DESIGN AND OPTIMIZATION OF MAGNETOSTRICTIVE STRAIN SENSOR

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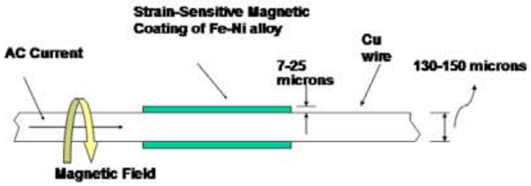
OBJECTIVE

- Understand the mechanism and working of sensor
- Develop a model for magnetostrictive strain sensor
  - Indicate influence of all parameters sensor response
  - Study effect of stress/strain on sensor response
- Optimize sensor properties:
  - Range of strain
  - Sensitivity
  - Resolution
  - Repeatability

CONFIGURATION OF SENSOR

Configuration

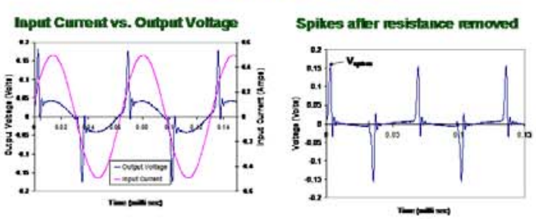


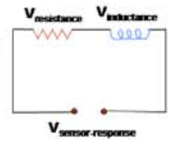
• *Electrochemical deposition using Watt's nickel bath*

MOTIVATION

- Applications:
  - In service strain measurement
  - Cure information of resin
  - Health monitoring of structures
- Advantages:
  - Simple to examine response
  - Compared to Capacitance/Resistive Strain Gage
    - Better sensitivity; Less susceptible to noise
    - Higher dynamic range (>15KHz)
  - Compared to Fiber Optic Sensors
    - Lower cost - \$1 vs. \$50 per sensor; Easier to handle

SENSOR RESPONSE

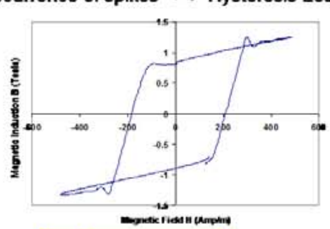




$V_{sensor\ response} = V_{spikes} + V_{resistance}$

ANALYSIS OF SENSOR RESPONSE

Occurrence of spikes ➡ Hysteresis Loss



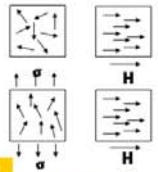
y-axis: $B = \frac{1}{A}\int V_{inductance}\,dt + const.$

x-axis: $\overline{H} = \frac{\ln\left(1+\frac{t_m}{r}\right)}{2\pi t_m} I$

OPERATING PRINCIPLE

- Domain theory:

Application of strain → Change in permeability
↓
Change in spike height ← Change in impedance



- Electromagnetic analysis:

$$V_{spike} = -\frac{l}{2\pi}\ln\left(1+\frac{t_m}{r}\right)\left(\mu I_o \cos\omega t + \frac{\ln\left(1+\frac{t_m}{r}\right)}{2\pi t_m} I_o^2 \sin\omega t \cos\omega t \frac{d\mu}{dH}\right)\omega$$

Stress Analysis

$$\mu = \frac{M_s^2}{\lambda_s \sigma + K_1}^{[1]}, \frac{d\mu}{dH} = 0 \Rightarrow V_{spike} = -\frac{l}{2\pi}\ln\left(1+\frac{t_m}{r}\right)\frac{m}{\sigma+n} I_o \omega \cos\omega t$$

[1]Cullity, B.D., *Introduction to Magnetic Materials*, Addison-Wesley Publishing Company, Inc., Reading, Mass. (1972).

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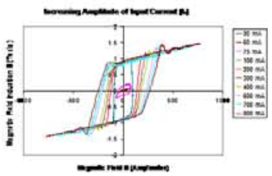
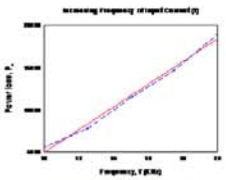
RESULTS: PROOF OF MECHANISM

Amplitude: Saturation of curve



Frequency: Proof of Hysteresis



$$M = M_s\left(1 - \frac{a}{H} - \frac{b}{H^2} - \frac{c}{H^3} - \ldots\right) + kH \quad [1]$$

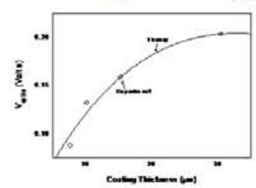
$$P = C_a f + C_h f^2 + C_e f^{3/2} \quad [2]$$

[1]Bozorth, R.M., *Ferromagnetism*, D. Van Nostrand Company, Inc., Toronto (1951).

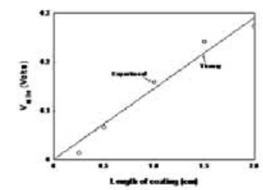
[2]Bertotti, G., *Hysteresis in Magnetism for Physicists, Materials Scientists, and Engineers*, Academic Press, Inc., San Diego (1998).

RESULTS: INFLUENCE OF MAGNETIC FILM

V_{spike} vs. Coating Thickness (t_m)



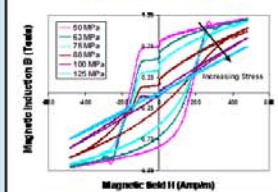
V_{spike} vs. Coating Length (l)



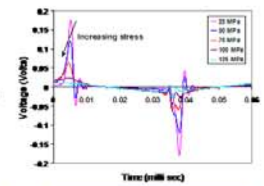
$$V_{spike} = -\frac{l}{2\pi}\ln\left(1+\frac{t_m}{r}\right)\left(\mu I_o \cos\omega t + \frac{\ln\left(1+\frac{t_m}{r}\right)}{2\pi t_m} I_o^2 \sin\omega t \cos\omega t \frac{d\mu}{dH}\right)\omega$$

RESULTS: EFFECT OF STRESS

Effect of stress on hysteresis loop



Effect of stress on spikes



B-H curve becomes more linear as stress increases

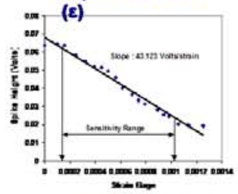
Spike height decreases with increasing stress

RESULTS: CALIBRATION OF SENSOR

V_{spike} and Permeability (μ) vs. Stress (σ)

Bare wire

V_{spike} and Strain (ε)



Embedded wire

Stress range (σ): 25-80 MPa

Strain range (ε): 0.01%-0.1%

CONCLUSIONS

- Occurrence of spikes due to hysteresis loss in magnetic coating
- Model accurately captures geometrical and process parameters
  - ↑ in Stress/Strain → ↓ in V_{spike} → within elastic limit of wire
  - ↑ in length of coating → linear ↑ in V_{spike}
  - ↑ in thickness of coating → logarithmic ↑ in V_{spike}
  - ↑ in radius of copper wire → ↓ in V_{spike}
- Model can be used to tailor/optimize sensor
  - Range of strain: 0.01% - 0.1%
  - Sensitivity:
    - Resistive strain gage: ~2
    - Magnetostrictive strain sensor: 1030

ACKNOWLEDGEMENTS

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