EMdrum: An Electromagnetically Actuated Drum

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ABSTRACT

The EMdrum, a drum electromagnetically actuated in the manner of a loudspeaker, is presented. Design principles are established and implementation is described; in particular, two alternative electromagnetic actuation designs, *moving-coil* and *moving-magnet*, are discussed. We evaluate the time-frequency response of the instrument and present a musical application.

Keywords

EMdrum, actuated, drum, speaker, electromagnetic

1. OVERVIEW

Acoustic musical instruments extended via electromechanical means have attracted considerable interest from researchers and composers in recent years, notably [10, 12]. The electromechanical actuation of drum membranes would seem to offer particularly interesting sonic possibilities, very distinct from those of other types of actuated instruments and from the possibilities afforded by simply striking or rubbing a drum membrane. However, such possibilities have not been widely explored. We here present the "EMdrum", a design in which drum membranes are actuated in the same manner as a loudspeaker cone. First we overview the artistic history of membrane actuation and electromagnetic actuators. We then present the design principles and implementation choices used to create the present instrument. Finally, we evaluate the time-frequency response of the drum using a synthesized frequency sweep and describe a composition written for live performer and EMdrum.

2. BACKGROUND

Actuation of general acoustic resonating surfaces has been ably explored. Electronic audio effects applied to physical instruments can be first attributed to David Tudor's *Rainforest* [5], where the composer applied piezoelectric contacts to instruments to both amplify and generate sound. More recently, the motion of a vibrating string was modified using electronic processing [3].

Electronic extensions of acoustic drums have included automated striking mechanisms ("robot drumming" [7]) and voltage-based modification of drum head tension [6]. Electroacoustic pseudo-drums have also been created, notably the "Haptic Drum" [1], in which a rigid surface is adhered to a loudspeaker cone and fed with a microphone signal such that when struck it generates "haptic" (i.e. tactile) feedback to the percussionist. Much of the other research in the area of drums and electronics involves *controllers* rather than *instruments* (e.g. [11]).

Figure 1: The EMdrum with bass clarinetist Heather Roche.

Many acoustic-electronic hybrid musical instruments that have emerged in recent years use electromagnetic (EM) actuators. This technology was first applied to the actuation of piano keys [8], but more recently EM actuators were proposed as a means of generating sound directly from ferromagnetic piano strings [2, 10, 9], and even more recently to actuate the metal bars of a vibraphone (the EMvibe, namesake of the current design [4]).

One advantage afforded by EM actuation over mechanical methods is the straightforward translation between continuous voltage fluctuations inputted to an EM actuator and the physical motion it outputs, modified solely by the idiosyncrasies of the actuator and instrument. The input and output of this technology may thus be considered fundamentally of the *same kind*, and indeed the technology for EM actuators is inherent in both loudspeaker design and dynamic microphone design. The EMdrum attempts to exploit the creative possibilities thereby suggested.

3. MOTIVATION

The design of an actuated instrument might be formulated as responses to three questions. First, what will be the **acoustic properties** of the instrument, *distinct* from its

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mechanism of actuation? Second, what will be the **mechanism of actuation** and its contribution to the sonic properties of the instrument? Third, what should characterize the **input signals** to the actuator?

The motivation behind the EMdrum was to create an actuated drum offering the *broadest potential* for artistic use; we thus focused on two objectives: a) adding a versatile means of electromagnetic actuation to a drum while b) maximally retaining the acoustic properties of the unmodified drum. That is, the mechanism of actuation and the manner of input were designed so as to most strikingly *explore* a drum's natural acoustics without *constraining* them.

4. DESIGN

4.1 Maintaining Natural Acoustics

Two components define the acoustics of a drum: the shell and the membrane(s). Two components also define an electromagnetic actuator: a heavy stationary component (e.g., the magnet assembly in a moving-coil design, discussed in section 5.2.1) and a lightweight moving component (e.g. the coil). In the EMdrum a stationary actuator component is mounted to the shell, while the corresponding moving actuator component is mounted to both membranes.

Both mountings require careful design if they are to minimize disruption of the drum's acoustics. We identify three **design imperatives** for maintaining these acoustics. First, the moving and stationary components of the actuator must never touch. Second, dampening of the drum membranes by the actuator (due to fluid resistance, mass of the moving component, etc.) must be minimized. Third, modifications to the drum shell must not greatly impinge on its natural resonances. These three imperatives circumscribe all subsequent design choices.

4.2 Mechanism of Actuation

A mallet actuates a drum membrane by striking perpendicular to it. A speaker coil actuates a speaker cone by applying a time-varying force perpendicular to it. The EMdrum uses the latter method to accomplish the former task.

There are two primary ways a loudspeaker actuator may be implemented. In a *moving-coil design*, the speaker cone is attached to a *bobbin* around which wire is coiled and connected to external leads. This bobbin is free to move along a stationary magnetized *pole piece*. Current sent through the coil thus causes it to move relative to the magnetic field in accordance with electromagnetic induction. Present day moving-coil designs offer highly linear frequency response, and their wide availability and economy make the moving-coil design an ideal actuating mechanism.

A *moving-magnet design* is precisely the inverse of a moving-coil design. A heavy duty coil is the stationary component and a lightweight magnet or assembly of magnets is the moving component. Alternating current sent through the coil thus generates a changing magnetic field that alternately opposes or attracts the magnets, causing their movement. This design permits the creation of variable magnetic fields, with points of stability and instability, through unusual arrangements of individual magnets on the moving component. The response can thus be highly idiosyncratic, offering creative possibilities difficult to achieve with a moving-coil design.

4.3 Input Signals

In its simplest use, the drum requires no interface aside from an audio cable. External signals may be inputted to an amplifier driving the actuator coil, and thereby "convolved" with the character of the actuator and drum. This will yield useful musical results for certain classes of external signals, to be discovered through experimentation. However, the instrument can be made more versatile, and its character perhaps more thoroughly explored, by integrating a feedback mechanism into the instrument.

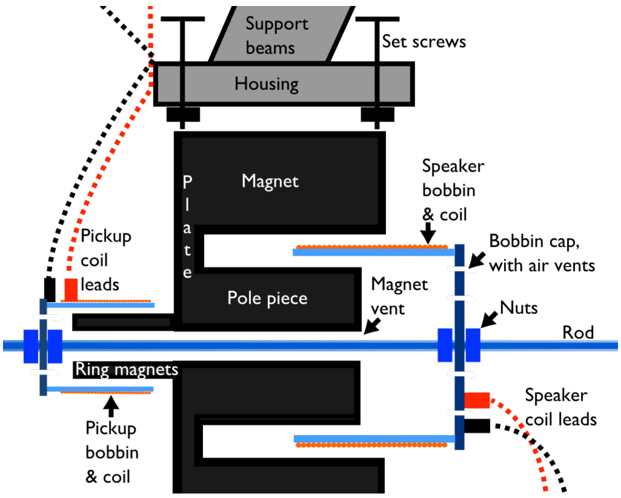

Figure 2: Moving-coil implementation, close detail

Our design couples a pickup coil and magnet (the essential components of a dynamic microphone) to the actuator coil and magnet, respectively. The pickup components resemble those of the actuator but operate in reverse: while (for moving-coil designs) a current *sent* through the actuator coil *causes it to move* relative to a magnetic field, *movement* of a pickup coil relative to a magnetic field *induces a current* in the pickup coil. Coupling the pickup and actuator components in this way offers feedback possibilities distinctive to the instrument, as the pickup coil moves in sync and at zero lag relative to the drum membranes and thus the properties of the feedback are determined primarily by the internal dynamics of the instrument and not external factors. This contrasts with typical microphone-based feedback, the character of which is largely created by phase lags introduced by the microphone's physical distance from the source/output.

Positive feedback, one may imagine, would be predictable and uncontrollable in the present system. Negative feedback – achieved by reversing the polarity of the pickup coil leads relative to the actuator coil leads, such that the pickup outputs to the amplifier a signal that opposes the movement of the actuator coil – can however generate unusual, even chaotic oscillatory responses via hysteresis (delayed response) effects. The EMdrum uses a negative feedback circuit; the achievable effects are described further in section 6.3.

5. IMPLEMENTATION

5.1 Acoustics

A circa-1930 Leedy bass drum shell of diameter 28" and depth 14" was obtained. A frame composed of 0.75" x 2.5" pine boards was constructed and installed on the interior of the drum shell to permit rigid mounting of the stationary component of the actuator. Eight ***set screws*** were added to a ***center housing*** (a square inner frame six inches on end); the stationary actuating component would contact the frame only at the tips of these eight screws. Calibration of these screws allows precise translation and rotation of the stationary actuating component, necessary to ensure that the moving and stationary actuator components do not come into contact, while nevetheless maintaining the narrow clearances between them necessary for efficient actuation.

5.2 Mechanism of Actuation

5.2.1 *Moving-coil implementation*

(Consult Figure 2 for this section.) The voice coil of a Bowers and Wilkins ASW608 subwoofer was obtained. Its speaker cone and "spider" were removed. Two now-separated components remained: the ***magnet assembly*** (composed of a magnet, plate, and vented pole piece, attached securely together) and the bobbin/coil assembly. A rigid aluminum cap was secured with epoxy to one end of the bobbin cylinder. A hole was drilled in the precise center of this cap. Through this hole, an 8-32 stainless steel threaded rod was inserted, and two lock nuts were used to secure the bobbin to the rod (henceforth the ***bobbin/rod assembly***).

The magnet assembly was placed in the frame's center housing, and the set screws were adjusted until the magnet axis aligned perfectly with the central axis of the drum shell. The bobbin/rod assembly was then placed over the magnet assembly and the coil leads were wired to an amplifier (discussed in section 5.4). Drum membranes were then placed on the drum shell and holes were drilled in their precise centers. Two lock nuts and washers were then used on each membrane to couple it to the bobbin/rod assembly.

5.2.2 *Moving-magnet implementation*

A 10 mH 18 AWG air core inductor (i.e. coil) was secured in the center housing. A set of N48-strength ring magnets, of outer diameter 0.5", inner diameter 0.25", and thickness 0.25", were obtained. A 0.25" diameter carbon fiber rod was also obtained, and several of the ring magnets were fitted over the middle of the rod (in an arrangement described below) and secured into place via pins through drilled holes. Threaded aluminum nuts were then epoxied to both ends of the rod, such that screws could be used to couple the drum membranes to the rod. The rod was then inserted through the inductor and secured to the membranes, and the leads of the inductor were attached to the amplifier.

In the magnet arrangement used here, two ring magnets facing opposite directions (thus resisting each other's fields) were placed so that in the equilibrium position they rested at either edge of the inductor. This arrangement was chosen after experimentation because it appeared to produce the most efficient actuation for a given total magnet mass.

5.3 Pickup/Feedback

A 600 Ohm pickup coil was created by winding 500 feet of 42 AWG enameled copper wire around a short 0.75" diameter plastic tube using a sewing machine's bobbin winder. This coil was placed either on the rod (in the moving-coil design) or on the frame (in the moving-magnet design), along the axis of the actuator coil. This pickup outputted its signal to both a) an external jack (allowing the drum to function as a figure-8 microphone) and b) the system's amplifier, in reversed-polarity configuration, by way of an external gain knob (see Figure 3).

In the moving-coil implementation (Figure 2), several ring magnets identical to those described in section 5.2.2 were secured onto the speaker's magnet assembly such that the bobbin would move alongside them, parallel to their field, as it was stirred to motion by either the actuator coil or external blows to the drum membranes. In the moving-magnet implementation, the coil was secured in the same manner as the actuator coil, and additional ring magnets were then placed on the rod relative to the pickup coil in the arrangement described in section 5.2.2.

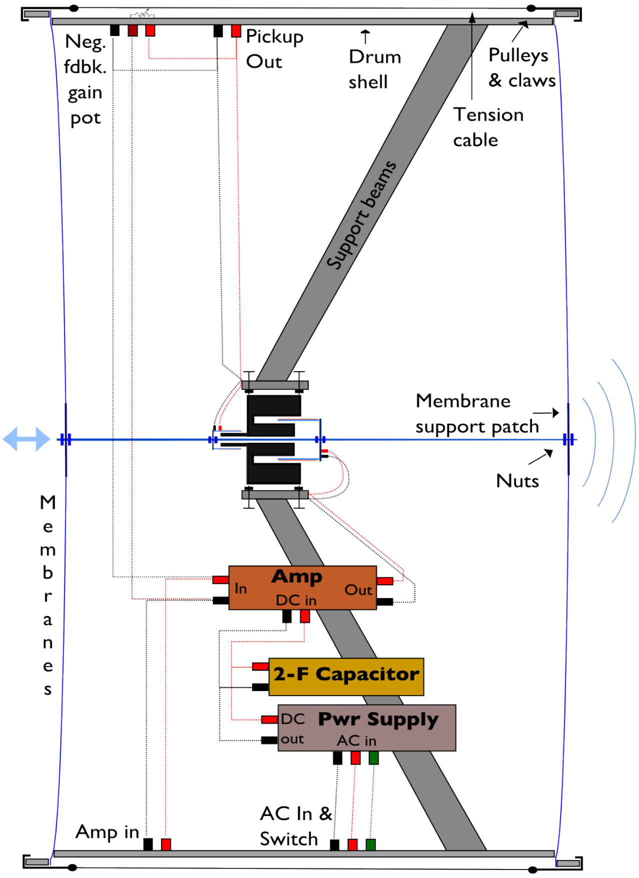

Figure 3: Moving-coil implementation, complete

5.4 Supporting Hardware

For maximum portability, a Boss AR1500M audio amplifier and 12V 30A DC power supply were integrated inside the drum shell. A 1/4" TS input jack was installed on the shell to access the amplifier input. For improved performance, a 2-Farad capacitor was wired in parallel between the DC power supply and the amplifier to prevent dynamic compression or clipping during extreme transients.

6. EVALUATION AND DISCUSSION

6.1 Time-Frequency Response

To test the frequency response and resonance characteristics of the instrument, we synthesized a 30 second frequency sweep (chirp) from 1Hz to 20kHz and played it back through the drum at a moderate volume. We then recorded the live output of the instrument in a research studio using an Earthworks QTC50 microphone one meter away. Figure 4 shows a comparison between two spectrograms: the frequency response of the actuated drum (top), and the "ideal" response from the synthesized frequency sweep (bottom).

It is evident from these spectrograms that the frequency response is heavily "colored" by resonances from the drum, as one would expect. Notably, at low frequencies, between $3 - 25$Hz, the actuator produces distinguishable impulses that have the character of typical mallet strikes to the drum. Source frequencies beyond 250Hz begin to "use" the drum more as an acoustic space, with harmonics emerging as distinguishable resonances.

6.2 Musical Application

The first composition for the EMdrum was *Hot Mess* featuring solo bass clarinet [13]. Throughout the work the

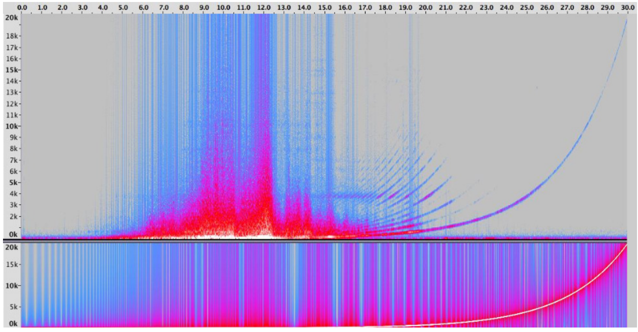

Figure 4: Comparison between drum response (top spectrogram), and source test (bottom spectrogram) consisting of a 30 second Frequency Chirp from 1Hz to 20kHz.

performer “plays” the drum using a microphone inputted to the drum in one of two ways. First, the performer may tap the microphone stand to produce a kick drum-like response. Second, the performer plays into the drum, using it as a resonator.

One observes in Figure 4 the particular broad responsiveness of the EMdrum to low to low-mid frequencies, while higher frequencies provoke more sparse, unpredictable responses. This character is well suited to exploration by the bass clarinet. Of particularly note is the EMdrum’s coloration of multiphonics, or multiple overtones, from the bass clarinet, which at times also produced sub-harmonics in the drum.

The signal requires no other processing than amplification of the signal within the drum. The sound thus becomes an acoustic hybrid of the bass clarinet and bass drum, merged via electronics but without an electronic character.

6.3 Future Work

Two different sonic characters were achieved via the two experimental implementations attempted over the course of this project. The moving-coil design offers a smooth, fairly broad frequency response of the actuating mechanism, which we anticipated since the voice coil used was taken from a commercially developed speaker. This characteristic permits explorations of the high frequency response of the drum. Conversely, the moving-magnet design has a poor frequency response, rolling-off rapidly around 160 Hz. However, this design permits one to easily “customize” the dynamics of the actuator via unusual magnet arrangements on the rod; these may create unstable oscillation patterns that result in chaotically evolving feedback responses. Future work would profitably consider the feedback responses created by such magnet arrangements, as well as how the introduction of audio processing or mechanical performance on the drumheads into the feedback loop modifies these responses.

In addition, experimentation with special input signals tuned to the acoustic response of the instrument, as explored in [4], also deserves consideration. In particular, non-smooth input signals, such as half-wave rectified and intermittent signals, may provoke acoustic responses of the EMdrum not accessible with smooth signals.

7. CONCLUSION

We have presented the design and implementation of an internally actuated bass drum we call the EMdrum, and described its use. Our evaluation suggests that the instrument possesses an unusual character that is a hybrid of an acoustic and electroacoustic instrument. The primary challenge of implementing this design is to prevent noticeable disruption of the natural resonance of the drum membranes due to mechanical or fluid resistance of the actuating mechanism. Our implementation demonstrates that this is achievable with sufficient care in construction. Future artistic work using our implementation will consider how experimental alterations to the actuator mechanism and input characteristics interact with the acoustic response of the instrument.

8. ACKNOWLEDGMENTS

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