Experimental Design for Flexible Acoustic Transducer for the Violin

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Abstract. This paper explores an experimental design for a transducer which is able to conform to surfaces with curves in multiple directions. The purpose of this is to create a flexible transducer which reduces the distortion attributed and created by the lack of uniformity between a rigid flat transducer and a curved surface. Using an array of magnets arranged and a loose weaved coil, it is possible to construct a coil which can conform to such a surface and produce motion, like a classic transducer, creating sound using the surface like a speaker cone. In this musical application, this design was tested using a violin body as the curved surface. The resultant prototype may serve as a viable alternative to rigid transducer technology with further improvement and refinement.

Keywords. Actuator, Nano-Suction, Magnetism, Instruments.

1 Introduction

The focus of this research project was to solve a problem traditional transducer technology presents when interfacing with musical instruments with curved surfaces. The idea is to create a transducer which is able to conform to curved bodies, reducing discontinuities. Traditional transducer technology wraps a voice coil around a rigid cylindrical body and passes current through this voice coil in a magnetic field, generating alternating force and vibrations which then transmit energy to whatever medium is in contact with the transducer. The traditional technology is effective for flat surfaces such as walls, tables, and guitars, but presents problems when working with curved surfaces such as violin and cello bodies. With uneven curved surfaces, the rigid cylindrical body will be in contact with the surface in some areas and not in others, causing distortion from unwanted temporary contact against the surface from flexing and bending of both the rigid cylindrical body and potentially the applied surface itself causing distortion.
Transducers that are designed to adapt to curved surfaces are not common on the commercial market. There was a previous study [1] on a novel planar magnetic loudspeaker, which uses a similar design in that it uses a coil embedded into a flat surface, which allows it to bend around surfaces which curve in one dimension, and similarly oriented magnetic field to produce vibrations. The transducer described in this paper takes the concept a step further, beyond one dimension of curvature, by implementing a wound coil and multiple contact points producing multiple dimensions of flexibility. This

allows it to conform to more extreme curvatures, making it more useful for cavities with odd symmetries. This paper presents the electromagnetic theory behind this transducer, the method of design and construction, an evaluation of the frequency response, and a short discussion of the timbral implications of the frequency response.

2 Theory

A Generative Theory of Tonal Music (GTTM)

Modern transducer technology utilizes the Lorentz Force for current carrying wires as described by Eq 1 [2]

$$F_{mag} = \int (v \times B)\rho \, d\tau$$

Where F is the force on the flowing current, v is the current velocity, B is the magnetic field strength, and τ is the length of the flow. Simplifying by defining I as the product of v and ρ, and replacing τ with L as the length, this follows

$$F_{mag} = \int I \times B \, dL$$

This cross product, using the right hand rule, makes the orientation of the magnetic field B relative to the current direction I paramount for function. This current flows through the component known as the voice coil. Transducers consist of several components, among which are a magnetic core and voice coil. The voice coil is generally wrapped around a rigid cylinder, which is placed between two permanent magnets to ensure a strong uniform magnetic field as seen in Fig 1 (a).

This new proposed transducer design operates under the same principles, but with novel modifications. The voice coil is loose, meaning that it is not wound around a rigid structure, leaving it free to conform to a curved cavity. Consequently, a uniform magnetic field cannot be achieved by implementing a magnetic core, so rather than the voice coil being between two strong magnets, there is an array of strong magnets operating a distance away from the coil as seen in Fig 1 (b). The magnets are configured such that the same downward force is acting on the coil.

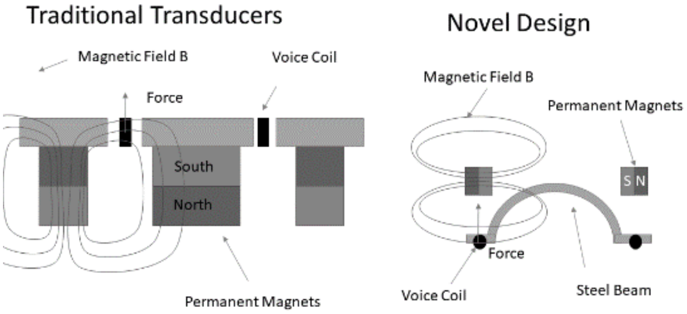

Fig. 1. Traditional Transducer Design (a) and Novel Transducer Design (b).

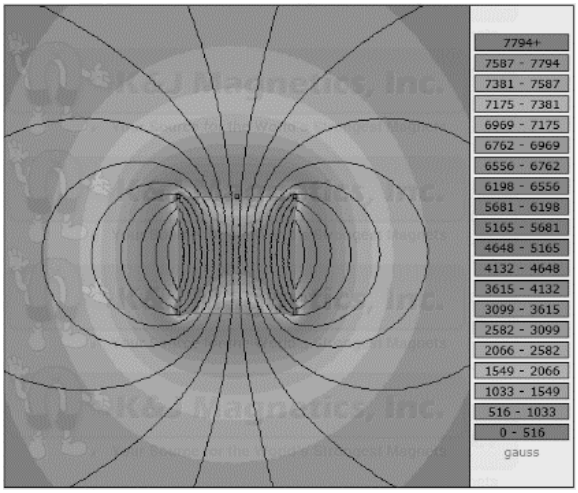

Fig. 2. Magnetic Field Strength of one N52 Magnet According to Manufacturer, Adapted from [3].

Optimizing Resistance and Power

The resistivity of the 36 AWG wire used for this coil is 1.36 Ω/m. The coil is optimized for 4 Ω, as this is a standard impedance and allows for interchanging amplifiers.

TABLE I: TRANSDUCER SPECIFICATIONS.

Wire Gauge	Wire Length	Resistance	Magnet Strength
36 AWG	2.94 m (1.47 m usable)	4 Ω	N52 (6 total)

The magnetic array is constructed such that half the total voice coil is usable due to manufacturing constraints. The magnetic field strength can be increased further by using more powerful permanent magnets or increasing the number of magnets beyond the six currently in use. Additionally, more wire length may be added by using a larger gauge or running multiple coils in parallel to reduce resistance at the cost of added weight.

In this prototype, one coil optimized for 4 Ω is used. The maximum power of the amplifier used is 20W, resulting in a current of ~2.24A. The lack of uniformity in distance to the magnet array requires an estimated range of magnetic field strength. From the manufacturer's specifications [3], the estimated field strength very close to the N52 magnets is approximately between 2000-3000 Gs or 0.2-0.3T which can be found in

Fig 2 [3]. With a current 2.24A rms, a field strength of 0.2-0.3T, and a total usable length of 1.47m, the resulting rms force is 0.659-0.989N.

3 Methods and Materials

The transducer coil is wound with 36 AWG laminated wire and held in tension by two curved steel beams acting as springs. From the steel beams, four contact points are formed and suspended by a nano suction "gecko" material. The gecko material is used as it is a reusable adhesive material which provides an impermanent setup. A magnetic field is created using an array of six N52 ½" magnetic cubes. The magnetic array is held externally and, for the purposes of this prototype, are not directly attached to the cavity. The arrangement is shown in Figure 3. The transducer coil is attached to the body, where the violin acts as the vibrating surface and as an acoustic cavity for amplification.

To test the sound emanating from the violin cavity during operation of the cavity, two tests are performed, one for the response of the violin/actuator system, and one for the impulse response of the violin itself. For the first test, a sine sweep is applied using the program EASERA with a Focusrite Scarlett 2i2 as the audio interface. The signal is recorded using a Beyerdynamic MM 1 Microphone. The bottom of the violin is held above the ground using a cut cardboard box to make room for the magnet array. The magnetic array is placed on the ground under the violin, ¼" from the transducer coil. The results of the testing are the impulse response and the frequency response of the violin/transducer system Fig 3. The complete setup for the frequency sweep is shown in Fig 4 and the impulse response in Fig 5.

The second test is roughly based on the violin impulse response method described in [4]. For the second test, the test violin is suspended at the neck and chinrest. The bridge is then struck by an allen wrench and a 1/8" metal rod in two independent tests. The responses are then recorded using audacity and the same microphone setup from the first test, where the microphone is pointed directly above the bridge.

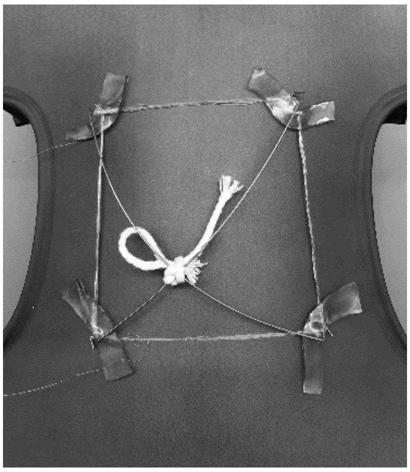

Fig. 3. Violin Transducer System.

Fig. 4. Impulse Response Setup.

Fig. 5. Frequency Sweep Setup.

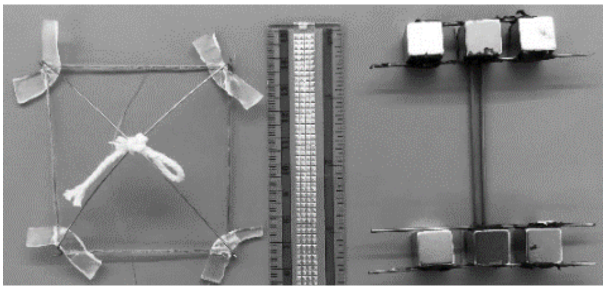

Fig. 6. Transducer (L) Mag. Array (R).

4 Results and Conclusions

Using a sine wave sweep through EASERA, the following frequency response was recorded Fig 7.

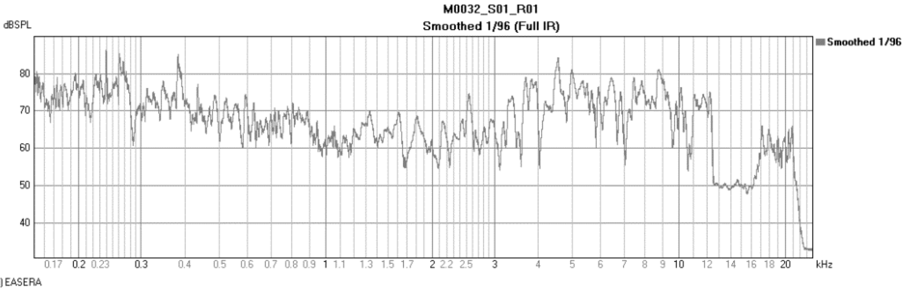

Fig. 7. Frequency Response of Violin Transducer System.

The impulse response was imported into MATLAB, where the data from the strike on the bridge was isolated and a fast Fourier transform was applied. Then the data was smoothed using the movement () function and a sample size of 300 data points. The results are shown in Fig 8.

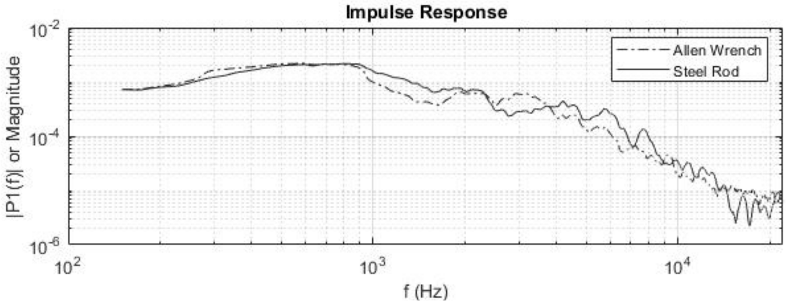

Fig. 8. Impulse Response of Violin (150 Hz - 20 kHz).

The range of 150 Hz – 20 kHz was selected as this is the operating frequency range of a violin. Relevant frequencies are generally operating at 55-85 dB SPL with a significant dip in the mid-range frequencies (1 kHz – 4 kHz) of around 10 dB. When accounting for the impulse response of the violin, it becomes clear that this is primarily due to transducer performance as the violin is most active in the range of 150 Hz – 5 kHz.

Subjectively, this transducer/violin system had a bright signature when playing a variety of different music genres. The low frequency range (150 Hz – 1 kHz) was punchy but weak, the midrange was often hard to discern in faster passages, which may be attributed to the dip in sound pressure levels in the corresponding mid-range frequencies. Overall this prototype was entirely audible at a distance though not loud. Further development will increase efficiency and raise the overall volume of this transducer.

While the high frequencies were the loudest and most audible both in the pulse response test and subjective listening, in the subjective test it is still significantly distorted. This may be attributed to possibly due to insufficient tension in the steel beams. Thicker steel beams would increase tension for the same length. The mid-range, around 1 kHz – 4 kHz, are quieter than expected.

This design addresses that problem of conformity, with a few drawbacks. The magnetic array used to construct this design is positioned an inconsistent distance away from the coil, which makes the magnetic field at the coil inconsistent along its length. The second drawback is that, due to the flexible nature of this transducer design, there should be significant power loss due to the low rigidity and friction caused by a looser coil.

5 Future of this Project

Some goals for the future of this project are to smooth out the frequency response curve and create a more natural signature which will resemble a violin or other instruments more accurately. Potential changes of wire gauge could be optimized around current density. Furthermore, mounting the magnet array onto the body of the acoustic cavity should increase bass response and improve portability. Using specialized bar magnets, rather than an array of cube magnets, should increase the stability of the array and improve power output as well.

The musical goal of this project is to use this transducer with instruments in electronic music compositions, creating new ways for composers to implement sonic effects in performances, such as emanating violin type of sounds out of a violin alongside the sound of the performer's playing. Although this prototype is centered around the violin, this prototype could be adapted to fit on other instruments with acoustic cavities, due to its ability to adapt around curved surfaces. Future adaptations will focus on building a frequency response that has a more neutral response for the purpose of swapping this transducer between a large variety of instruments. This prototype shows the concept and the feasibility of using this configuration of loudspeaker technology to extend transducer technology for musical applications.

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