## Introduction to the Electromagnetically-Prepared Piano

The Electromagnetically-Prepared Piano (EMPP) allows for direct control of piano strings through the use of an array of electromagnets. It was developed several years ago at Stanford University's Center for Computer Research in Music and Acoustics (CCRMA) as a collaboration between myself and two engineers, Steven Backer and Edgar Berdahl. The device consists of a rack of twelve electromagnets which is placed over a piano frame, each electromagnet positioned over a string. By design it is flexible enough to accommodate any model and size grand piano. This device differs significantly from other instruments based on similar principles in that each electromagnet is controlled by an arbitrary external audio signal. This signal might consist of non-pitched, or even percussive sounds, resulting in much greater variety and a higher degree of control over both pitch and timbre. In addition to its own fundamental, any string can be excited quite effectively at any of its first fifteen or so partials. It is possible to create glissandos, sharp attacks, and evolving timbres. A particularly unique quality is obtained by sending a single audio file through all twelve electromagnets simultaneously. The extraordinary sonic results of the system are surprisingly synthetic in timbre, though the sound is entirely acoustic, emanating solely from the piano strings.

The system is capable of receiving a signal from any audio source, making it quite flexible. However, if one wishes to control each of the twelve electromagnets independently, a system capable of multi-channel output is obviously required. I have thus far relied on Max to generate these twelve discrete signals, which then run out a standard audio interface into the EMPP's audio inputs.

## Proposal Summary

Building on my research and compositional activity involving the EMPP, I propose to work primarily with the Instrumental Acoustics Team to develop a physical model of the coupling between a resonator (initially a piano string) and an electromagnet. After an initial exploratory phase, this coupling would then be implemented in Modalys. Such an implementation has three primary functions: 1) as a sound source in its own right, capable of generating interesting and unusual sonorities, 2) to facilitate research on string properties under the influence of alternate sources of excitation, or more specifically on the effects of electromagnets on strings, and 3) to allow for ease of testing, experimentation, and composition with the Electromagnetically-Prepared Piano without need of its physical presence. During this residency the EMPP will be on hand and available for experimentation. In addition, I plan to offer full access to the device, as well as my support, to anyone who wishes to explore its capabilities for compositional or research purposes.

I propose to focus initially on the coupling between a piano string and an electromagnet, working with physical modeling researchers and the Instrument Acoustics Team in general. This is an obvious starting point due to the presence of the EMPP for testing and validation purposes, and because of the sophistication of current physical models of piano strings. Once a satisfactory model of this type of coupling has been established, I further propose to extend the research to include other types of resonators, either already existing as part of Modalys or gathered for this purpose. Finally, because I have a great interest in real-time musical interaction, I would hope to incorporate this model into modalys~. This aspect is especially appealing in that it would provide an opportunity to work with additional teams, including the Analysis-Synthesis Team and the Real-Time Musical Interactions Team.

**Project Motivation**

Since the debut of the EMPP in 2005, I have been continually amazed by the intensely positive reactions listeners have expressed to the timbral characteristics of the device. This has led me to attempt to develop similar sounds through software, relying mostly on the implementation in Max of the Karplus-Strong algorithm with a number of its various extensions. While my results have been interesting in their own right, they certainly have not come close to emulating the sound of an electromagnet in a piano. The ability to approximate these timbral characteristics though software would, I believe, be a most welcome addition to the available sonic palate.

In addition, this project draws on a compelling characteristic of physical modeling – the expanded sonic possibilities available when control parameters are detached from the physical restraints of the hardware system. Electromagnetically exciting the spans of the Golden Gate Bridge, for example, would be quite an interesting aural experiment! Applying the model to a variety of types of resonators would provide additional fertile ground for sonic and compositional investigation.

Finally, as I have presented concerts and lectures about the EMPP, an increasing number of composers have expressed interest in composing for it. Since the device is unique, there is currently no way to experiment with its capabilities without it being physically present. The implementation of a physical model of the system would act as a compositional aid for anyone not currently in the presence of the device.

**Detailed Description**

Though any number of studies have looked at the effects of electromagnets on metal strings, in my research I have not come across an adequate physical model of the specific interaction here proposed. Edgar Berdahl and Steven Backer's "If I Had A Hammer: Design and Theory of an Electromagnetically-Prepared Piano" (*Proceedings of the 2005 International Computer Music Conference*, Barcelona, Spain) summarizes research conducted during construction of the EMPP, and in fact includes a plan for a simplified virtual physical model of the system. Andrew McPherson and Youngmoo Kim's "Augmenting the Acoustic Piano with Electromagnetic String Actuation and Continuous Key Position Sensing" (*Proceedings of the 2010 International Conference on New Interfaces for Musical Expression*, Sydney, Australia) describes a more practical approach to creating a physical system, outlining a device that relies on feedback similar in design to an Ebow. Nicholas G. Horton and Thomas R. Moore, in "Modeling the Magnetic Pickup of an Electric Guitar" (*American Journal of Physics*, Volume 77, Issue

2, pp. 144-150, 2009), do describe a simple physical model, but it explores the more common pathway of a pickup's response to the vibration of a string. There is clearly a rich field of research on which to draw that describes systems *similar* to the one I propose.

A potential challenge to the design of this model involves the presence of non-linear response characteristics inherent in the interactions between electromagnets and metal strings. However, as has been demonstrated by Berdahl and Backer, the presence of a permanent magnet can magnetically saturate the string, moving the response pattern into an approximately linear area. In addition to maintaining the linearity of the system, this magnetization of the string allows it to be both pushed and pulled on by the electromagnet. It is assumed that this magnetization of the string would be incorporated into the model as well.

An example of a specific line of inquiry for which this physical model might prove useful involves the location of the electromagnet along the length of the string. This has a significant effect on the resulting sound, yet is quite difficult to predict (adjusting for location of nodes and varying amount of string displacement). It is also impractical to test given the requirement that the electromagnet be re-anchored at each new location for experimentation to occur, and the fact that many locations on the string are inaccessible due to piano hardware. Further analysis of the effect of location would greatly increase ease of setup, and could provide interesting information about the acoustic properties of piano strings.

The parameters of the physical model of this coupling would include air gap (distance of the electromagnet from the string), location of the electromagnet along the length of the string, strength and width of the electromagnet, strength of the permanent magnet, and the signal sent to the modeled electromagnet. Ideally this signal would be obtained from a source external to the modeling software, though the use of an audio file would also be effective. Of course all the standard variables of a piano string would come into play as well.

During work on this project I envision the Instrumental Acoustics Team being my primary collaborators. Joël Bensoam, with whom I have been in communication, has expressed interest in such an enhancement for Modalys. The possibilities for conducting experiments with both the physical model and the physical device would also potentially be of interest to those working to improve traditional instrument-making techniques. The final phase, in which the new coupling model was incorporated into modalys~, would presumably involve members of the Analysis/Synthesis and Real-Time Musical Interactions Teams as well.

In addition, during each phase of the project I plan to be continuing my own compositional work, incorporating new aspects of the project as they develop. I hope that such real-world application of the technology will help guide its development, ensuring its usability and relevance beyond my own residency.