VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2024.1.05
Vibrations in Physical Systems, 2024, 35(1), 2024105

Electrodynamic pick-up for electric string instruments

Edward RESZKE[1], **Andrzej DOBRUCKI**[2]

[1] Ertec-Poland , ul. Janiny Kłopockiej 13, 54-530 Wroclaw
[2] Wroclaw University of Science and Technology, Department of Acoustics, Multimedia and Signal Processing, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw

Corresponding author: Edward RESZKE, email: ertec@wp.pl

Abstract The most important elements in electric musical string instruments are pick-ups. They convert vibration of strings into electric signal. Usually, two types of pick-ups are used: electromagnetic and piezoelectric. Electromagnetic pick-up, called also a pick-up with moving armature, converts vibration of string into an electric signal using change of magnetic flux in the magnetic circuit by the vibration of the string made of magnetic material. Vibrating string causes change of the air gap between the string (which is a moving armature) and rest of magnetic circuit. A variable electromotive force is generated in the stationary winding. In order for it to be proportional to the speed of vibration, polarization is needed, which is achieved by using a permanent magnet in the magnetic circuit. In a piezoelectric transducer, an electric current is generated due to the deformation of the piezoelectric material under the influence of a vibrating string. The subject of this paper is description of a stringed instrument with a electrodynamic transducer, which converts mechanical vibration of strings into an electromotive force which is produced between the ends of moving wire placed in the permanent magnetic field. This transducer is also called a transducer with moving wire. A wire (string) is made of a conductive material, but not necessarily a magnetic material. The principle of operation is similar to that of a ribbon microphone. The electromotive force induced at the ends of the string is very small and must be strongly amplified. It's a novel technique which is applicable in electric stringed instruments such as guitar, violin, viola, cello, double bass, and others.

Keywords: electric string instrument, electrodynamic transducer, low-noise amplifier.

1. Introduction

In general, the known transducers used in electric stringed instruments are built on the principle of converting mechanical oscillations indirectly into electrical or magnetic signals using piezoelectric or electromagnetic sensors. The piezo transducers act through acoustic waves and vibration propagated in and along the instrument's elements which are received by piezoelectric sensors. Electromagnetic pickups act using modulation of the magnetic field by vibrating string, and then the modulated field induces a voltage in a immobile coil wound around the magnetic system. Therefore using the electromagnetic transducers, it is necessary to use magnetic strings, i.e. only those interacting with magnetic field and are capable of modulating its strength.

There exists another possibility to produce suitable electric signal which could be immediately linked to vibrations of the string. It is based on the law of electromagnetic induction originally formulated by Faraday in 1830. According to this law, every electrical conductor which moves across the lines of magnetic field produces the Electro-Motive-Force (EMF) between the wire ends. This physical law had not been applied to musical instruments earlier because levels of obtained electrical signals were too low and the idea of applying that principle had years ago been rejected as inapplicable.

However, many years later this idea has been successfully applied in ribbon microphones which are currently in use being the choice of many professionals today. The technology of ribbon mics which could have been simply adopted to vibrating strings of musical instruments has not been found useful. Nowadays, fortunately we have engineered to 'reused the old Faraday law' by offering the new pick-up technique to immediately read signal from the strings and what's even more important this reborn approach brings a new idea how to elevate sound quality of electric instruments. The first report on this subject was developed in Denmark by researchers from Aalborg University [1]. This work presents its own original solution based on a patent [2], and the use of an ultra-low noise amplifier [3].

2. Novel pickup's essential

The principle of operation of an electric stringed instrument is that strings made of electrically conductive material, not necessarily magnetic, are placed in the field of at least one permanent magnet. When the strings vibrate, electromotive forces are induced at both their ends, which are fixed and do not participate in the creation of sound. Each of these electromotive forces is given by [2]:

$$E = Blv, \tag{1}$$

where: E – electromotive force, B – magnetic induction of a permanent magnet, l – length of the wire covered by the magnetic field, v – speed of the string under the magnet. Electromotive forces are very small, so they must be applied to the input of a low-noise preamplifier, from which the output signal is sent to the input of the power amplifier. The first stage of a low-noise preamplifier may be a step-up transformer. It is also possible to use two step-up transformers in this first stage using push-pull connection. This solution helps to reduce external interference. A similar combination known as a humbucker has been developed in the traditional electromagnetic pickups used in modern electric guitars.

The principle of operation of a dynamic guitar pickup is shown in Figure 1. The taut string is supported on one side by the TS nut and on the other by the bridge support. There are two magnets placed under the string. The total electrical signal is generated between the terminal contacts of the KT string, which are connected by two KB cables, at the ends of which there is a sum of electromotive forces E1 and E2, generated in the string sections located under the magnets.

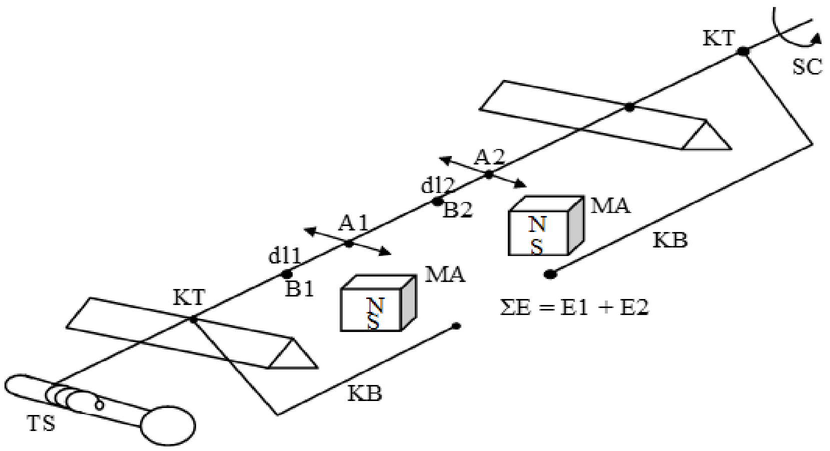

Figure 1. Principle of operation of the electrodynamic pickup of an electric string instrument.

The use of more than one magnet makes it possible to optimize the timbre, because different amplitudes and phases of velocity are amplified at different points in the string. A certain difficulty in the construction of transducers is the need to electrically connect the strings outside their vibration zone. In new instruments, these connections can be permanent, hidden construction elements, while in old instruments the necessary connections must be made, for example, by sticking thin conductive foils to the outer surfaces of the instrument. Fortunately, in many practical cases it is perfectly satisfactory to make one joint common to all strings. As mentioned, the strings can be made of conductive but non-magnetic materials, e.g. acid-resistant steel or phosphor bronze, as well as other metals with anti-allergic or bacteriostatic properties. Nylon cords having a metal coating or a metal wound can also be used. Due to the fact that non-magnetic strings are not attracted by magnets, they are free to oscillate without damping, making a natural timbre and free sustain. In addition, it is possible to expose the string to strong magnetic fields.

3. Design variants

The simplest solution that was tested first was to connect the strings in parallel, i.e. shorting their ends on the bridge and on the nuts (Figure 2).

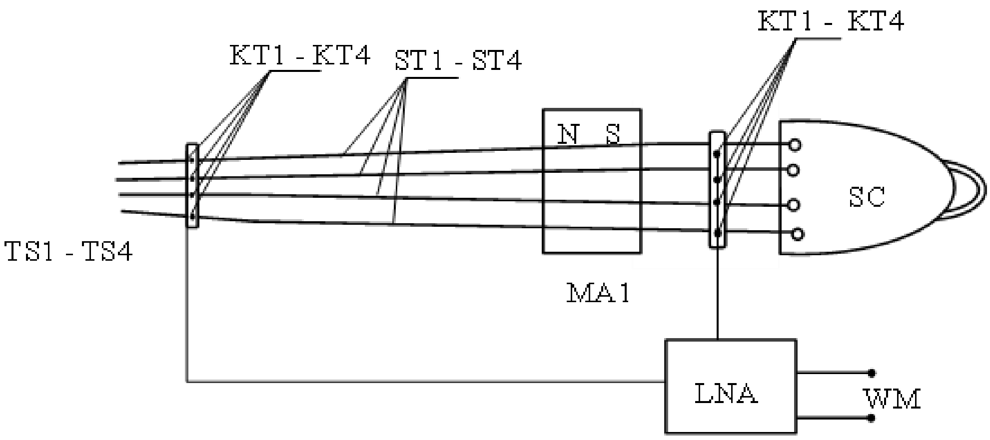

Figure 2. Four-string instrument equipped with four common electrical contacts (KT1-KT4) on the nut and bridge, and one MA bar magnet placed under the ST1-ST4 strings. The signal is delivered to the WM power amplifier through a low-noise LNA preamplifier [3].

Figure 3. View of a double bass with 4 strings, one magnet and common contacts on the bridge and nuts.

The view of the instrument (double bass) built according to this principle is shown in Figure 3 [4]. This solution seems to be beneficial from the point of view of vibration damping, because the strings interact with each other. In practice, however, the solution did not work. The sounds emitted by individual strings are often perceived with different volume and timbre. It is possible to achieve an improvement by individually selecting the magnets responsible for the level of magnetic field strength near each string, but this effect is difficult to obtain, especially since the position and strength of the magnets also determine the timbre of the sound.

So a solution was introduced where the ends of the strings are shorted at the nut and at the tailpiece each string is connected to a series resistor R_S (Figure 3).

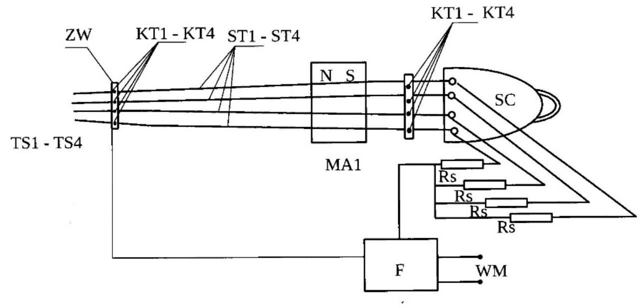

Figure 4. 4-string instrument with strings electrically shorted at the nuts and connected to series resistors at the tailpiece.

The transducer system shown in Figure 4 is passive, i.e. it does not contain any semiconductor elements. The anti-interference filter is a transformer that increases the voltage, which avoids the use of an electronic preamplifier. This solution has worked very well in practice. The series resistance value should be between 1-100 times the sum of the resistances of all individual strings. With this choice of resistors, the total resistance is still kept low, and thus the equivalent resistance of the string system can also be kept low. Low resistance guarantees the possibility of obtaining a low thermal noise figure, and moreover, it can introduce an appropriate electromagnetic damping into the system, because a closed circuit moving in a magnetic field is always damped. The well done selection of resistors connected to the strings allows precise equalization of their volume so that it is the same for all strings. It is worth noting that the introduction of resistors will always result in some signal loss. For example, in violins and other 4-string instruments, the signal from one string is generally split 1:4, but the ratio is almost independent of the value of the series resistors as long as they are all equal. Of course, the smallest possible resistance will be important from the point of view of noise level and electromechanical damping. The tailpiece in the former example must be made of non-conductive material. The signal from strings with series-connected resistors is fed to the power amplifier through an anti-interference filter that suppresses electromagnetic interference. A variant of this solution [5] is the use of resistors at the nuts, while the longtail is made of conductive material, i.e. metal (Figure 5). As in the previous case, the signal from the strings is fed to the power amplifier through an anti-interference filter. The instrument (cello) made on this principle is shown in Fig. 6.

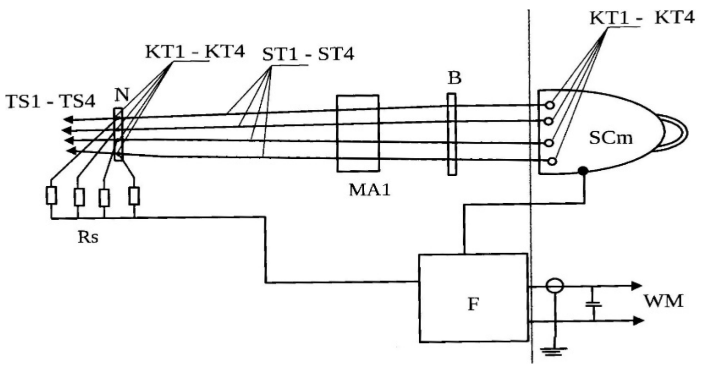

Figure 5. Passive system with resistors at the nut and conductive longtail.

Figure 6. View of the passive system with strings connected in parallel and resistors by the nuts, on the left - view of 6.8 Ω resistors connected in series with the strings,
on the right - the signal cable from the strings.

The same solution can be realized with strings connected in series. In this case, additional adjustable resistors should be connected to the resistance of individual strings not in series, but in parallel. This is shown in the mandolin example in Fig. 7. Resistors connected in parallel are marked with R_r.

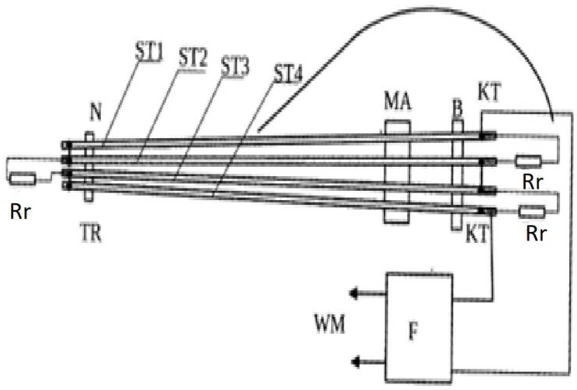

Figure 7. Passive system with strings connected in series. Example of a mandolin.

When strings are connected in series, the input impedance of the preamplifier must be as low as possible to ensure proper levels of both attenuation and noise. This solution was used in the acoustic-electric guitar shown in Figure 8.

Figure 8 shows the magnet of the electrodynamic pick-up directly above the resonance box. When strings are connected in series, resistors must be connected at both the nuts and the tailpiece. For the guitar according to Figure 8, it is shown in Figure 9.

Figure 8. An acoustic-electric guitar with strings connected in series and resistors in parallel.

Figure 9. Connecting strings in series with resistors connected in parallel.
On the left - by the nuts, on the right by the tailpiece.

4. Magnet placement and interference suppression

The solutions shown in Figures 2–9 use one magnet placed under all strings. Much better results can be achieved by using either magnets placed individually under each string, or two or more magnets placed in appropriate locations under all strings. In such cases, the placement of the individual magnets is the key issue. Classical stringed instruments are equipped with a resonance box, which is not only an acoustic amplifier, but also a specific filter. When the resonant box is incorrectly constructed, you can hear unpleasant sounds, while the proper construction of the box in a similar instrument allows you to admire the beautiful timbre of the instrument built by a talented luthier. In the case of an electric instrument, the quality and placement of the transducers, and in the case of an electrodynamic pick-up, the position and shape of the magnets are of great importance. It was found experimentally that the best sound of the instrument is obtained by using typical ferrite bar magnets 3-5 cm long, grouped between the neck and the bridge. In classical instruments, where there is free space between the fingerboard and soundboards, magnets can also be placed under the fingerboard. Proper selection also requires their distance from the strings and their attachment to the body of the instrument. It is advantageous when the mounting enables individual correction of the distance between the magnets and the strings.

The signal from the electrodynamic pick-up is very low, so it is very important to prevent these interferences. Meanwhile, the strings, whose total length is up to several meters, are an antenna tuned to radio frequencies and mobile phone bandwidths. Then, it is very important to prevent interference. Therefore, measures should be taken to suppress interference as much as possible. Belong to them:

I. The system of strings and resistors must be passive, i.e. it must not contain any semiconductor elements that can process foreign RF signals. No semiconductors, ICs, transistors can be near the strings before proper RF filtering.
II. The output signal should be filtered using a passive filter with an appropriate band corresponding to the acoustic band of the instrument.
III. An element built into the filter should be an acoustic transformer that increases the voltage of the electrical signal. Such transformers are commonly used in ribbon microphones.
IV. A capacitor should be used on the secondary winding of the transformer to short-circuit the frequency of interference in the radio band. A clean signal in the acoustic frequency range can be further amplified using electronic amplifiers.

5. Conclusions

Relatively simple but effective measures have been used to improve the properties of stringed electric instruments with an electrodynamic transducer, in which the vibrating as well as the generating electromotive force element is each string vibrating in the field of a permanent magnet. Using just a few resistors and connecting the strings in series or in parallel one obtains equal loudness for each string and equal timbre which are independent of string make. The resulting signal is prevented from EMI with the use of anti-interference filtering including the step-up transformer magnifying the signal magnitude. The results obtained can be used as tips that are required to start the process of industrial implementation of the presented methods of signal and picking-up in the stringed musical instruments.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. L.S. Pardue, K. Buys, M.I. Edinger, D. Overholt, A. McPherson; Separating sound from source: sonic transformation of the violin through electrodynamic pickups and acoustic actuation; Proceedings of the New Interfaces for Musical Expression 2019 conference, 278-283; NIME Proceedings; URL: https://www.nime.org/proceedings/2019/nime2019_paper053.pdf
2. A. Dobrucki; Przetworniki elektroakustyczne (in Polish); WNT, Warszawa, 2007
3. V. Janašek; Design of ultra-low noise amplifiers; URL: www.janascard.cz
4. E. Reszke; A stringed musical instrument with strings constituting elements of a dynamic vibration transducer (in Polish: Strunowy instrument muzyczny ze strunami stanowiącymi elementy dynamicznego przetwornika drgań), Polish Patent Application No. P.445636 (submitted electronically on July 19, 2023)
5. A. Dobrucki, E. Reszke; Evaluation of a New Electric Viola with Dynamic, Pickup; Ertec Private Report 1a/2023