ELECTROMAGNETIC EXCITATION METHODS OF ACOUSTIC MUSICAL INSTRUMENTS - AN EXAMPLE OF PIANO AUGMENTATION: SYMPATHETIC VIBRATING PIANO

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Abstract

Augmentation of musical instruments is a relatively new field for extending both performance techniques and timbre opportunities of traditional instruments. Several recent designs are offered which use the principle of electromagnetic actuation. Application of this principle is by inducing vibrations in the acoustic mechanism. In turn acoustic sound is created from the instrument. Traditional sound of an instrument can be manipulated and new timbral territories can be explored with similar designs. This paper mentions the physical princip les of this method and explains various actuator designs. In addition, an alternative setup designed by the writer will be explained; as the outcome of yet unpublished Ph.D. disser tation at ITU MIAM, conducted by Doç. Dr. Can KARADOĞAN, in 2015.

Background: The E-Bow as the Fundamental Example

From the beginning of the 20th century, music authorities had started indicating the need for exploring the physical properties of sound in compositional studies. Timbre had not been considered as an individual musical property until then besides melody, harmony and rhythm. It became widely considered in musical composition.

Timbre had been always considered as a prominent feature in electronic music. As the new electronic instruments, their performing methods and composition techniques had improved and diversified, the pursuit of new timbre had been one of the primary motivations of such developments. After the theoric understanding had formed and took root among electronic music pioneers and composers, different approaches were established discussing the authentic source of sound material used.

Considering the compositions in the electronic music literature, the origins of the sound material can be divided into three main categories:

1- Synthetic (artificial) sounds: Musics organized with sounds produced from various equipment, which can oscillate waveforms that do not exist in nature; whose properties like frequency, timbre and envelope are designed.

2- Sampled (recorded) sounds: Musics organized by replaying the sounds whose authentic vibrations are captured previously and then used as authentic versions or be manipulated with various techniques.

3- Feedback: Musics organized by the resonances that occur when sound outputs are f edback in the sound inputs.

In a historical context, the first and the second methods were initiated and represented by the German school of Electronic Music *(elektronische musik)* and the French school Solid Music *(musique concrète)* approaches consecutively. However, the third method being feedback cannot be explicitly related with a foundation or a group. It found its place in avant-garde compositions and performances. Composer Robert Ashley calls feedback “the only sound that is intrinsic to electronic music.” (Holmes, 2008:26).

Feedback is a phenomenon well known by artists, performers or technicians operating in the live sound business. It is caused by the controlled or uncontrolled electronic or acoustic connection of the input and the output of a sound system. Most common example of feedback is the interaction of a microphone and a loudspeaker connected to the same sound system. When the sound coming from the loudspeaker is captured by a microphone, it follows the signal path and it will be amplified more and more each time; just like a snowball turning into an avalanche. The result will be a loud howl or squeak, depending on the resonating frequencies causing the feedback.

One distinctive feedback application, specially designed for excitation of instrument strings is the popular E-bow (Figure 1). E-bow is a hand-held, battery powered electronic device for playing the electric guitar, invented by Greg Heet in 1969 (Heet, 1978. U.S. Pat. 4,075,921). Instead of having the strings hit by the fingers or a pick, they are moved by the electromagnetic field created by the device, producing a sound reminiscent of using a bow on the strings.

E-bow uses electromagnetic feedback to vibrate metal strings. In this very basic setup, there are two coils inside, one input and one driver coil. Two electromagnetic transducers operate in opposite ends: one solenoid is working like a microphone where the other is playing back the amplified version of the former. First transducer convert the change in magnetic field to electric signal, the amplified signal is converted to magnetic field by the latter. This is why E-bow does not produce any sound on its own. It is because the change in the magnetic field caused by the unit does not interact with air. Sound only emerges when E-bow gets into interaction with a vibrating object that reacts to magnetism. The device results in a change in the magnetic field and this causes the string to vibrate. As the string vibrates, it interacts with the input transducer and a feedback loop is generated. This electromagnetic loop causes the vibrating object to oscillate in its natural mode: the first mode being the fundamental frequency. Subsequently this vibration is captured by the input and the signal follows the same looping path until amplification power dies out. Resulting sound is the acoustic sound of the string, or the instrument.

Figure 1: The E-bow.

Electromagnetic Excitation

For electro-acoustic music composition, a hybrid method can be offered as a potential for sound creation: Electromagnetic excitation. In this method, a music instrument is set to vibrate with an actuator signal and the sound is obtained acoustically. Electromagnetic actuation techniques can trigger acoustic sounds without the original exciter mechanism of the instrument. This excitation is done with a generated signal, which can be either synthetic or sampled sound, or sometimes both. Even in some designs, the system adjusts its certain properties using feedback, as the details will be explained in the next chapters. Thus, these are the combination of all three sound sources types mentioned in the above list. Electronically born sound signal sets the acoustic mechanism in motion. In one end of the process, electronic signal synthesis can be realized in its own realm with its unique flexibility; in the other end warm acoustic sound, authentic and rich timbre is achieved.

One constraint of this method to be applied: due to the nature of physics, the material of the vibrating element should be metal that would interact with a magnetic field. Each design is contains electromagnetic transducers of some type. It would be beneficial to explain this type of transducers in detail.

Electromagnetic Transducers

To create an electro-magnet, electrical wire is wound around a magnetic substance. A round coil that is a solenoid is formed by this way and it is mounted near the strings for close interaction. When a string is put into motion as it vibrates in three dimensions, the string moves closer to and further from the magnet. This interaction causes a change in the magnetic field around the coil. Subsequently this causes electrons to move around the wire hence an electric current occur (Figure 2).

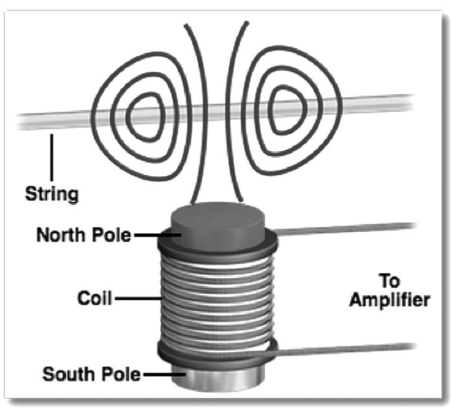

Figure 2: Typical electric guitar pick-up – the red edge is the north pole of the magnet sitting inside the coil, blue lines indicate the magnetic field. The movement of the string causes a change in the magnetic field that creates voltage in the coil [12].

In the case of an electric guitar pickup, this current is then sent to an amplifier and amplified - e.g. larger enough to move the speaker cone of a cabinet. Using this scheme of electromagnetic coils, any kind of instrument with metal vibrating parts – meaning that will interact with magnetic force – can be actuated with an appropriate coil setup. The transducer coils would be driven with a source signal, the actuator signal to be precise, and the coils would cause vibrations in the metal vibrating parts of a musical instrument. Let this be string of a piano or a tambur, similar setups will work on each case.

In a typical solenoid, the magnitude (amplitude) of the generated electric current depends on the following properties:

• Magnet:
Type and size of the magnet affects the strength of the magnetic field around it. Typically, neodymium magnets are used in electromagnets.

• Wire:
If the wire will be wound on itself, there must be an isolator layer around the wire in order to avoid short circuits. Isolated cupper wires are used in solenoids.

• Wire diameter and length:
Thickness of the electric wire affects the impedance of the solenoid. In addition, the length is another attribute that affects. Impedance affects the handling of the electrical power. Lesser impedance specifications are typical in applications; however this can change regarding the power source. Conventionally, wire diameters are stated in millimeters or inches. If coils are considered, wire diameters are expressed by index numbers on the list of American Wire Gauge (AWG). The bigger the number, the thinner the wire gets. Oppositely, smaller AWG numbers relate to the thick wires.

• Distance:
The actual distance between the solenoids and the strings is another parameter of efficiency. The closer, the better interaction is obtained.

• Power:
Power of the signal amplification is directly related to the sound levels obtained from the instrument. The electrical power capability of the amplifier device or the circuit determines this quantity. In addition, convenience of the solenoid impedance and the power amplifier is a major electronic constrain in typical applications.

Electromagnetically Actuated Instrument Designs

In the concept of electromagnetic actuation, the signal flow is like the following:

• Generation of an actuator signal,
• Amplification of the actuator signal,
• Sending signal to the electromagnets.

By including feedback to this concept, information can be gathered by monitoring the emanated sound from the instrument and certain parameters can be manipulated as desired:

• Actuator signal generation,
• Amplification of actuator signal,
• Sending signal to the electromagnets,

• Monitoring the sound by capturing via an acoustic transducer,
• Deriving information by processing the incoming signal,
• Manipulating and processing the actuator signal as desired,
• Sending the new version of the signal to the electromagnets.

Electromagnetically Prepared Piano (Berdahl&Backer, 2005; Blodahl, Per. 2007) is a system developed by Per Bloland and Edgar Berdahl consisting of twelve electromagnetic actuators placed on the piano strings. Each actuator is connected to its own amplifier and each amplifier channel has a dedicated DAC channel feeding it. Signals are generated in Max/MSP including periodic waveforms, filtered noise and prerecorded samples. Any note can be actuated without using the traditional hammer mechanism of the piano. Analog audio signal is amplified and sent to electromagnets placed in close proximity to piano strings. This amplified signal causes a variable electromagnetic field which causes the strings to vibrate, in turn creating sound.

Andrew McPherson's Magnetic Resonator Piano (McPherson, and Kim, 2010) uses a similar actuation system, this time covering the entire range of the piano. Each actuator is driven by its own amplifier, each amplifier is connected to a 16-channel multiplexer routing the DAC channels. This design employs a feedback-based approach, using a single piezo pickup on the piano soundboard as the source. This is an advanced tool for piano performance; besides the fact that it does not use the hammer mechanism either, also individual harmonics on any desired note – on any desired string – can be actuated as well.

There are other actuator setups designed for various different instruments: violin (Boutin, and Besnainou, 2008), xylophone (Boutin and Besnainou, 2008), vibraphone (Britt and Snyder McPherson, 2012), drums, electric guitar, shaker and fiddle (Overholt, Berdahl, and Hamilton, 2011).

Offered Design: Sympathetic Vibrating Piano

The writer of this paper has offered a new method of using electromagnetic actuators (Deneç, 2015). This method is a custom-built hardware used in a live processing setup for the purpose of a Ph.D. thesis. Sixteen solenoids are placed on a concert piano, covering a range of four octaves (Figure 3).

Actuator concept is different in this application though electromagnets are not divided functionally and are not assigned to individual notes or strings. A single actuator signal is being generated with a complex harmonic content, consisting of synthesized periodic waveforms and filtered noise realized in Pure Data. This initiator signal is sent to all of the electromagnets at the same time. This feature enables the setup to interact with the whole range of the piano. The sound modeling is inspired from the works from the Sound Mass composition style, especially György Ligeti and Krzytof Penderecki. The sound of the piano is captured by a pickup microphone, processed and sent back inside the piano strings. Generation algorithm produces continuously deviating sound patterns by the actuator signal and the force of feedback. Any string can be vibrated with the sympathetic vibration principle, when triggering signal corresponds to the partials in their harmonic structure.

Figure 3: Actuator setup offered by the write, on a concert piano. Sixteen solenoids are placed on piano strings.

Conclusion

Sound production in actuated instruments occurs by the manipulation of vibrating elements of musical instruments via computer aided electromechanical systems. As an introduction to electromagnetic transducers' capability, the technique of exciting piano strings using electromagnetic waves are explained with some recent actuated instrument examples and a specific alternative design offered by the writer. Major application of these setups is as an expressive accessory to piano performance and composition. Based on preliminary experiments and implementation of musical ideas, it can be concluded that these setups are helpful for new ranges of expression in composition.

The augmented version of traditional instruments can be suggested as a revival in their evolution. Each particular setup is designed by focusing on an individual instrument and pleading new ideas and improvement. As the actuator techniques develop, unique musical instruments that are beyond the reach of human performances will be designed to fulfill the musical desires of composers. Furthermore, other instruments that these techniques are not applied yet are waiting in line as potential candidates for exploring new performance techniques and timbre.

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