A highly accurate plucking mechanism for acoustical measurements of stringed instruments

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Abstract: This paper introduces a fully automated plucking apparatus for stringed instruments. The basic idea of the proposed mechanism is to make use of the constant tensile strength of bare wires. It defines the plucking intensity of a clasped string by pulling the wire until it breaks. The main components of the apparatus are bare wires for the string plucking, solenoids for the transmission of traction, bipolar transistors for the electric circuit switching, and a signal generator for the trigger settings. The mean average of the correlation coefficients between several individual excitations is well above 99%.

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1. Introduction

Methods to stimulate stringed instruments can generally be divided into string-plucking and non-string-plucking techniques. Non-string-plucking techniques, such as the force hammer method[1] or the shaker method,[2] are commonly used for impulse response measurements of acoustical instruments.

This paper aims at open string excitation for sound studies like, for instance, timbre estimations. For this purpose an adequate string-plucking technique is necessary. The following aspects should give a rough overview of the problems associated with the reliability of plucking an open string.

- Some of the variable boundary considerations of plucking an open string are already shown in Ref. 3. Both, human plucking techniques and the material properties of the exciter usually limit the repeatability of excitations.
- Usually, the exact geometric configuration of the acoustical measurement setup cannot be fully captured for repetition in comparative studies, because there are humans involved who plug or hold the instrument.
- The start time of excitation, the string displacement, and the string acceleration cannot be accurately set.

This paper shows how to excite strings without these limitations. A simple electric circuit triggers the excitation. Therefore, it is possible to exclude human error factors for the acoustical measurement setup. Furthermore, the inexpensive approach of the apparatus makes it an interesting tool for acoustical measurements of stringed instruments.

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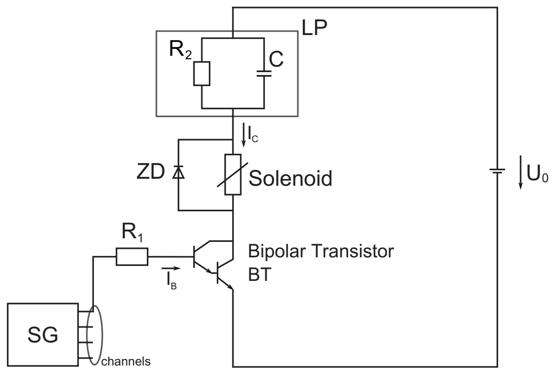

Fig. 1. Electric circuit of a single plucking unit, SG=signal generator, LP=low pass filter, and ZD=Zener diode.

2. The plucking apparatus

2.1 Basic principle: Bare wire plucking

The basic idea of the proposed apparatus is to pluck strings by means of a breaking bare wire which is a frequently used plucking technique, for instance see Ref. 4. The string is clasped with a wire and pulled up until the wire breaks. This type of string excitation has several advantages against plucking with finger nails or plectrums.

- Constant tensile strength of the wire. Constant plucking intensity due to homogeneous wire properties and low manufacturing tolerances, ±0.003 mm for wire diameter d_w=0.09–0.20 mm.
- Precise location of the exciting point at the string and therefore an exact string division. This allows controlling string formants and/or suppression of individual partial tones.
- Well-defined plucking direction in relation to the instrument.
- No material fatigue over time, due to one-time use of the wire.

2.2 Apparatus setup and room conditions

The proposed apparatus facilitates precise reproductions of measurement setups. This is due to the fact, that the relevant angles of the tensile force direction can easily be measured at the given string and wire. Such precision has been missed in alternative approaches, for instance, using an impact hammer at the bridge.

Finally, the general automation approach also allows for remote operations, preventing people to disturb the acoustical ambience of a recording session.

2.2.1 Operating principle of the mechanism

The plucking apparatus is a signal generator (SG) controlled traction transmitter. A current leading solenoid provides the required tensile force which depends on the individually used wire diameter d_w (see Sec. 2.1). In order to control the excitations separately every plucking unit consists of an electric circuit (see Fig. 1). It is evident that the apparatus can easily be expanded to numerous channels. Simple SGs can be used to control the sequence of excitations. For flexibility and accuracy of sequences a microprocessor can be used. Such setup also allows for providing additional recording triggers (markers).

Figure 2 shows the moveable core which exists of an iron and an aluminum part. The two-component design in construction with the difference of permeability (iron: $\mu_{\mathrm{Fe}} \gg 1$, aluminum $\mu_{\mathrm{Al}} \approx 1$) helps to prevent uncontrolled movements of the core inside the rail of the solenoid. Due to this permeability relationship, the motion direction of the core only depends on the oscillating dipping depth of the iron part within the magnetic field inside the solenoid. For this setup, where d is the difference between l_i and l_c, the core will move back and forth around the variance d (for

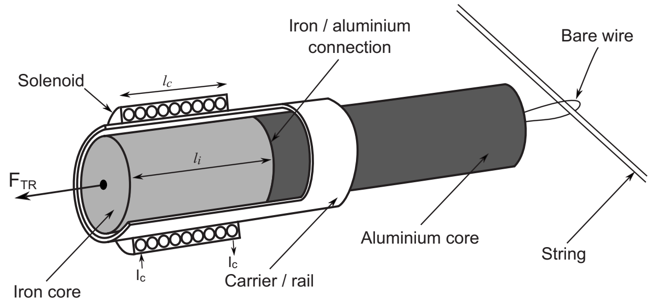

Fig. 2. Solenoid, the traction transmitter is taken out of a single plucking unit, F_{TR}=traction force and direction at excitation start time, for the detailed use of the two-component core, see Sec. 2.2.1.

details see Fig. 2 and Table 1). Such oscillation can be avoided by reducing the switched current I_c. This is achieved by a low pass filter (LP) in the electric circuit. The time constant (see Table 1) of the LP must suit the required traction force during the plucking process and the time which elapses until the oscillation of the core will fully stop.

2.2.2 Specifications of the electronic components

The set of the electronic components is shown in Table 1 which was used for the proposed prototype. This specific implementation should give a first idea of what is needed to build, for instance, a violin plucking apparatus.

3. Results

In this section an exemplary measurement series of a stringed instrument will be discussed. A high quality violin (OP.96 Martin Schleske, 2008) served as test device. The instrument is plucked by hand but also by the proposed apparatus to identify possible improvements which are achievable by the apparatus. The recordings for the upcoming results are made with two different wire diameters $d_w=0.09$ mm and $d_w=0.14$ mm, where both diameters are used for both types of excitations, manual and mechanical.

3.1 Recording conditions

The operational capability of a device within an acoustical measurement chain is intercepted by its sound level. Therefore, measurements were made which show the relationship between the sound level of the plucked instrument and the sound level of the apparatus alone, without instrument (Table 2). The measurements were taken at a distance of 60 cm normal to the violin in the amount of the bridge.

Table 1. Main parameters of the prototype plucking mechanism; for details see Figs. 1 and 2.

Parameter	Value	Remark
Solenoid winding number n	3300	Wire diameter $d_s=0.19$ mm
Solenoid diameter D	1 cm	
l_c	3 cm	
l_i	4 cm	$\rightarrow d=l_i-l_c=1$ cm
R_1, R_2	1000 Ω	
C	940 μF	$\rightarrow \tau=0.1$ ms
U_0	120 V	Variable for variable wire diameters
Base current I_B	3 mA	Output voltage SG-channel: 3 V
Amplification factor BT	1000	
Resulting traction force F_{TR}	>15 N	at $U_0=120$ V

Table 2. Relationship between the violin sound levels (wire plucked by hand), the apparatus sound level (alone), and the sound level of the quiet recording room, all measured sound levels were *A*-curve weighted.

d_w (mm)	Violin (dBA)	Mechanism alone (dBA)	Room in quiet (dBA)
0.09	77	33	22
0.14	80		

In order to achieve an adequate noise level of the apparatus an electromagnetic traction controller was introduced in Sec. 2.2.1. Therefore, it is possible to decelerate the core without mechanical means after plucking the string.

3.2 Statistical results

We compare the exciting methods, manual vs mechanical, identifying the spread across repetitions. For this purpose, the Fourier spectra of 15 recorded excitations are compared in pairs what denotes a combination number ${}_nC_k$ of 105 ($n=15$ choose $k=2$). All recordings were done with the same microphone in the same position as for noise measurements in Sec. 3.1.

Well suited indicators of the comparisons are the individual correlation coefficients $R(i,j)$ of the respective pairs. The differences between the populations of the data series are depicted with a box-and-whisker diagram (Fig. 3) obtained from all individual $R(i,j)$. The results show an increased $R(i,j)$ for both wire diameters when the apparatus is used.

4. Conclusion

This paper presented an apparatus to excite stringed instruments with high precision. A prototype device was constructed which uses an electric circuit switching with a trigger and traction transmission unit. It was shown that reproducibility of bare wire string plucking, which is already very good in the manual version, can be even optimized by automated setups.

Repeated measurement series will be as precise as the mechanical tolerances measured in the static measurement setup.

The proposed apparatus allows producing plucked string sounds with an average correlation coefficient of more than 99% between individual excitations.

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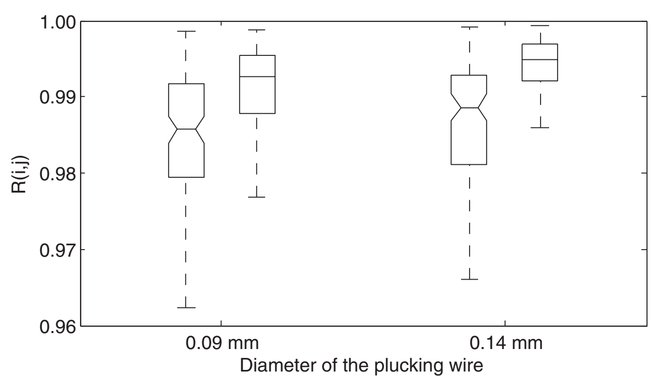

Fig. 3. Box-whisker-diagram of all correlation coefficients $R(i,j)$, notched boxes=string plucked with a wire by hand, and non-notched boxes=string plucked with a wire by the apparatus

References and links

[1]G. A. Bissinger and M. Bailey, "V-r model predictions of averaged radiation from a violin compared with spatial average of bridge force hammer-excited direct radiation," J. Acoust. Soc. Am. **101**, 3144 (1997).

[2]P. Müller and S. Massarani, "Transfer function measurement with sweeps," J. Audio Eng. Soc. **49**, 443–471 (2001).

[3]"The timbre space of the classical guitar and its relationship with the plucking techniques," in ICMC Proceedings, Beijing, China (1999), edited by N. Orio.

[4]J. Woodhouse, "Plucked guitar transients: Comparison of measurements and synthesis," Acta. Acust. Acust. **90**, 945–965 (2004).