Frequency Domain modeling of Inductive Position Sensor with Finite Element Tools

Dr.-Ing. habil. Ajoy K. Palit,
Lemfoerder Electronic GmbH (ZF-Friedrichshafen AG. Group), Germany
Contents

- Why Inductive Position Sensors?
- Structure of Inductive Position Sensor
- How does it work?
- Frequency Domain Modeling
- Simulation Results
- Conclusion
Why Inductive Position Sensors?

- Automotive Electronics must work in extreme weather conditions, e.g. dust, humidity, vibration and wide temp range -40°C to +90°C
- Non-contact type & low cost solutions needed
- Resistive/Capacitive Sensors will be unsuitable
- Hall Sensors with Magnets were usually used
- They have some problems, e.g. magnet fixing with adhesive/glue, B(remanence) changes with temp, compensation needed, not so cheap etc.
Inductive Position Sensors

- Planar coils are fabricated directly on the PCB
- Double layers coils are often needed
- Other shapes e.g. rectangular, trapezoidal, circular, elliptical are also possible

Figure: Inductive Position Sensor
How does it work?

- Activator is a very thin Rhombus shape Cu-plate
- Slides horizontally over the coils *(fixed vertical gap)*
- Multiple coils‘ inductances are affected due to Cu-Activator *(eddy current‘s effect)*

Figure: Inductive Position Sensor
Modeling of Inductive Pos. Sensor

- Inductive position sensor can be viewed as a leaky (air core) and loosely coupled transformer
- Planar coils behave like a primary and activator is like a shorted secondary winding with one turn.

\[
V_p = I_p R_p + L_p \cdot \frac{dI_p}{dt} - M \cdot \frac{dI_s}{dt},
\]

\[
M \cdot \frac{dI_p}{dt} = I_s (R_s + Z_L) + L_s \cdot \frac{dI_s}{dt},
\]

\[
V_p / V_s = I_s / I_p = N_p / N_s = a,
\]

\[
M = K_{coupl} \sqrt{L_p L_s}, \quad a = \sqrt{\frac{L_p}{L_s}}
\]

\[
aM = K_{coupl} L_p, \quad V_p = (1 - K_{coupl}) L_p \frac{dI_p}{dt}
\]

\[
I_s = aI_p, \quad V_p = (L_p - aM) \frac{dI_p}{dt}
\]
Figure: Geometry building steps of planar coil with activator element in Model Builder.
Simulations Results (single & double layer)

**Figure:** Cu-activator’s X-off position (mm) vs. Inductance (nH) graph for a single (left-bottom) & double layer (right-bottom curve) planar coil.
Simulations Results (2-layer Coils)
Conclusion

- Inductive position sensor was modeled as a leaky/loosely coupled (air core) transformer with a shorted secondary winding (one turn) and operated at MHz frequency.
- Multiple coils’ inductances are influenced (reduced) by the Cu-Activator element.
- Xoff-position vs. Inductance curve (single/double layer) of planar coil looks like an inverted Gaussian function.
- Sensor’s sensitivity is dependent on operating frequency and shape, size, location (both horizontal & vertical) of the activator element over the coil.
- The results have been implemented in the development of an automatic gear shifter module of a leading German car.
Thank you for your Attention!
Comsol Simulations of Inductive Position Sensor

Dr.-Ing. habil. Ajoy K. Palit, ZF-Lemfoerder Electronic GmbH, Germany