CASSETTE TAPE PHYSICAL MODELING AND ANALYSIS

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ABSTRACT

For this project, we implemented a physical model of cassette tape recording in MatLab to understand further the physics of magnetic tape recording and the sonic characteristics associated with cassette tape. This physical model can be used as an educational and analytical tool to research how changing certain factors of the tape and head construction, such as magnetic coercivity or gap length, affects the magnetization vectors of the tape's particles. This data can be used to better understand the workings of cassette tapes and the technology surrounding them, allowing for more accurate design of real-time processors.

Index Terms— Magnetic Tape Recording, Physical Modelling, Audio Analysis, MatLab, Cassette Tape

1. INTRODUCTION

Although recording audio to cassette tape is already a rather outdated recording method, it is still widely known for its characteristic analog sound, and thus still has sonic qualities that are sought after in music production. Today, there are many audio software developers that create tape emulator plugins for use in digital audio workstations. Many of these plug-ins work by simplifying the characteristics of cassette tape caused by the physics of magnetic recording down to transfer functions and simple digital signal processing features, such as filters, noise generation, and wow and flutter.

The idea behind this project was to create a physical model of the magnetic behavior of cassette tape to serve as an analytical tool when developing tape emulation software, as well as an educational tool to help users better understand the mechanics of tape recording. The model could allow one to implement controls in a plugin that more accurately emulate the physical behavior of cassette tape. We also initially hoped to include audio processing based on the model, but this proved impractical due to the intense computational demand. However, by programming functions in MatLab that process audio samples according to the equations that govern the magnetization of tape, the effects that tape recording have on an audio signal can be visually realized.

2. RESEARCH

Magnetic tape recording works by an audio signal being sent through a coil of wire to create a magnetic field in the toroidal record head that then magnetizes tiny oxide particles on the tape to store the audio signal. The diagram below shows a simplified illustration of the magnetization process.
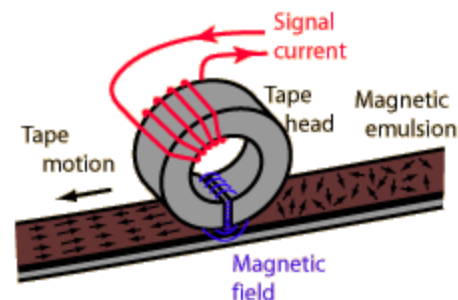
[3]

When conducting research for implementing our physical model in MatLab, we found the

following equations that relate the position of the oxide particles to the magnetic field induced on them from the record head [1]. These equations are incredibly useful for visualizing how the particles are magnetized to store the audio signal on the tape.

$$\frac{H_x(x,y)}{H_0} = \frac{1}{2\pi}(tan^{-1}(\frac{g/2+x}{y}) + tan^{-1}(\frac{g/2-x}{y}))$$
$$+ \frac{g}{2\sqrt{2\pi}}(\frac{(\sqrt{(x^2-y^2-(g/2)^2)^2 + 4x^2y^2} - x^2 + y^2+(g/2)^2)^{1/2}}{\sqrt{(x^2+y^2-(g/2)^2)^2+4y^2(g/2)^2}})$$

Equation 1.

Figure 1.

$$\frac{H_y(x,y)}{H_0} = -\frac{1}{4\pi}log(\frac{(x+(g/2))^2+y^2}{(x-(g/2))^2+y^2})$$
$$- Sgn(x)\frac{g}{2\sqrt{2\pi}}(\frac{(\sqrt{(x^2-y^2-(g/2)^2)^2 + 4x^2y^2} - x^2 + y^2+(g/2)^2)^{1/2}}{\sqrt{(x^2+y^2-(g/2)^2)^2+4y^2(g/2)^2}})$$
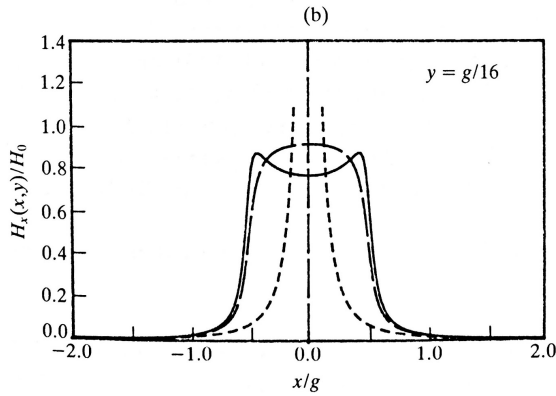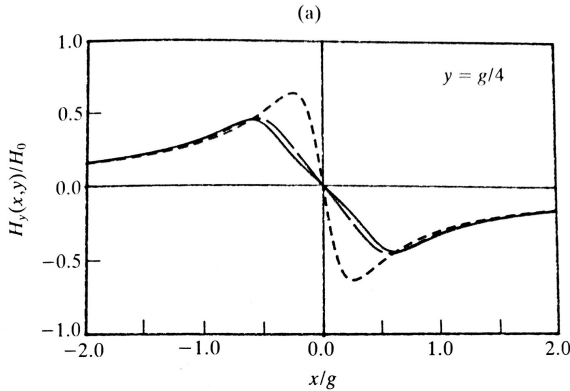
Equation 2.

Figure 2.

Equation 1 and Figure 1 depict the magnetic field strength longitudinally (across the length of the tape), and Equation 2 and Figure 2 show the magnetic field strength perpendicularly (into the tape). In these equations, g corresponds to gap length of the record head, and x and y correspond to horizontal and vertical distance from the record head center, respectively [1].

$$H_o = \frac{NIE}{g}$$
Equation 3.

Ho is an initial field that is represented by Equation 3. In this equation, N corresponds to number of turns in the record head coil, g corresponds again to record head gap length, and I corresponds to the current of the input signal. E is the potential difference across the head gap at each end of the record head's core, however this can be ignored for our purposes as it is approximately a constant value. By simply multiplying both sides of Equations 1 and 2 by H_O, we can acquire the magnetic field strength at any point around the head gap as a function of the input signal current [1].

3. METHOD

The physical model implemented in MatLab stores an array of values correlating to the magnetic domains (groupings of particles with electric fields trending in the same direction) on the cassette tape. These values define the magnitude of the horizontal (u) and vertical (v) magnetization vectors at each domain.

We found the estimated space between particles to be about 0.3 microns, which is the average of typical width (0.1 microns) and length (0.5 microns) of magnetic particles in Type I Fe3O2 cassette tape, assuming even distribution. We used this information, along with standard cassette tape dimensions (0.6 mm track width and 12 micron emulsion thickness) to determine the number of domains along the width, length, and

thickness of tape. For our default test values that appeared in the plots on our poster, the length of the tape contains 20 (6 microns/0.3 microns) domains per sample. This dimension was based on Figures 1 and 2 where a length of triple the gap length covered most of the head field. We used a gap length of 2 microns, meaning our length should be 6 microns. The thickness contains 40 (12 microns/0.3 microns) domains [2].

The width would contain 2000 particles (using a channel width of 0.6 mm) by the same metrics, but implementing width for our visualization would be unnecessary as width plots would simply manifest as repeated instances of the same head field, as it does not change across the width of the tape. Width on a physical tape is needed for a good signal-to-noise ratio, but it is unnecessary for visualization.

By this point, it became clear that the amount of calculation required for each sample (processing using equations 1 and 2 for 800 points with our default domain sizes) would make even offline audio processing at a reasonable sample rate very impractical. Moving forward, we decided to focus on perfecting the analysis and design parts of our tool instead of spending time trying to force audio processing to work. It is very likely that the compromises regarding domain size, domain count, and sample rate that we would have had to make to speed processing time would have resulted in inaccurate, lackluster audio emulation.

4. IMPLEMENTATION

We began our Matlab implementation by writing a function to return the magnetic field due to the record head at any point in the tape, given an input sample. This was achieved by simply implementing equations 1 and 2 and processing the input arguments through them. We then wrote another function to calculate the field at each domain's location for a chunk of tape corresponding to approximately one sample of data. The field strengths were then stored along with their coordinates in four separate arrays corresponding to X-coordinate, Y-coordinate, horizontal field strength, and vertical field strength. The data was stored in these four arrays to facilitate easy plotting of the resulting vector field using Matlab's built-in Quiver function. We then added an optional block of code to this function to calculate and display the magnetization of each individual domain in the chunk of tape. This is achieved by checking at each domain if the magnitude of the field strength is larger than the coercivity of Fe_3O_2. If it is, then the domain is considered magnetized, and the magnitude of the vector is set to a constant value that represents the resulting permanent magnetization of the domain. Otherwise, the magnitude and direction of the vector is set to some small random amount to represent the default random noise of the domains when demagnetized.

We then wrote a script to plot a real-time animation of the physical model alongside an audio file at 20 frames per second. This animation can display either the magnetic field due to the record head or the resulting magnetization of the domains, depending on the user's preference. In addition, we developed another Matlab script to plot a single chunk of tape given an input value.

In our code, we added a number of design parameters to allow the user to experiment. The user is able to set the coercivity of the particles within the tape, to allow for the simulation of different tape formulations. Furthermore, the user is able to set an amount of random variation in coercivity between individual particles. This simulates the inherent randomness in coercivity due to varying particle dimensions, orientations, and impurities. Additionally the user can set the vertical and horizontal spacing between domains, and also set the number of domains in each dimension to be modeled. These enable the user to zoom in and out on the visualization, as well as experiment with different domain densities which could be used to offer changes in resolution of the visualization for a given material. Finally, the user

is able to set the number of coils and gap length of the record head, to allow different designs of record heads to be tested.

5. RESULTS

Below are three graphs generated by our program. In Figures 3 and 4, all design parameters were set to their default values, and an input signal of 3mA was provided. Figure 3 demonstrates the magnetic field strength at all points, and is scaled by 2 for visibility. Figure 4 demonstrates the corresponding magnetization of each domain, with no variation of coercivity. In figure 5, the number of domains to simulate was increased to a 40x40 grid, a variation in coercivity of +/- 4 was added, and the gap length of the record head was increased from 2 microns to 6 microns.
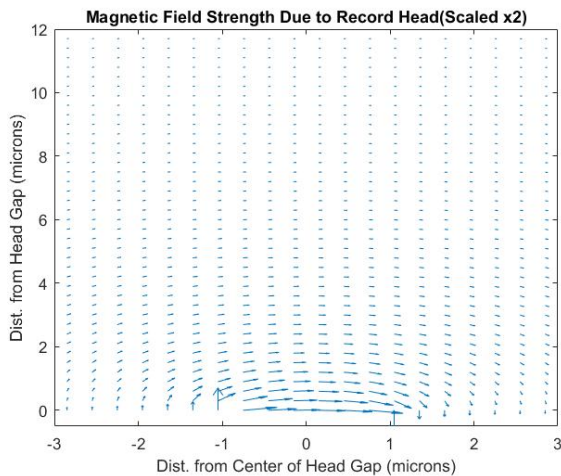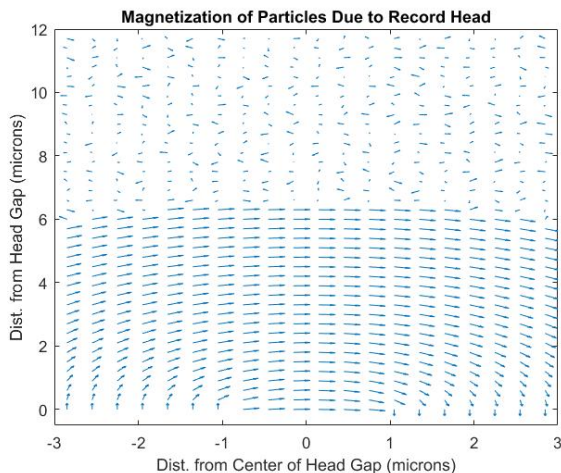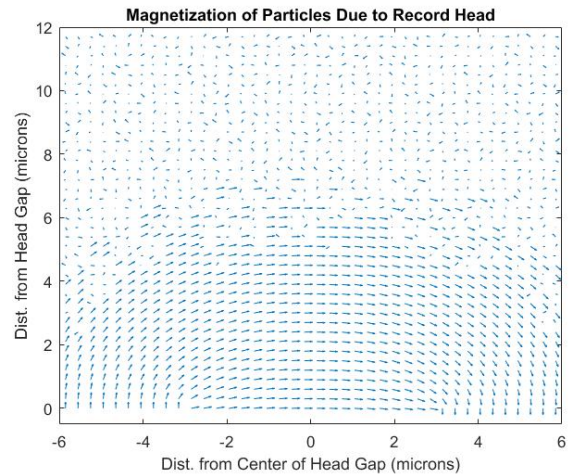

Figure 3.

Figure 4.

Figure 5.

6. CONCLUSIONS

The resulting plots from our MatLab program clearly depict the expected changes in how the particles are magnetized by the record head based on variability in the design. Despite our inability to implement the real-time audio processing functionality, the physical model of cassette tape we programmed in MatLab proved to be useful for better understanding magnetic tape recording.

The foundational code developed here can be applied in the future as an analysis tool to facilitate development of cassette tape emulation processors. Future changes to improve our program could include showing the accumulated magnetization on the tape over time as sequential frames of the tape overlap and interact with each other. Furthermore, we believe future research and development into the possibility of a practical real-time audio processing physical model of cassette tape is a worthwhile endeavor, based on our discoveries here. We hypothesize that many of these design parameters could be manipulated to noticeable and creative effect when used in the context of an audio plug-in. This tool thus can serve as a foundation for future research and experimentation into the development of a real-time cassette tape physical model.

7. REFERENCES

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