

LVIT position sensor with improved linearity

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Summary:

This paper presents a design optimization of a linear variable inductive transducer position sensor to extend the linearity range and decrease the nonlinearity error. The linear variable inductive position sensor has only two coils, serially connected, and the voltages across both coils are measured. The voltage difference is a function of the armature position, which is used for the position estimation. The position sensor has a cylindrical structure with toroidal coils. The optimized linear variable inductive sensor features segmented coils to control wire distribution in the axial direction, or along the armature's movement. The measurement of prototype position is conducted to validate the analysis and design. A measured nonlinearity error of approximately 1.0% can be achieved for a ± 30 mm movement range.

Keywords: LVIT, nonlinearity error, measurement, modeling, position sensor

Introduction

The linear variable differential transformer (LVDT) position sensor is the most common type of transducer used for measuring linear positions. LVDT position sensors offer primary advantages, including cost-effectiveness, low maintenance, a long lifespan, high sensitivity, high resolution, and excellent mechanical durability [1]-[3]. They have three coils: one excitation coil and two pickup coils. In linear variable inductive transducer (LVIT) position sensors, there are only two coils in series. Achieving the maximum nonlinearity range and minimum nonlinearity error is critical for the efficient and accurate operation of position sensors. They are challenging when a limited axial length constraint is demanded. Design optimization is performed to extend the linearity range with low nonlinearity error. The 2D axisymmetric finite element method is used for analysis and optimization of LVIT position sensors. The shape and number of turns are optimized to minimize nonlinearity errors to extend the linearity range. Two cylindrical LVIT sensors with different armature dimensions are considered for the design, prototyping, and measurement.

Design

Fig. 1 presents the models of LVIT position sensors with two coil structures connected in series, with their generated magnetic fields aligned. It shows a cylindrical ferrite armature moving within the coils. The first structure uses two identical cylindrical coils. The second structure uses conical-shaped coils [2]-[3]. The 2D FEM calculated normalized inductive voltages difference, $U_d = U_1 - U_2$, versus armature position is presented

in Fig. 2. The LVIT sensor with conical-shaped coils exhibits a considerably higher linearity range, corresponding to the voltage difference, U_d , versus armature position. It is shown to be within ± 30 mm, compared to ± 15 mm for the LVIT sensor with cylindrical coils. Segmented coils are used in the optimized LVIT model with 14 slots, as illustrated in Fig. 3, enabling more precise control over the number of turns per coil segment.

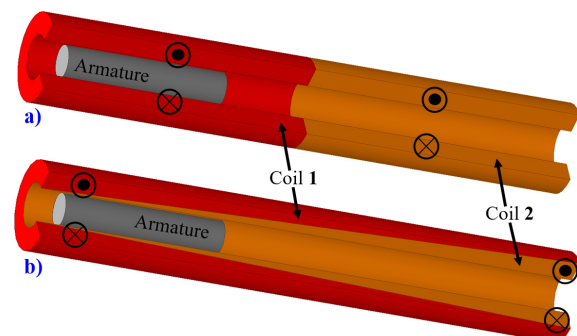


Fig. 1. 3D model of the LVIT position sensor, a) cylindrical shape coils, b) conical shape coils - total axial length of the coils is 100 mm

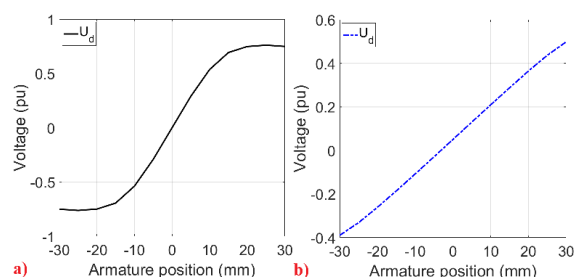


Fig. 2. 2D FEM results of LVIT position sensor with Ferrite armature length of 30 mm- normalized inductive voltage difference versus armature position, a) cylindrical shape coils, b) conical shape coils

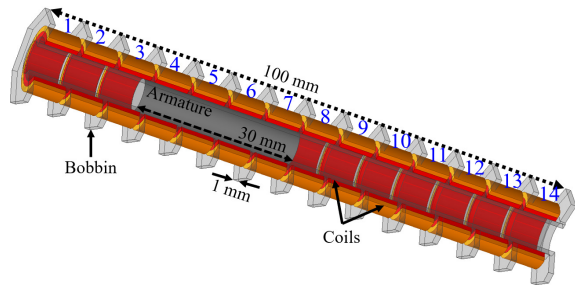


Fig. 3. 3D model of the LVIT position sensor with segmented coils

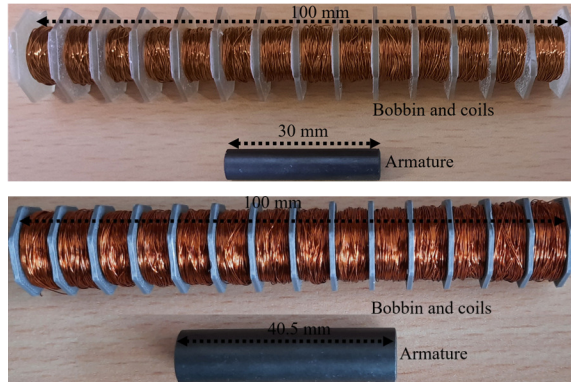


Fig. 4. Experimental LVIT, the coils and the Ferrite armature, a) position sensor 1 with a smaller armature b) position sensor 2 with a larger armature

Experiment

Fig. 4 shows the two prototypes of LVIT position sensors. Sensor 1 has a smaller Ferrite armature measuring 30 mm long and 6 mm in diameter. Sensor 2 has a larger Ferrite armature with a 10 mm diameter and a 40.5 mm length. The voltage ratio, $r = (U_1 - U_2) / (U_1 + U_2)$ versus armature position is shown in Fig. 5 for sensor 1, which shows a lower nonlinearity error of about 0.5% for FEM results and less than 1.0% for experimental results. Fig. 6 presents the voltage-ratio results and the corresponding nonlinearity error for sensor 2. The linearity range with nonlinearity error less than 1.0% is ± 30 mm for sensor 1 and ± 25 mm for sensor 2. The higher nonlinearity error in sensor 2 compared to sensor 1 for movement ranges above ± 25 mm is due to its longer axial length and higher armature diameter, which amplify the effect of the sensor's finite length.

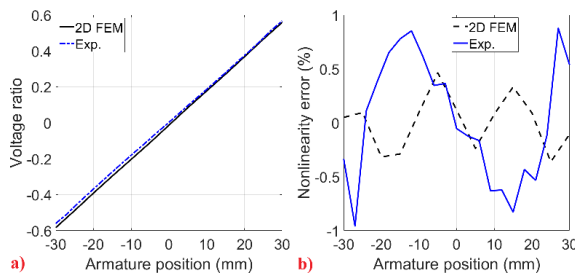


Fig. 5. Experiments vs 2D FEM results of LVIT position sensor 1 with a smaller armature and segmented coils, a) inductive voltage ratio versus armature position, b) nonlinearity error versus armature position

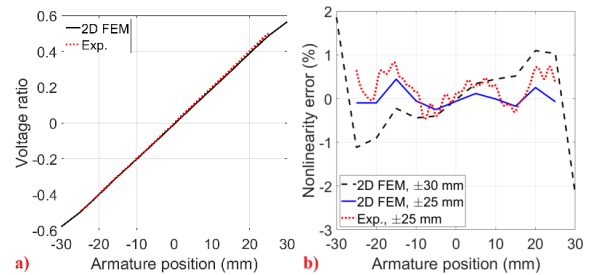


Fig. 6. Experiments vs 2D FEM results of LVIT position sensor 2 with a larger armature and segmented coils, a) inductive voltage ratio versus armature position, b) nonlinearity error versus armature position

The larger armature causes the finite length of the LVIT position sensors to affect the flux uniformity in the inner tube of the coils, reducing it in the larger-armature position. The magnetic flux reduction in the larger armature position decreases sensor voltages at larger positions, thereby increasing the nonlinearity error. The linearity range to total coils axial range ratio is 0.6 ($2 \cdot 30$ mm / 100 mm) for sensor 1 and 0.5 ($2 \cdot 25$ mm / 100 mm) for sensor 2, corresponding to a nonlinearity error below 1%.

Using the voltage ratio, r , also helps compensate for variations in frequency, current, and temperature, and it is well-suited for extending the linearity range. This compensation is essential for the accurate and efficient operation of LVIT position sensors.

Conclusion

The linearity extension of LVIT position sensors was developed and presented. The number and distribution of turns in the coils are optimized using a 2D FEM analysis to extend the linearity range and reduce the nonlinearity error in LVIT position sensors. The nonlinearity error can be reduced to below 1.0% for a ± 30 mm armature movement range using the voltage ratio. The segmented coils were used to simplify the winding and improve the accuracy of wire distribution in the two-winding coils. The LVIT position sensor has a simpler structure than the standard LVDT position sensors, which have a separate excitation coil.

References

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