The Voltage Waveform of Transformer Core Halves with Magnetization and an Air Gap ... and Maybe Motion Too

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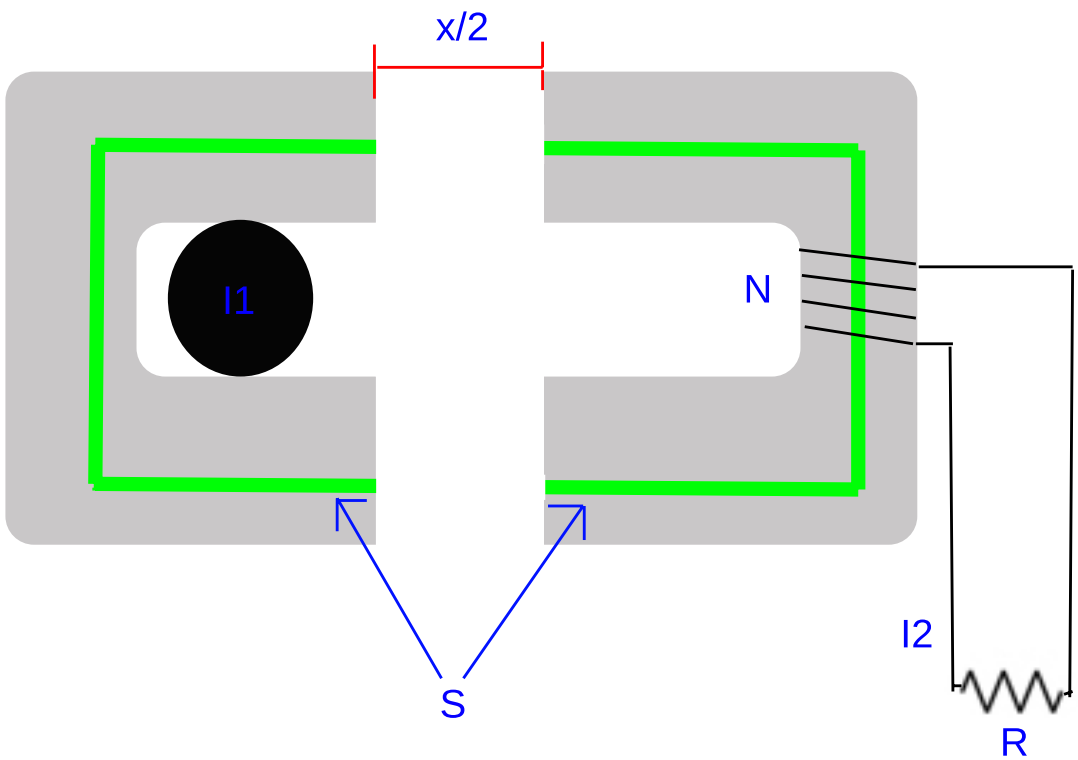
What is this Modeling?



Questions to Answer

- What is the output waveform?
- How does it depend on distance?
- How does it depends on the number of turns?

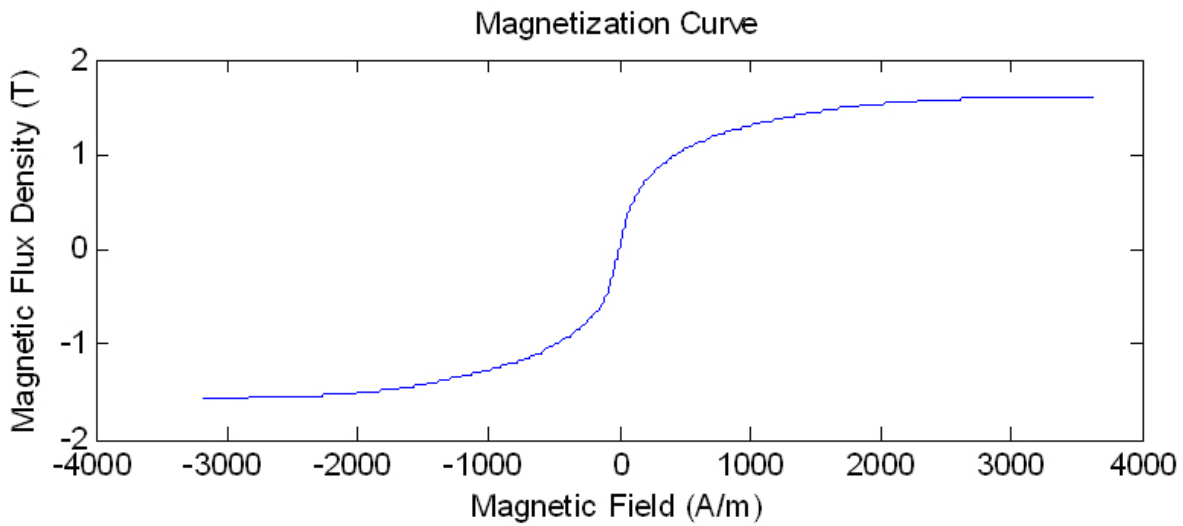
Governing Equation for Output Voltage

In a simple world, it would be

$$I_2 R = \frac{-NA\mu}{s}\left(\frac{\partial I_1}{\partial t} + N\frac{\partial I_2}{\partial t}\right)$$

Governing Equation for Output Voltage

Since this is iron, there is a magnetization curve.



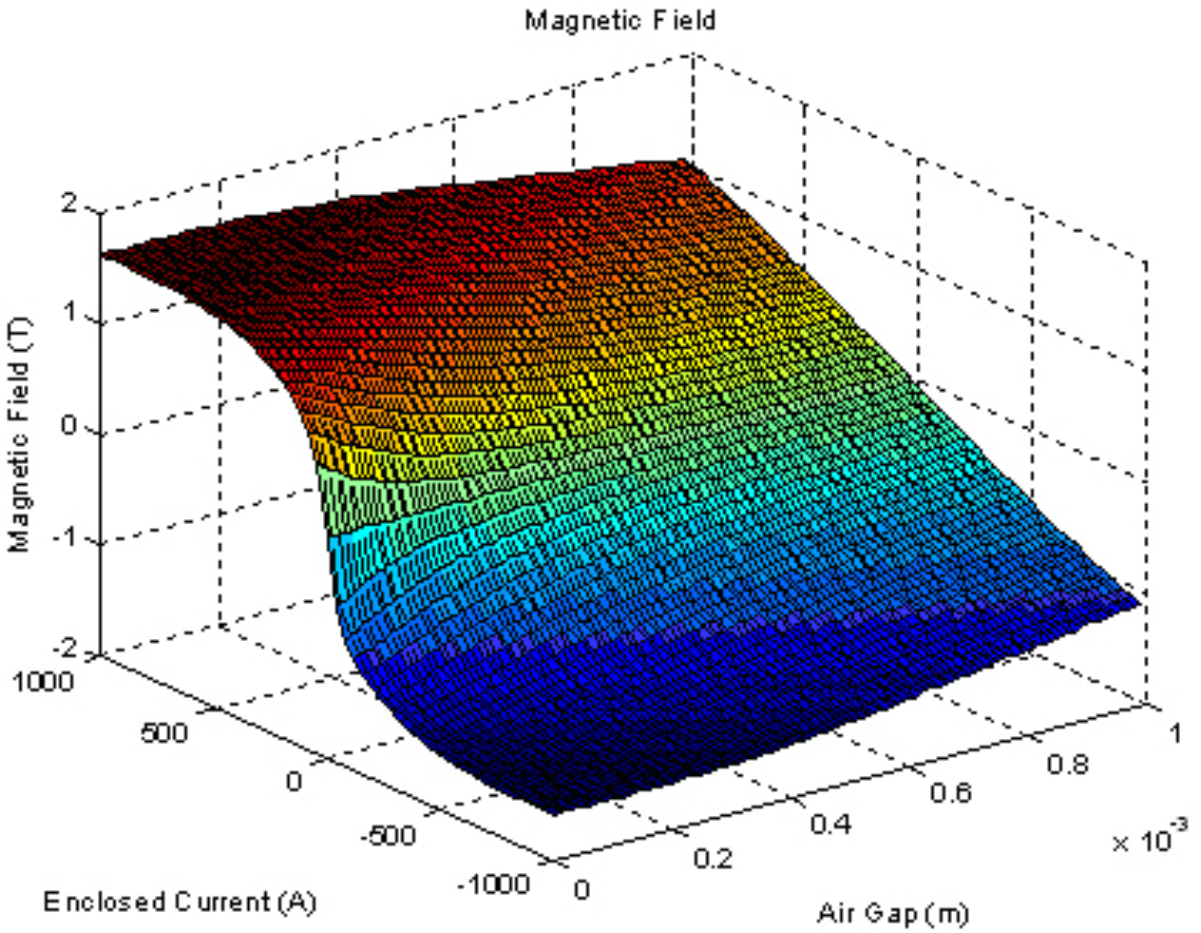
Governing Equation for Output Voltage

To find the magnetic field with an air gap, this equation needs to be solved

$$f(H) = \frac{\mu_0}{x}(I_1 + NI_2 - Hs)$$

Governing Equation for Output Voltage

After the Rootfinding....

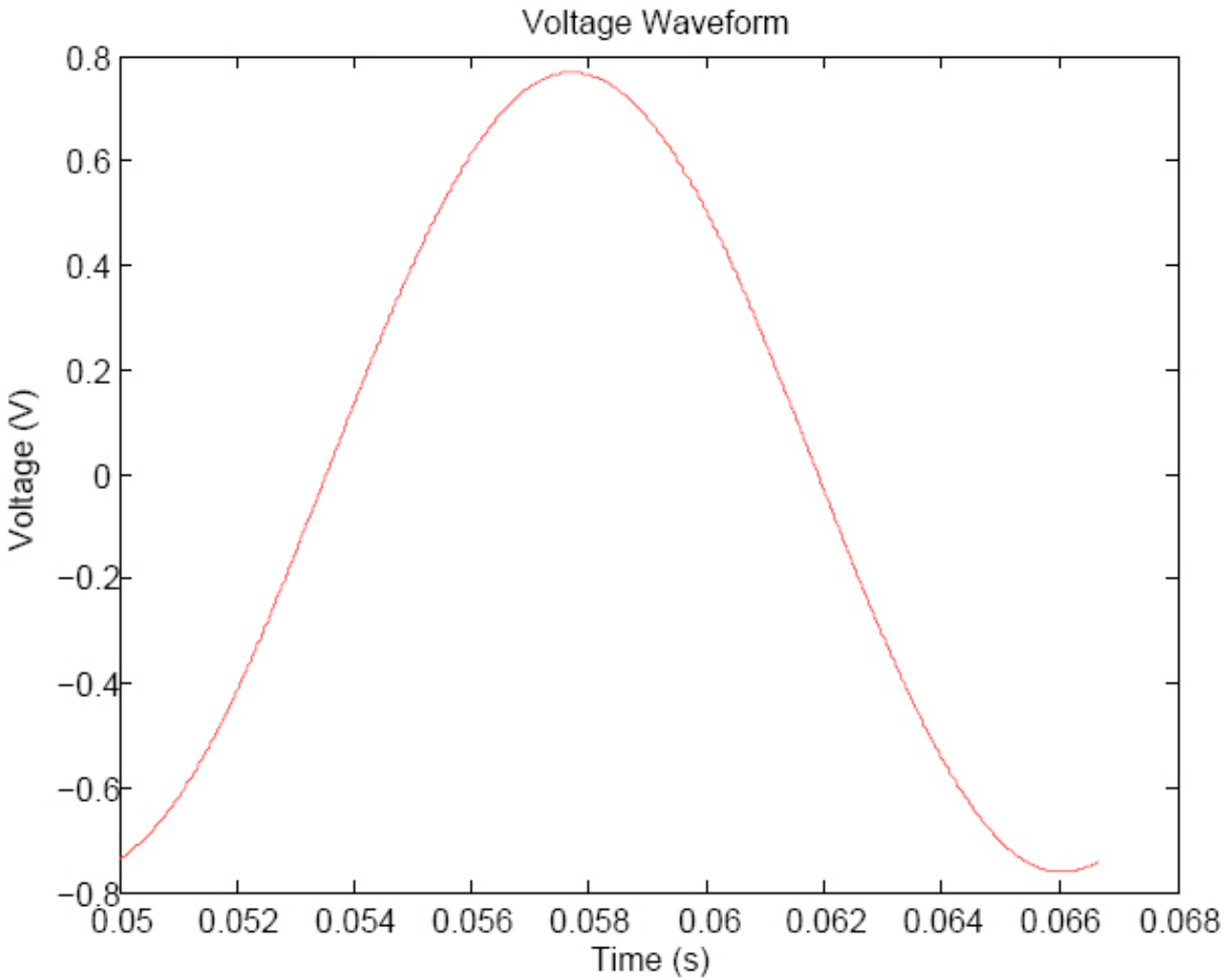


Governing Equation for Output Voltage

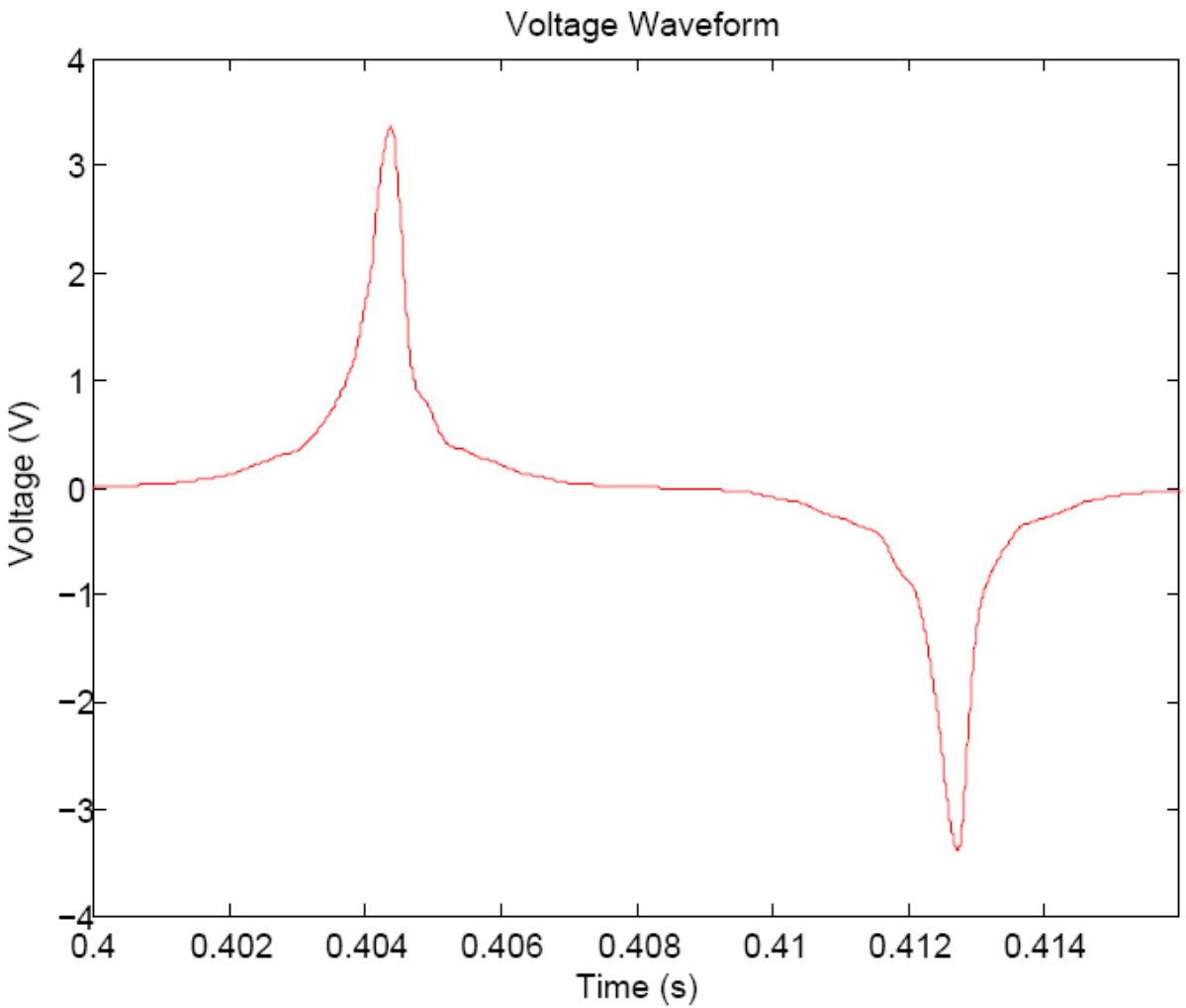
No longer as nice, the governing equation is now

$$I_2 R = -NA\left(\frac{df}{dH}\right)\left(\frac{\partial H}{\partial I_1}\frac{\partial I_1}{\partial t} + N\frac{\partial H}{\partial I_2}\frac{\partial I_2}{\partial t}\right)$$

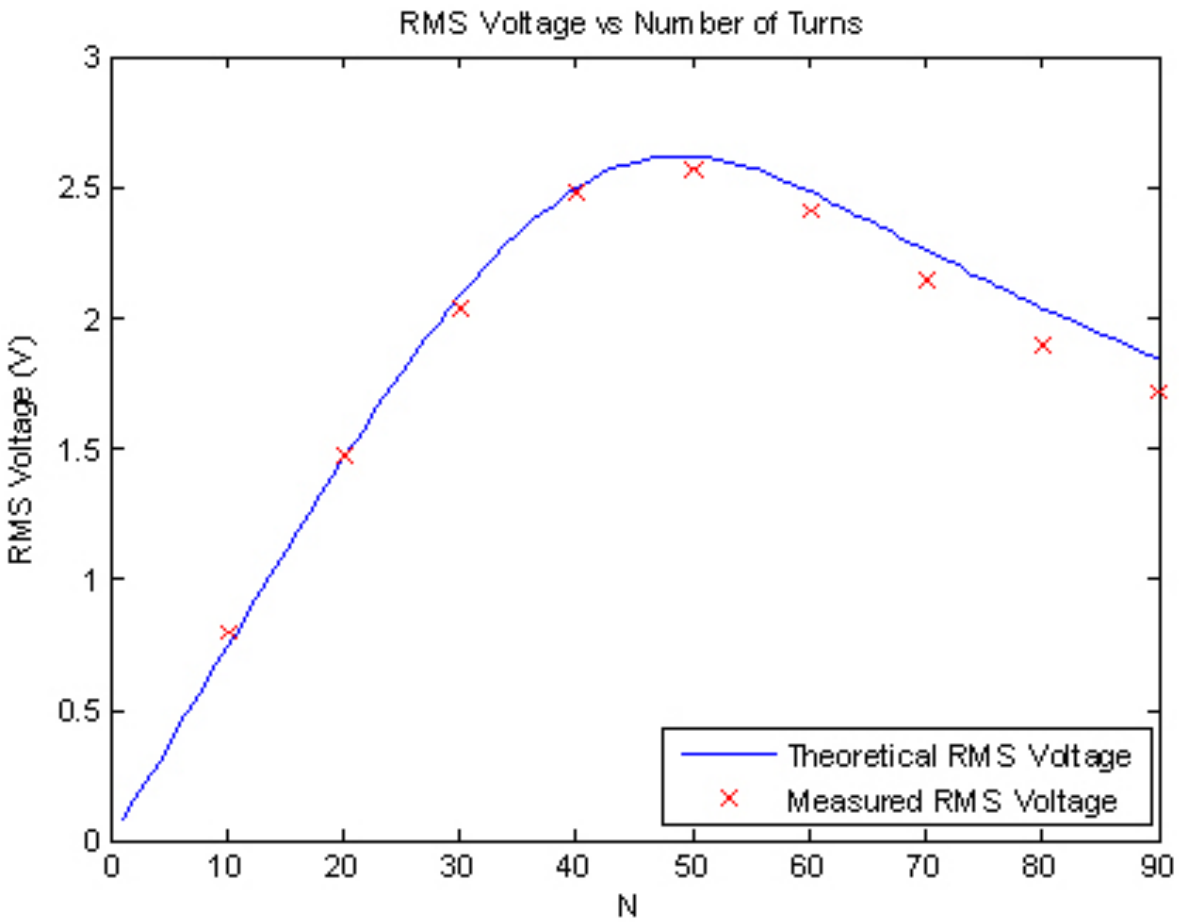
Output Voltage at Low Current



Output Voltage at High Current



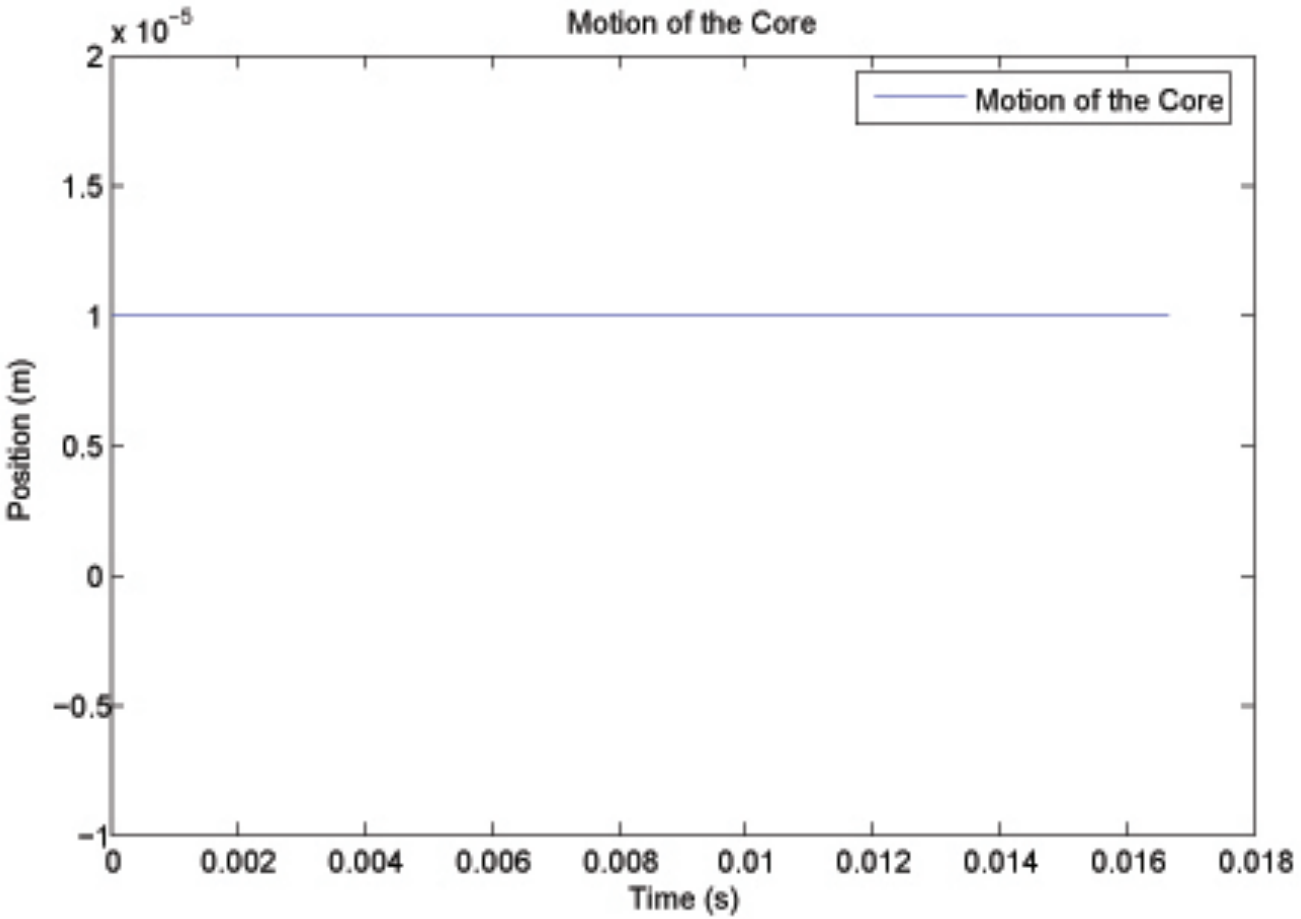
Dependence on the Number of Turns



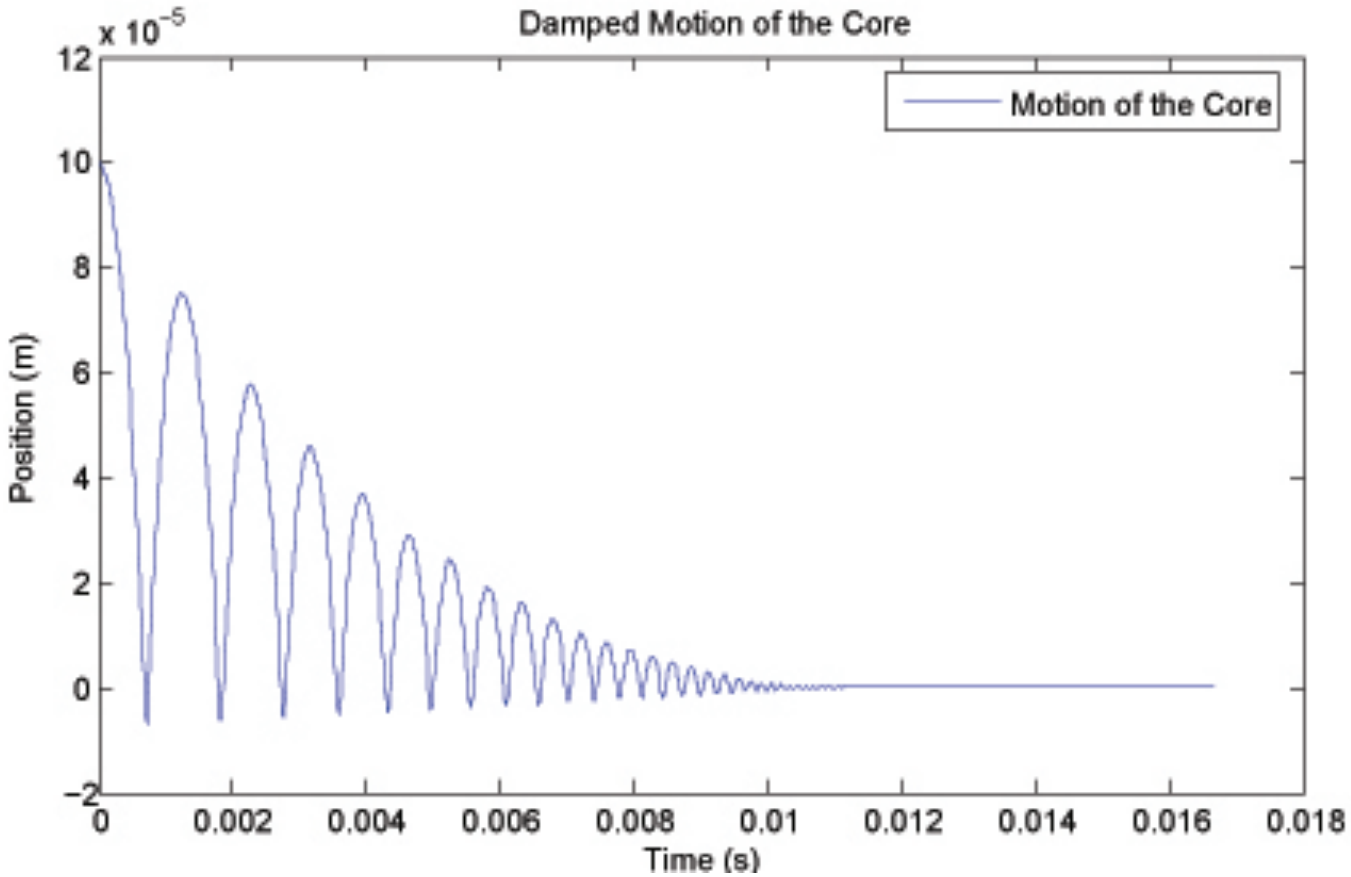
Governing Equations

$$
\begin{aligned}
I_2 R &= -NA\left(\frac{df}{dH}\right)\left(\frac{\partial H}{\partial I_1}\frac{\partial I_1}{\partial t} + N\frac{\partial H}{\partial I_2}\frac{\partial I_2}{\partial t}\right) \\
\dot{x} &= 2v \\
\dot{v} &= \begin{cases} -\frac{B^2 A}{2\mu_0} - \frac{v}{|v|}\mu_k g & \text{if } x > x_0(t), \\ k(x_0 - x) & \text{if } x \leq x_0(t). \end{cases}
\end{aligned}
$$

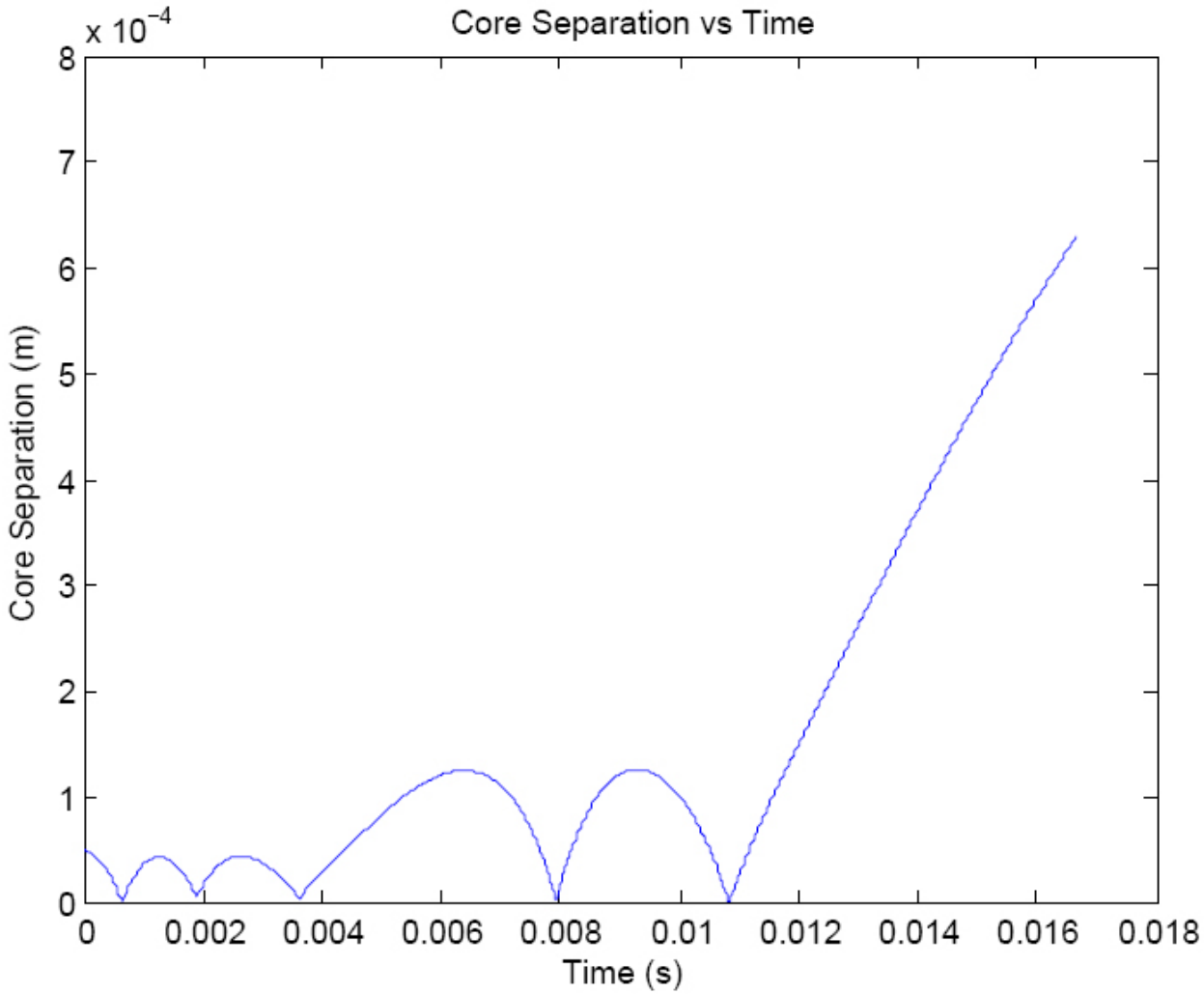
Yay! It Does Nothing!



Friction Actually Works!



But...Then This Happens



Future Work

- Check Governing Equations for Motion
- Look for a way to make the solver less sensitive
- Find parameters values that match the measured voltage

Conclusions

- The deformed waveform is caused by the magnetization curve
- Increasing the air gap lowers the output voltage and affects the shape
- Accounting for the air gap without a Magnetization Curve is ineffective
- Having mobile cores creates a less deformed waveform
- The number of turns, N, greatly affects magnetic flux density

References

Burden, Richard and Faires, J. *Numerical Analysis: 8th Edition*. Belmont: Brooks/Cole, 2005.

Goldstein, Herbet et. al. *Classical Mechanics*. New York: Addison Wesley, 2002

Tanenbaum, Sam. *E-84 Electric Circuits and Magnetic Devices*. Claremont. 2004