An electroacoustically controlled vibrating plate

Mark Kahrs, David Skulina, Stefan Bilbao, Murray Campbell
Acoustics and Fluid Dynamics Group, School of Physics
Univ. of Edinburgh
Edinburgh, UK
mark.kahrs@gmail.com, dskulina@ph.ed.ac.uk, Stefan.Bilbao@ed.ac.uk, dmc@ph.ed.ac.uk

Abstract

Large vibrating plates are used as thunder sheets in orchestras. We have extended the use of flat plates by cementing a flat panel electroacoustic transducer on a large brass sheet. Because of the thickness of the panel, the output is subject to nonlinear distortion. When combined with a real-time input and signal processing algorithm, the active brass plate can become an effective musical instrument for performance of new music.

Keywords: Electroacoustics, flat panel

1. Introduction

Percussion instruments use a variety of vibrating surfaces, e.g. drums are vibrating membranes whereas the cymbal is a circular vibrating plate [1, 2]. These instruments are struck by the performer using a mallet or stick during a performance and the resulting sound may be recorded and transformed by computer.

In this paper, we present an electroacoustically controlled rectangular plate. Unlike a flat panel loudspeaker, the goal is not reproduction but rather the use of the modal interactions of the plate as an intentional distortion. Additionally, the flat metal plate acts as a radiator, so that it can form part of the performance space.

In the second section, we will review the acoustics of rectangular plates. Then, we will discuss the design and construction of flat panel transducers. In the fourth section, we will discuss our implementation. The fifth section is devoted to illustrating various signal processing algorithms that can be used with the plate. Finally, we offer a conclusion and suggest future work.

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2. Plate Acoustics

The vibration pattern of a plate depends critically on whether the plate edges are free, clamped or simply supported. We will assume that all edges are free. According to Leissa [3] (pp. 95), Chladni [4] was the first to study vibrating plates with free boundaries. Lord Rayleigh recognized this was a difficult problem [5] and suggested a method for solving it. Ritz [6] extended Rayleigh's method in the early 20th century (now known as Rayleigh-Ritz Methods).

c_L is the longitudinal wave velocity found from the following equation:

$$c_L = \sqrt{E/\rho(1-\nu^2)} \tag{1}$$

where ρ is density of the material, ν is Poisson's ratio which relates the strain in X and Y, E is Young's Modulus (a measure of stiffness), and h is the plate thickness.

The flexural rigidity is defined by equation 2

$$D = \frac{Eh^3}{12(1-\nu^2)} \tag{2}$$

The spacing between modes is approximately 2κ, where κ is given by equation 3, where D is the plate flexural rigidity, ρ is the density, h is the thickness and finally A is the area.

$$\kappa = \sqrt{\frac{D}{\rho h}}/A, \tag{3}$$

Given c_L and thickness h, the equation for moding frequencies of a rectangular panel is given equation (4) [1, 2].

$$f_{mn} = 0.453 c_L h [(\frac{m+1}{L_x})^2 (\frac{n+1}{L_y})^2] \tag{4}$$

The important lessons to be gained from this equation are the dangers of degenerate modes as L_x becomes close to L_y (i.e., as the panel becomes square). Additionally, the modal lines are no longer straight as they are when the edges are "simply fixed". Additionally, it must be recognized that no plate is entirely "free". A plate supported by a stand is "point supported".

Further details on all variations of vibrating plates can be found in the magnum opus by Leissa [3].

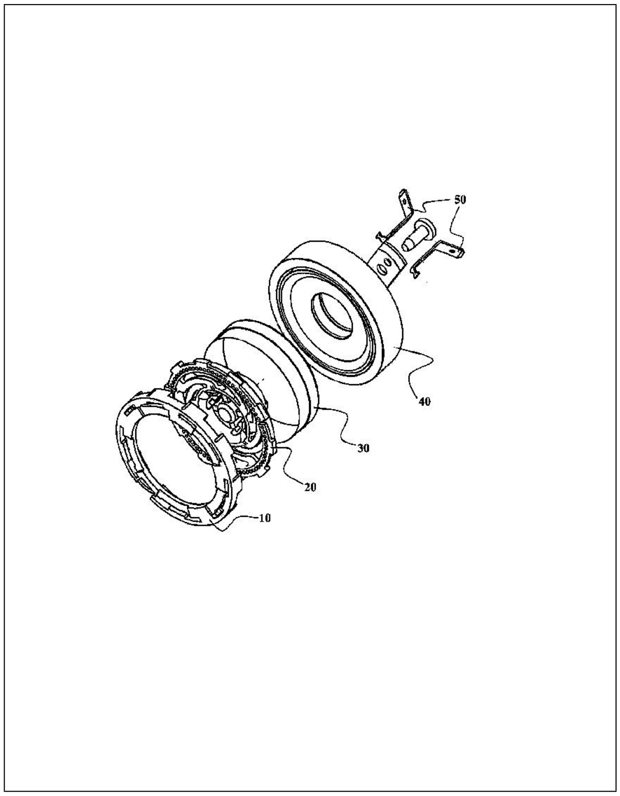

Figure 1. ELAC flat panel transducer

3. Flat panel transducers

Transducer design for flat panel loudspeakers is different from the conventional conical loudspeaker driver due to the need to couple energy directly to the plate. An ad-hoc method is to remove the cone from a driver and epoxy the spider to the panel. However, beginning with NXT's flat panel loudspeaker patent [7], new designs have been created. Since the cone isn't needed or required, it is now possible to create a flat suspension. This was the approach taken by ELAC [8]. As shown in figure 1, the suspension (10) is connected to the vibrating beam (20). This beam is in turn connected to the coil (30), which is located inside the permanent neodymium magnet (40) . The suspension is attached to the flat panel at three points.

4. Design considerations

The first design consideration is the choice of material. Poisson's ratio (ν) varies between 0.2 (Cast Iron) and 0.36 (Copper). Both Young's Modulus (E) and Density (ρ) are given in Table 4.

Each choice is problematic. Aluminum is a possibility, but it soft. The material density will also affect the nodal density. Brass is a very nice material, but it is expensive. Copper is too soft. Cast Iron is too brittle. Carbon steel (or any stainless steel) is a possibility, but it will interact with the transducer magnet. Nickel is also magnetic and expensive.

Metal	Modulus (E, in GPa)	Density (ρ, kg/m^3)
Aluminum	70	2712
Brass	100-124	8525
Copper	110-130	8930
Cast Iron	120	6800-7800
Carbon Steel	190-210	7480-8000
Nickel	214	8800

Table 1. Table of Properties

Figure 2. Commercially available thunder sheet

It is possible to buy a sheet of metal marketed as a "thunder sheet" and attach a transducer. One example is shown in Figure 2. Note that this model is made from steel which interacts with the transducer magnet. As discussed in section 2, the critical aspects of the plate design are the dimensions and the plate material. In the ideal case, the dimensions L_x and L_y would be ideally be related by an irrational number. The transducer should not, if possible, be located at a nodal line or point. As an approximation, we placed the transducer at the 2/3rds point.

The first experiment used a large sheet of stainless steel. Two holes were drilled near two corners and thin wires used to attach the panel to the mount. An ELAC 3720 37mm transducer itself is attached with epoxy to the sheet metal. Inital impressions were favorable although the transducer would "cut out" due to overheating (the ELAC transducer has a thermal fuse). It was not clear whether the overheating was due to the interaction between the electromagnet and the metal sheet or whether the sheet was just too thick.

Subsequently, we were able to obtain a thin (1 mm) brass sheet from the department stores. Again, the transducer was epoxied on the sheet (n.b. initial use of a semi-permanent epoxy failed due to the transducer dropping on the floor). This was very successful and was the initial vehicle for the DSP experimentation described in the following section.

The ELAC transducer has a maximum power output of 15 watts and an X_{max} of ± 0.5mm. This is sufficient power and displacement to deform the panel. The low frequencies are particularly effective to the listener.

5. DSP algorithms and musical performance

Due to reciprocity, the flat panel can be used as both an input and output device. This far, we have concentrated on its use as an output device in concerts and environments.

In this context, the flat panel was re-engineered for performance including a flat panel exciter by SFX Technologies as well as a custom stand as shown in Figure 3. A pair of these panels were exhibited as an interactive installation in “Rock Music, Rock Art”: the opening exhibition of the Pangolin Gallery, London; and were used in Nigel Osbourne’s 2008 piece “Rock Music”. In this piece, movement of the trombonist was captured using a webcam and digital processed in real-time with a `Max/MSP` [9, 10] and `pd` [11] patch. The performer’s movement was used to modify the spectrum of a stored sample. This spectrum was used to control a waveguide synthesis model.

The `Max/MSP` patch essentially converted the inharmonic impulsive sound of a Ugandan rock gong into a continuous aura and allowed the performer to explore the timbres available within its transient decay. Driven through the plates at high levels this produced some quite dramatic and theatrical results, due to the inharmonic distortion and visible wobble of the plates.

In the context of the concert, the architectural form of the panel matches well with the performer on the raised stage (as shown in Figure 4). The *Guardian* had the following review [12]:

> Rock Music’s third movement throws a spotlight on superb trombonist David Purser (making his final appearance with the Sinfonietta), who took part in the Ugandan field trip with Osborne, Maxwell and percussionist Tim Palmer. The agitated central section yields to a calm coda in which we finally hear the electronically processed ”aura” of the rock gongs.

Figure 3. Re-engineered flat panel

Figure 4. Placement of stereo pair of panels on stage

6. Conclusion

The use of flat panel electroacoustic exciters has opened new possibilities in the design of computer controlled percussion instruments. As we have shown, a thin flat metal panel can be used to intentionally distort and project a computer generated (or modified) sound. When coupled with analysis and synthesis algorithms, this striking instrument can be an affecting part of a new music concert.

Future work includes using the plates as sensors and processing the input as well as the exploration of new and novel DSP algorithms that explicitly use the modal frequencies of the plate to advantage.

7. Acknowledgments

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