1. Inductive Sensors Continued

Given:

\[ L = \frac{\mu_0 N^2 A}{L} \rightarrow x(t) \]

If the turns are consistently ordered so that \( N/L \) is a constant: \( N/L = C \)
then \( L = \mu_0 \mu_r NGA \)

a. Movable high \( \mu_r \) core

Given:

\[ M_r \text{ core} \]

air or vacuum \( N \)-turns \( \rightarrow x(t) \)

\[ L = L_1 + L_2 \]

\[ = \mu_0 G A k x(t) + \mu_0 \mu_r G A (N - k x(t)) \]

Example: let \( \mu_0 G A N = 1 \mu H \) and let \( \mu_r = 5000 \) (Fe)

let \( L = 1 \) cm with 1 turn/mm

\( \rightarrow \) show plot

for \( \mu_r \gg \mu_0 \), \( L \approx L_2 = \mu_0 \mu_r G A (N - k x(t)) \)

where \( K = \text{turns/distance} \)

Variable Core Inductor
Variable Core Inductor

Inductance vs Displacement

Nearly Linear
a. Variable Core Transformer → Differential Transformer

Given $L_1$ and $L_2$

Assume

$L_1 = \mu_0 \mu_r GA (N - Kx(t))$

$L_2 = \mu_0 \mu_r GA (N + Kx(t))$

\[ N_1(t) = N - Kx(t) \]
\[ N_2(t) = N + Kx(t) \]

\[ \therefore U_2 = \frac{N_2}{N_1} U_1 = \frac{N + Kx(t)}{N - Kx(t)} U_2 \]

Example: $N_1_{\max} = N_2_{\max} = 20$

Show plot

$U_2 = V_{out}$ is a nonlinear function of displacement

b. Linear Variable Differential Transformer (LVDT)

$L_{s1}$ and $L_{s2}$ are connected so that

$V_{out} = 0$ when $L_{s1} = L_{s2}$
Differential Transformer

N2/N1

Displacement in terms of N

N2/N1 Log Scale

Displacement in terms of N
As the core moves over its range, the amplitude of $V_{out}$ is a linear function of displacement over a wide range.

![Diagram](image)

- Moving past the balanced position of the core, the polarity of $V_{out}$ flips.

- At the balanced position of the core, $V_{out}$ is ideally 0V. In reality, $V_{out} \neq 0V$ and is called the null voltage due to quadrature voltages and harmonic components of the excitation voltage which do not cancel out.

- Quadrature voltages due to the difference in winding capacitance between the primary and secondary.
What is the Phase Shifter for?

consider an inductor: \( L \)

\[
L \rightarrow \frac{m}{R_L} L
\]

there is a phase difference between \( V_{out} \) and \( V_{in} \)

Synchronous Demodulation needs \( V_{in} \) and \( V_{out} \) to be in phase \( \rightarrow \) the Phase Shifter provides this