

# **The Electromagnetically-Prepared Piano and its Compositional Implications**

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## **Abstract**

The Electromagnetically Prepared Piano device allows for direct control of piano strings through the use of an array of electromagnets. Created several years ago at Stanford University's Center for Computer Research in Music and Acoustics (CCRMA), the EMPP differs significantly from previous instruments based on similar principles in that each magnet is controlled by an arbitrary external audio signal, resulting in a much higher degree of control over pitch and timbre. The resultant sounds range from simple sine tones through complex, often ethereal textures. For the most part, these timbres are more evocative of electronically synthesized sonorities than of the acoustic piano strings from which they emanate. This paper has three primary goals: 1) to examine the compositional implications of such a hybrid instrument, 2) to describe several of the compositions that have utilized the device, and 3) to provide a detailed mechanical description for others who may wish to experiment with such a device.

## **1. Introduction**

A previous paper [1] has already described many of the technical aspects of the electromagnets and their interactions with metal strings. This paper will take a more compositionally oriented approach, describing some of the resulting timbres and the roles they have played in several compositions, and discussing practical issues of implementing and utilizing such a device. In doing so, the author hopes to describe in more general terms the applications to which the electromagnets have been applied thus far.

## **2. Historical Context**

The idea of using electromagnets to resonate piano strings is by no means a new one. In fact the first instance of such a system occurs as far back as 1886, with Richard Eisenmann of the German firm Electrophonisches Klavier. Through the use of electromagnets positioned near the strings, Eisenmann produced an infinitely sustaining note [2].

More recently, Alvin Lucier has experimented rather extensively with the use of electromagnets to resonate strings. For *Music on a Long Thin Wire* (1977), a single segment of piano wire is stretched over two bridges. A large horseshoe magnet straddles this wire on one end, and the system is controlled with sine waves passed through a power amplifier [3]. In *Music for Piano with Magnetic Strings* (1995), Lucier updates this concept by

incorporating EBows. These small handheld devices, familiar to many electric guitarists, allow the guitar to sound with no attack and with infinite sustain. In his piece, Lucier calls for several of these devices to be held over piano strings. Rather than using standard musical notation, the score provides a text description of the desired resultant sounds [4]. Whereas the first piece has a raw, "sinusoidal" quality, in the second the use of multiple strings, the fact that they remain within the body of a piano, and the mechanism of the EBow all serve to create a smoother sound with a richer overtone content. In addition, Lucier's use of a handheld device such as the EBow opens the possibility of augmenting the pure resonant sound by bringing the device into physical contact with the vibrating string.

### 3. Origins

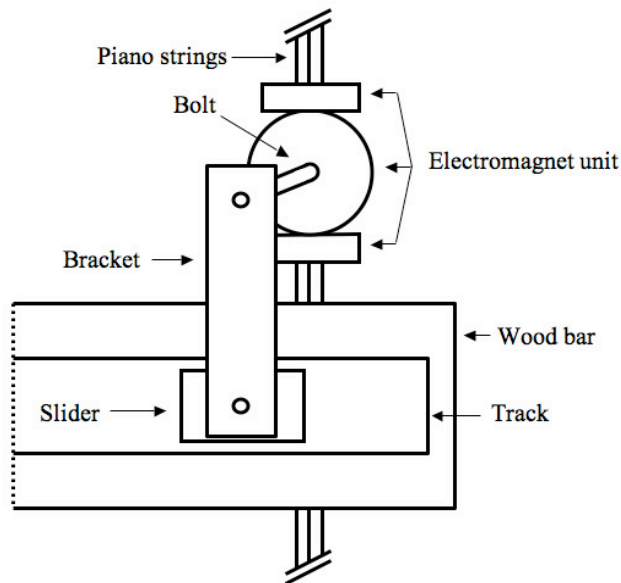
The use of resonant piano strings was first explored by the author in a piece for solo trumpet, entitled *Thingvellir* (2001). In this piece, the performer is instructed to play the trumpet into a microphone which feeds a loudspeaker placed beneath a grand piano. If the damper pedal on the piano is held down, the strings then resonate sympathetically with the projected sound of the trumpet. In addition, the piano itself is amplified in order to provide a better balance between the resonating strings and the acoustic trumpet. A similar approach is taken by Luciano Berio in his piece *Sequenza X* (1984), also for trumpet, in which the performer is periodically required to blast notes into a piano while another performer holds down specified keys. *Thingvellir* focuses more directly on the resonant potential of the strings in that the entire first half of the piece is performed into the piano, and all the strings are free to resonate.

After initial experiments with *Thingvellir*, the desire for more direct control over the vibrating string led to the idea of incorporating electromagnets. The author, Steven Backer, and Ed Berdahl, both of CCRMA, began the design process in the early months of 2005. One of the first decisions involved the number of electromagnets to build. Though full coverage of the piano had its appeal, the creation of eighty-eight individual electromagnets was deemed both unrealistic and unnecessary. It became clear that twelve would be sufficient, thus allowing for full coverage of the chromatic scale should that be desired.

### 4. Description

#### 4.1 Physical Description

The twelve electromagnets are attached to a rack that is secured to the piano frame, and each electromagnet is positioned directly over the two or three strings that constitute a single pitch. The rack is made from a wooden bar to which is attached a metal track, allowing the position of each electromagnet to be adjusted across the full width of the piano. Each electromagnet has a bolt screwed into it, the other end of which is attached to a bracket which is extended over the strings. The bracket is attached to a slider, allowing for lateral adjustment of the electromagnet's position (see Figures 1 and 2). Such an arrangement allows for a great deal of flexibility in the positioning of the units, a characteristic required by the variability of piano frames and string positioning. The system also allows the composer to place the electromagnets above any twelve strings, though it remains impractical to reposition the electromagnets during a performance. Finally, each electromagnet unit consists of two permanent bar magnets glued in a specific arrangement to the actual electromagnet.



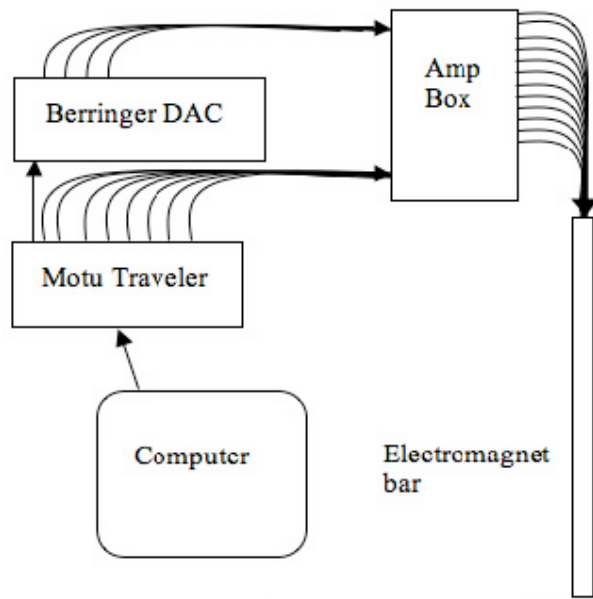
**Figure 1.** Diagram of an electromagnet suspended over piano strings



**Figure 2.** Electromagnets in a grand piano

Unlike an EBow, the electromagnets may be sent any audio signal, including nonpitched, even percussive sounds. This signal can originate from any source, though one capable of outputting twelve independent signals is obviously preferred. In our case, the software of choice has so far been Max/MSP. Whatever the audio source, it is passed through twelve small amplifiers contained in a single box before reaching the electromagnets (see Figure 3)<sup>1</sup>. It is recognized that the use of more powerful components might yield higher volumes, though there would in turn be an increased risk of overheating. Overall, it is interesting to note that the system can be compared to a standard loudspeaker in that an electromagnet, acting on a moving body, is controlled by an audio signal.

<sup>1</sup> Exact specifications for the components used in this implementation, as well as additional information and example audio files, can be found at <http://ccrma.stanford.edu/%7Esbacker/empp/index.html>.



**Figure 3.** Signal flow for entire system

## 4.2 Aural Description

In addition to its own fundamental, any string can also be resonated quite effectively at any of its first ten or so partials, as well as at an occasional subharmonic. The use of sine tones as an audio source produces rather sinusoidal results. When filtered noise is used, the result is a shimmering active sound that is quite attractive. However, the capabilities of the electromagnets are by no means restricted to the overtone series of the strings. Though the resultant sound tends to be louder when its pitch corresponds to one or more of the string's available partials, any sound is capable of being reproduced. For example it is possible to create glissandos, though as the audio signal sweeps through the lower partials the volume tends to suddenly peak then recede. Sweeping through the higher partials creates a much more accurate and dynamically even result. Sharp attacks are possible to some degree, though they tend to be softened by the lowpass characteristics of the physical system.

Of course it is also possible to send a single audio signal to all twelve electromagnets. If they are arrayed over a wide enough variety of pitch classes, all twelve being ideal, any sound can be reproduced. Indeed in Backer's piece, *Future Returns*, a human voice has even been rendered intelligibly. If the damper pedal is down and the strings free to resonate in such a situation, the resultant timbres are highly colored by the pitches of the strings. However if the damper pedal is left up, the sound retains much of its original qualities. It is in this situation that the voice becomes distinctly intelligible, though much less audible due to the dampers.

## 5. Compositional Implications

The simplest application of the device is as a straightforward augmentation of the piano's capabilities, without significant modification of its timbre. Through the use of electromagnets, it is possible to imbue the piano with capabilities formerly associated with stringed instruments, such as infinite sustain and the ability to vary dynamics throughout the duration of a note. One can easily imagine a Disklavier connected to a computer, which in turn controls some number of electromagnets. If that number were less than eighty-eight, the computer would determine how best to achieve the received midi pitch, either by resonating

the struck string at its fundamental if that string happens to be covered by an electromagnet, or by choosing a different string based on its available partials. A foot pedal might control the amplitude of the signal sent to the electromagnet, allowing for previously unavailable dynamic control such the crescendo of a single note. As noted earlier, the use of sine tones to drive the electromagnets would not yield the most convincing results. A better source would be the sound of a piano, either sampled or synthesized.

As soon as non-pianistic timbres are introduced into the electromagnets, however, the sonic results immediately appear to stray from the acoustic realm. Of course all the sounds are in fact strictly acoustic, emanating only from the piano strings, but the timbres are highly evocative of synthesized sounds. This later characteristic raises some interesting issues for the composer. Given the physical restrictions inherent in such a system, the question arises: are these restrictions worth the struggle in order to keep sound generation within the acoustic domain? A basic premise is of course that by doing so, a richness and presence of sound will be perceived by the listener.

One aspect of this richness is likely related to radiation patterns. Loudspeakers have several disadvantages when compared to acoustic instruments, the most obvious being their directionality. In addition, the polar radiation patterns of acoustic sounds vary a great deal with frequency, a characteristic not shared by most loudspeakers [5]. As a result, it is often quite difficult compositionally to achieve a satisfying integration of acoustic instruments and diffused electronic sounds, a problem that is solved by the device.

But perhaps there is more to such a system than mere sonic quality. The very act of exerting control over an acoustic instrument has fundamental implications. In this case that control is exerted through an electronic intermediary, but there is yet a sense of immediacy created in the interaction. In the context of a performance, this leads to an interesting challenge as a composer – the desire to "prove" that one's sounds are authentically acoustic, and not the result of digital synthesis. The issue is further compounded by the fact that the acoustic strings are responding to electronic stimuli. In effect, the piano strings act as a physical filter for synthesized sounds, both attenuating and coloring with the sonic quality of the piano.

Indeed the distinction between electronic and acoustic origination of sounds begins to blur. No one would dispute that a synthesized sound emanating from a loudspeaker was electronic, just as the act of striking a piano string is undeniably acoustic. But when the system is altered such that a piano string is vibrating rather than a speaker cone, are the results in fact acoustic even if initiated by synthesized sounds? What if the electromagnets were driving a metal sheet instead of a metal wire? Or for that matter, what of Lucier's *Music on a Long Thin Wire*? If we consider any of these acoustic, then we must concede that the source of the sound is less significant than the method of its diffusion. It should also be noted that there is an inherent functional difference between the two methods under consideration in that instruments are designed to declare their signature color, while most loudspeakers are designed to act as uncolored conduits. But perhaps these distinctions become irrelevant at this point, and we may simply approach such an instrument as a hybrid of the two.

## 6. Compositional Applications

With the stings damped, the device is capable of remarkably accurate sound reproduction. However, even were this more audible, exact replication of an audio signal is much better accomplished through the use of a loudspeaker. In fact it is the quality of the undamped strings that is sought. And yet the fact that this same quality is imparted to all sounds as they

pass through the strings becomes a major constraint. There is variety, but it is limited. Of course this is also true to some degree of all acoustic musical instruments.

The number of available pitches, though fairly wide when overtones are utilized, provides another compositional limitation. Other limitations include attack time and overall volume. In general, the sound quality tends to be ethereal and understated, making aggressive gestures nearly impossible. Indeed working within these limitations has proven an interesting compositional challenge, especially for a composer who's music generally does not match the above description.

Three compositions have thus far been composed for the device, two by the author, described below, and *Future Returns* (2005), by Steven Backer. In each case, Max/MSP was utilized to control the electromagnets.

### 6.1 Elsewhere is a Negative Mirror, Part I

The first of these compositions, *Elsewhere is a Negative Mirror, Part I* (2005) for solo piano with electromagnets, was composed concurrently with the device's creation. Much of its functionality was at that time speculation, an interesting situation for a composer. The piece involves a performer with a traditional score, playing a Disklavier which is used to control the software. Given the generally ethereal sound world of the electromagnets, it was decided that they would be responsible for a "supertheme", a layer of sound potentially detached from the player's activities at the keyboard. For this layer, based on initial experiments with the electromagnets, four types of musical gestures were identified: a) single pitches in counterpoint, b) pulsing chords, c) chords that grow pitch-by-pitch (essentially creating arpeggios), and d) chords whose constituent parts gliss between pitches.

During the course of the piece the electromagnets progress through these material types in the order given above. The piano part progresses through them as well, though not in a linear fashion. Material types are recycled, each subsequent repetition having a shorter duration. The piece begins with the performer and the electromagnets playing the same material type. However the performer moves on well before the electromagnets, and the two layers are only periodically in sync from that point forward. This results in a sense of unity at the beginning which is gradually broken down throughout the piece until by the end the layers are distinctly separate and unrelated. In addition, the role of the performer gradually increases in significance, at the end essentially drowning out the electromagnets. In the last segment of the piece, the electromagnets lie dormant while the player, reaching into the piano, physically manipulates the strings.

### 6.2 Negative Mirror, Part II

*Negative Mirror, Part II* (2006, revised 2007) takes a similar approach with an opposite trajectory. This second installment of the series utilizes a larger group of instruments, including flute, clarinet, violin, violoncello, percussion, and piano with electromagnets. After an initial introductory sounding, the electromagnets are inactive for the first section of the piece, which is essentially an orchestration of the last section of *Elsewhere*.... Once the electromagnets do enter they are mostly chordal, again creating a framework against which the instruments move. At first the chords are fairly stable, but soon the pitches controlling the electromagnets begin to fluctuate very slightly above and below the string's partials. This has a number of interesting effects on the sonic quality. The most prominent is its effect on dynamics: as the pitch received by the electromagnet sweeps over the string partial, the volume peaks and then recedes as the pitch travels on. In addition, the sounding pitch does

indeed fluctuate, bending very slightly above and below the partial. And finally, the timbre shifts throughout the course of the sweep as various overtones become more or less prominent. This pitch fluctuation is controlled by a random walk of variable speed. A very rapid walk is used initially, resulting in a shimmering and somewhat indistinct sound. As the walk slows, a delicate timbre emerges defined by various extraneous partials fading in and out, punctuated by chordal blooms.

Initially there is little harmonic blending between the instruments and the electromagnets. As the piece progresses, however, the instruments are slowly drawn into the world of the electromagnets, until finally the entire ensemble is completely subsumed within them. To achieve this last effect, a prerecorded segment from earlier in the piece is played through all twelve electromagnets, resulting in a quiet yet recognizable blend of the two elements.

## 7. Conclusion and Areas for Further Exploration

There is yet much potential in exploring the timbral results that additional preparation might yield. Though the electromagnets are capable of creating a variety of timbres as they interact with piano strings, including ones that might be described as menacing, they do not lend themselves to particularly aggressive sounds. In addition, when the strings are undamped and thus free to resonate, noise components tend to be greatly overshadowed by pitched sounds. By placing additional materials on the strings, perhaps calling on a performer to touch items to the strings as they ring, the timbral possibilities could be greatly expanded. This would result in a much louder and certainly more aggressive sound, with a much higher noise content.

Overall, the use of such a hybrid instrument has many wide-ranging compositional implications, a few of which have been touched on in this paper. As the device matures, these implications will continue to be revealed, both through abstract consideration and practical application.

## References

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