CASSETTE TAPE PHYSICAL MODEL 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 number of coils in the record head 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.

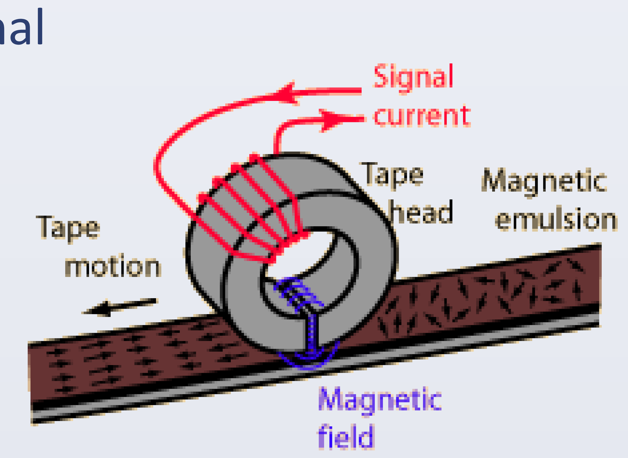
OBJECTIVES

- Cassette tape has sonic characteristics that are still sought after in music production, such as tape saturation and hiss, subtle wow and flutter effects, and analog warmth.
- Many tape emulation plug-ins simplify these characteristics down to filters, distortion, and added noise without fully analyzing the physical properties of cassette tape that cause these effects
- The physical model we implemented in MatLab can potentially be used as an analytical tool to get more accurate, detailed, and realistic data when designing real-time cassette emulation plugins
- Design the tool to additionally help others to understand more fully the effect that various physical aspects of magnetic recording have on the sonic quality of an audio signal, such as number of coils in the record head or gap length

RESEARCH

Magnetic Tape Recording Basics: How it Works

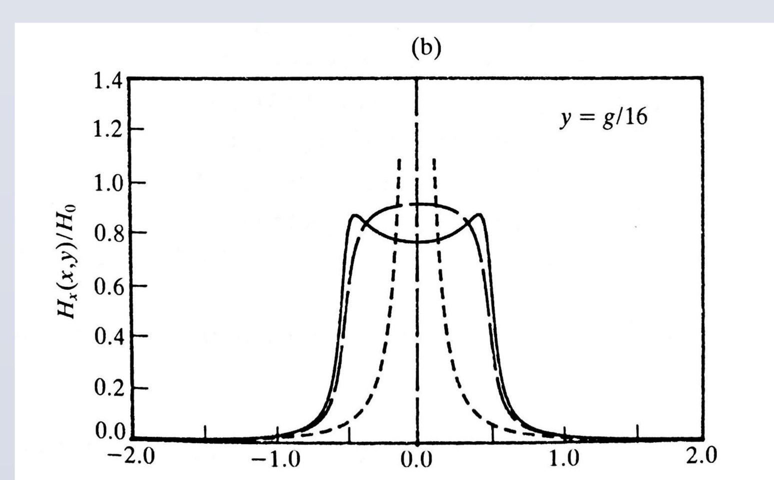
- Record head consists of a wire coiled around an iron core
- Audio signal is sent through coiled wire, creating an alternating magnetic field in the iron core
- Oxide particles on the tape are magnetized by the field and their fields are reoriented to store the audio signal



Magnetic Field Strength as a Function of Distance from the Record Head

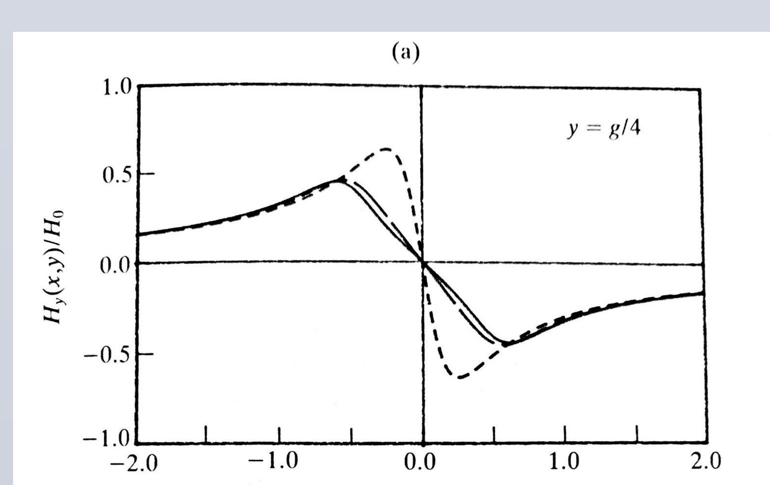
Longitudinal (Across Length of Tape)

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



Transverse (Into Tape)

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



RESEARCH

Number of Domains (Dipoles) Within Tape

- We use a grid of domains as a simplification
- Calculation:
- Estimated space between particles = 0.3 microns (average of typical width and height of magnetic particles in Type I cassette, assumes even distribution)
- Width of the tape will contain **2000 Domains** (0.6mm/0.3 microns) (on stereo cassette, each channel has width of 0.6 mm)
- Thickness of tape will contain **40 Domains** (12 microns/0.3 microns)
- Length of tape window **20 Domains** (6 microns/0.3 microns) (assumes 2 micron head gap on record and playback)
- Coercivity of Ferric Oxide: 20 kA/m

Problems With Real-Time Audio Processing

- In implementing our physical model, we quickly determined a real-time audio application would be impossible due to the sheer amount of processing required.
- Requires processing field strength and magnetic force for 20*40 domains per sample.
- We found processing for one sample takes about 20ms in MatLab, far too slow for real-time processing of a 44.1kHz audio file.

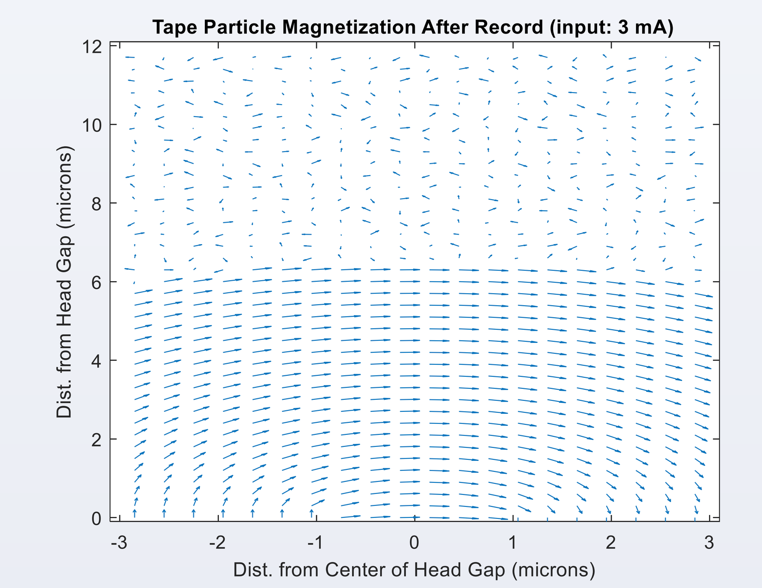
Reciprocity Principle

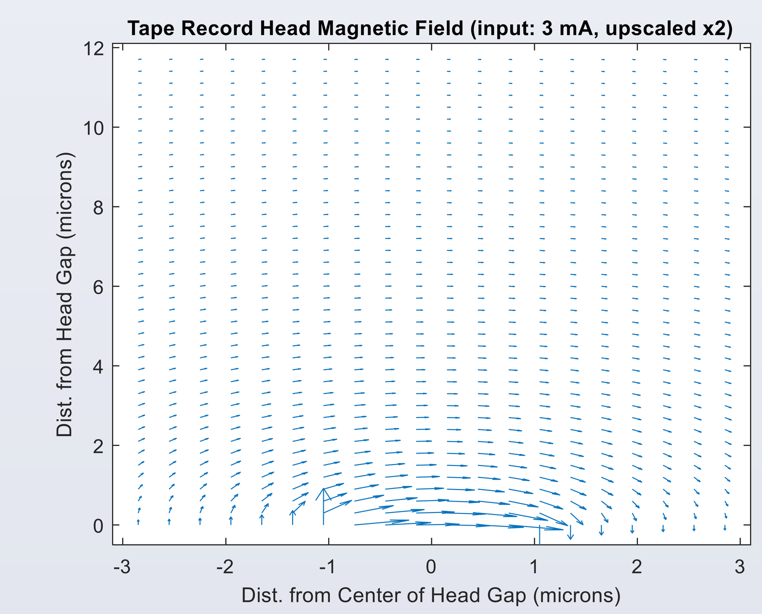
$$E = kvN\frac{d}{dt}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\overline{M}\bullet\overline{H}\,dxdydz$$

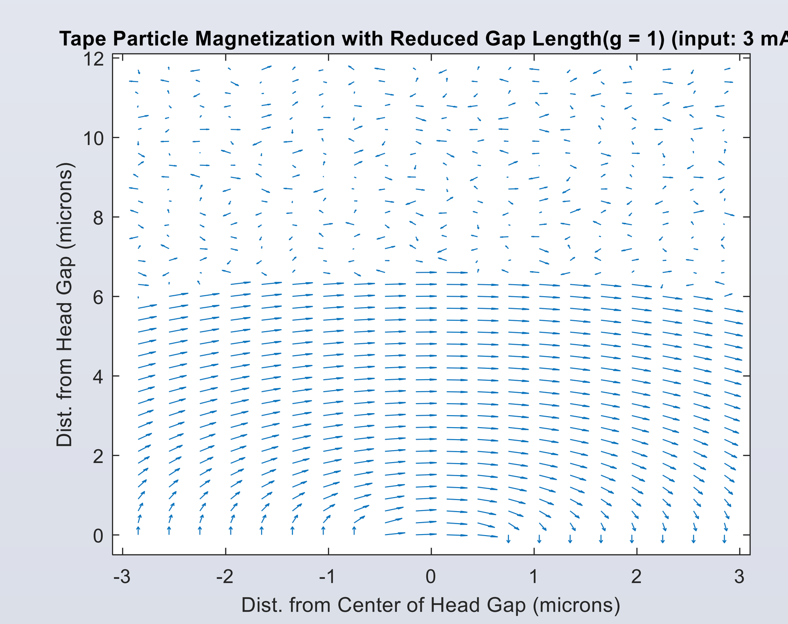
Implementation

- Wrote a Matlab function to take in distance(X and Y coordinates) of a domain from the tape record head and the input sample as a current value and output the magnetic field due to the head at that point.
- Wrote a Matlab function to fetch field at domain due to the tape head's magnetic field, and reset the domain's magnetization if above the coercivity (20 kA/m)
- Plotted an animated vector field representing the magnetization of each domain in a sliver of tape corresponding to the current sample. This animation plays in real-time with an input audio file, updating 30 times per second.

RESULTS







CONCLUSIONS

- Plots clearly show expected changes in particle magnetization based on design variables.
- Despite failure to implement audio processing functionality, program still proves 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.
- Program could be improved in the future to show accumulated magnetization on the tape over time.

SOURCES

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