a violin

Fig. 6 – Detail of the prototype installed

The choice of the audio signal is of great relevance. The best option was decided to be a real violin piece, with the real vibratos if possible, as it was the closest sound to the one that the violin will produce when it is played. With the objective of exciting homogeneously the frequencies that will be likely most played (that is, the notes), the best option was a chromatic scale that includes all the notes (tones and semitones) between two octaves. That way, all the notes are equally excited on the body of the violin. For the test, the chromatic scale used starts at the lowest possible note of the violin, G3, and goes three octaves above it, up to G6. Typically, higher notes can be produced on a violin, but for this purpose G6 is a good upper limit. The audio file was downloaded from [16] and it can be listened here [17].
A violin that has never been played before has been used for tests. The sound of the instrument is measured at the very beginning and periodically to obtain the evolution of the sound. The test lasts for a whole week (176 hours). A total of 11 recordings were performed according to Fig.7, most of them at the beginning, where a greater variation of sound properties is expected.

Measure number	1	2	3	4	5	6	7	8	9	10	11
Number of hours	0	1	2	4	8	16	32	56	80	104	176

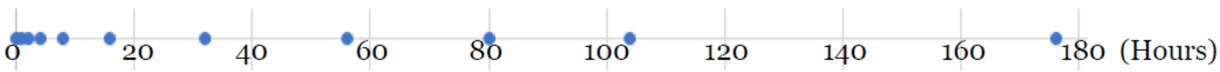

Fig. 7 – Test recordings

Each recording consisted in a 50 second measurement of the chromatic scale used as an audio signal, ascending and descending. That way the frequency analysis is performed twice for each note, one time during the ascending part of the scale and another during the descending one.
The acquisition frequency used was the maximum the acquisition card allowed, 51.2 kHz. This allows us to analyze the frequencies up to 25.6 kHz, which is above the human hearing capabilities and prevents aliasing.

5. RESULTS

The main notes excited during the test are the diatonic notes from G3 (196 Hz) to G6 (1568 Hz). However, as higher notes are also excited due to the different harmonics, the frequency range of analysis was extended up to F#9 (11840 Hz). To obtain the ranges among which the energy is to be calculated, every interval between two consecutive notes was divided into two, with the lower interval being assigned to the lower frequency note and the higher interval to the higher note. For example, between the note G3 (196 Hz) and G#3 (207.65 Hz), the middle point is 201.825 Hz. This is the upper limit for the G3 interval and, at the same time, the lower limit for the G#3 interval.
Figure 8 shows the frequency Fourier transform of the sound measured at the beginning of the test. The highest amplitudes correspond to frequencies between 1000 and 2500 Hz, which are the natural and first harmonics of the notes played.

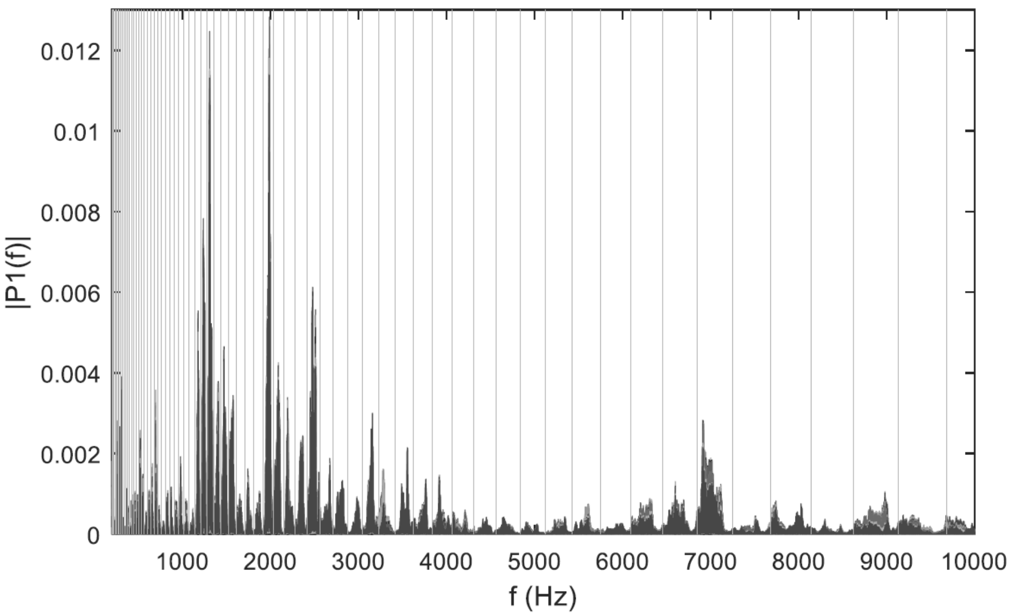

Fig. 8 – FFT of measurements acquired by microphone 1

According to the definition of ranges of frequencies associated to each note, the power spectral density (PSD) has been calculated to investigate changes in the sound reproduced over time. Evolution of PSDs has been calculated for all the 72 notes between G3 (196,00 Hz) and F#9 (11839,82 Hz). For the sake of briefness, in the following only some notes will be considered.
For some notes (eg. G#, A#, B, collected in Fig.9), a stabilization of the PSD can be observed over time, while for others a trend (both increasing and decreasing) is observed, meaning the instrument is still far from be stable even after this long period of activity (Fig. 10, Fig. 11).

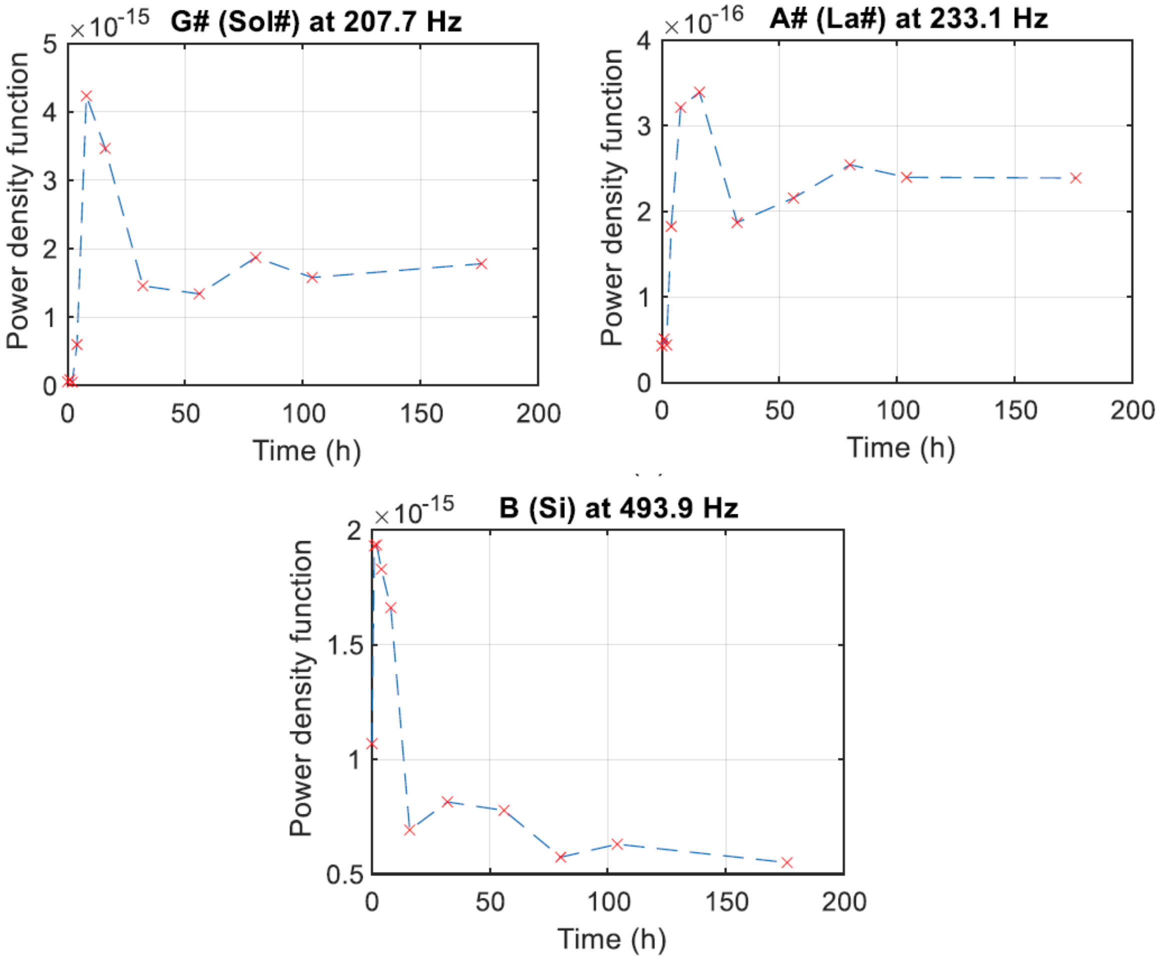

Fig. 9 Notes showing a stabilization over time

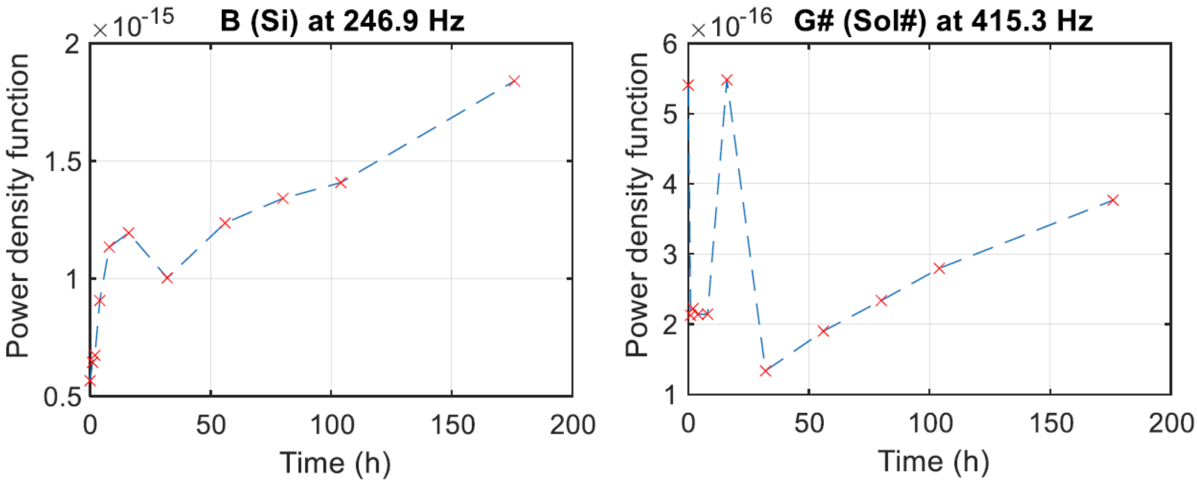

Fig. 10 Notes showing an incremental tendency over time

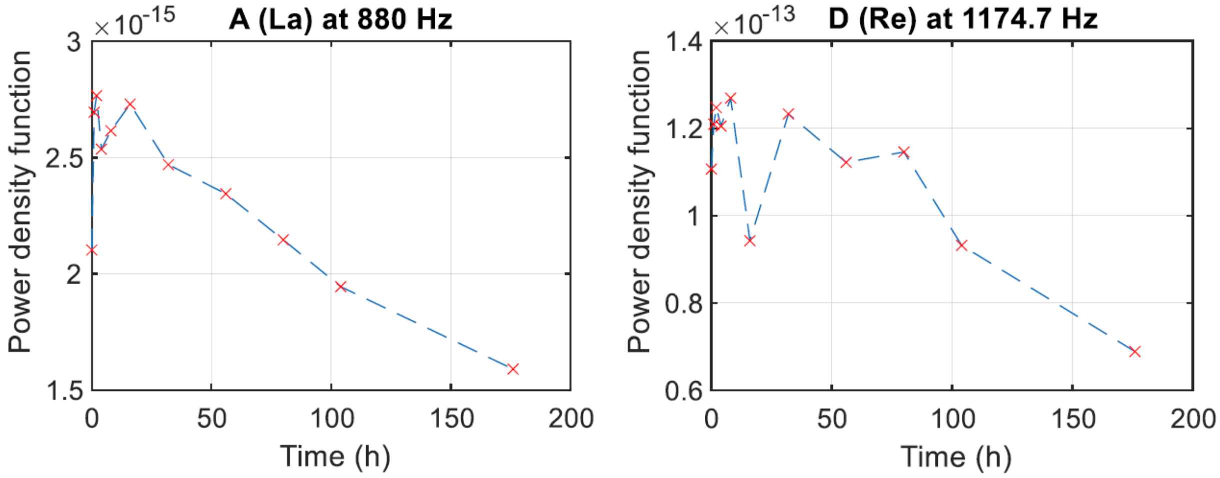

Fig. 11 Notes showing a decremental tendency over time

6. CONCLUSION

A device to train string instrument has been designed produced and tested. The system can be installed on a violin and it is able to exert the forces needed to let it sound as well as if it was played by someone. The device exploits magnetostrictive effect to generate forces and it is able to reproduce any kind of sound in the range of audible.

The device has been installed on a new violin and it was played for a week. During this time the sound reproduced has been measured and the power spectral density of each note has been compared over time. All the played notes show a trend in their PSD, demonstrating there is a change in the behavior of a string instrument when it is played after a long time and confirming the ability of the prototype to train the violin.

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