

LVDT Position Sensor with external armature

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Summary:

This paper presents a novel position sensor based on a linear variable differential transformer (LVDT). The position sensor consists of one excitation coil and one pickup coil, which are perpendicular to each other. The position sensor is a flat-type, featuring a block-shaped armature that moves in parallel with a rectangular-shaped excitation coil. The initial shape of the pickup coil is a rectangular coil, whose dimensions and position are optimized to extend the linearity range of the position sensor and reduce nonlinearity errors. The shape of the pickup coil is optimized to extend the linearity range further. The measurements are conducted to validate the design optimization of the position sensor.

Keywords: Design and analysis, LVDT, linearity range, measurement, position sensor.

Introduction

Extending the linearity range while reducing non-linearity error is a challenging task when the maximum axial length of the position sensor and the maximum armature movement range are constrained. Electromagnetic optimization can be applied to extend the linearity range by optimizing the coil shape and armature dimensions [1]-[3]. Implementing an external signal-processing unit is an alternative method for extending the linearity range. However, it complicates the position-measuring system and reduces reliability, especially in harsh environments. Achieving an adequate linearity range in flat-type LVDT sensors with an external armature is more complex because they have an open magnetic-circuit structure. A novel position sensor with an external armature based on a linear variable differential transformer (LVDT) is developed and presented. The design optimization of the LVDT position sensor is performed using the 3D finite element method (FEM) to reduce nonlinearity errors and extend the linearity range. The dimensions, position, and structure of the pickup coil are optimized to achieve the objectives. The proposed position sensor has a simpler structure than a conventional LVDT, with only one pickup coil instead of two.

Structure

Fig. 1 a) shows the 3D model of the LVDT position sensor's basic design. The excitation and pickup coils are perpendicular to each other. The induced voltage in the pickup coil is proportional to the magnetic flux difference through it, which depends on the armature position. The total net flux linkage in the pickup coil is zero for the zero

position of the armature, and it is nonzero when the armature moves from the zero position. A new structure of the pickup coil is presented in Fig. 1 b), with its dimensions and position altered. The pickup coil axis is rotated relative to the excitation coil axis with an angle of θ , as shown in Fig. 1 b). Fig. 2 a) presents the induced voltage in the pickup coil for the basic and enhanced designs, covering a ± 30 mm movement range, where the curve for the basic structure is not linear; thus, it results in a high nonlinearity error. The corresponding nonlinearity errors (enhanced) for the ± 20 mm and ± 25 mm ranges are shown in Fig. 2 b) for $\theta = 3.0$ deg. Linearity is considerably improved in the enhanced structure compared to the basic structure.

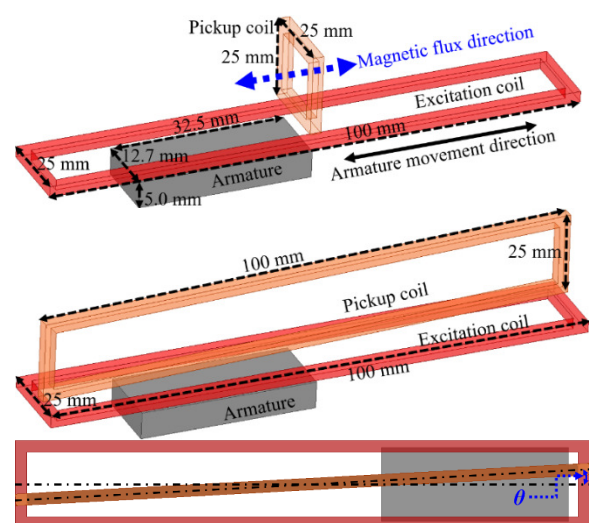


Fig. 1. 3D model of LVDT position sensor, a) basic structure (up), b) the enhanced structure of the LVDT position sensor (bottom), where the pickup coil was rotated with an angle of θ

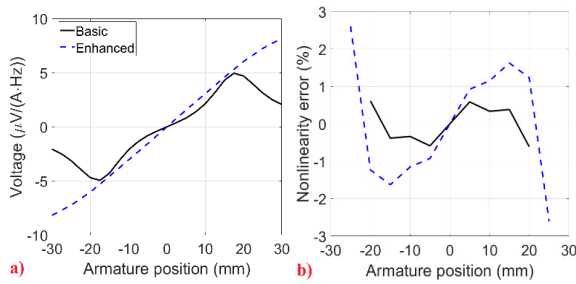


Fig. 2. 3D FEM results of LVDT position sensors with Ferrite armature ($\theta=3.0$ deg. for enhanced structure), a) voltage to current and frequency ratio versus armature position, b) nonlinearity error versus armature position (enhanced structure)

Experiments

Fig. 3 shows the prototyped sensor for the measurement. The experimental results for voltage and nonlinearity error in the ± 20 mm range for the enhanced sensor using Ferrite armature (Fig. 1 b)) are presented in Fig. 4 and agree well with the calculations in Fig. 2 a) for the voltage. The measured nonlinearity error is about 1.5%, which is higher than the simulated nonlinearity values, which are below 1.0%. Imperfections in the 3D-printed coil bobbin manufacturing process cause the discrepancy between the 3D FEM and measurements for the nonlinearity error. The measured nonlinearity error can be reduced to the calculated level by improving manufacturing precision. The armature length can be decreased from 32.5 mm to a smaller value. It helps achieve a higher linearity range despite the LVDT position sensor's decreasing sensitivity.

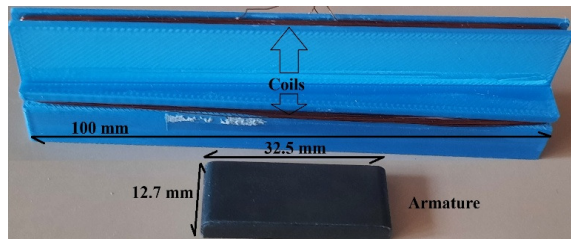


Fig. 3. Prototype of enhanced LVDT sensor- Bobbins, coils, and Ferrite armature ($\theta=3.0$ deg.)

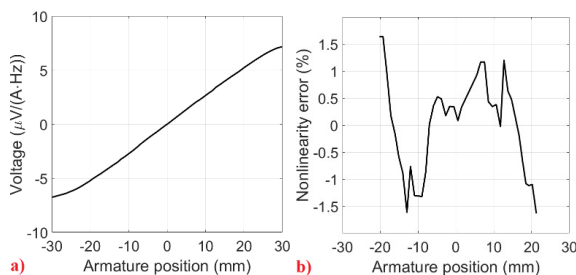


Fig. 4. Experiment results of enhanced LVDT position sensor, a) voltage to current and frequency ratio versus Ferrite armature position, b) nonlinearity error versus Ferrite armature position (The voltage was processed by a phase-sensitive detector (lock-in amplifier))

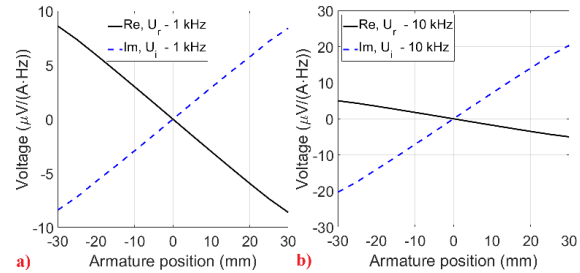


Fig. 5. 3D FEM results of LVDT position sensors ($\theta=3.0$ deg. for enhanced structure) with nonmagnetic conductive armature – real (Re) and imaginary (Im) components of voltage to current and frequency ratio versus armature position, a) 1 kHz, b) 10 kHz

Using Nonmagnetic Conductive Armature

The armature material is changed from Ferrite armature to a nonmagnetic conductive one with an electrical conductivity of 30 MS/m. Fig. 5 shows the real (Re) and imaginary (Im) components of voltage at 1 kHz and 10 kHz. The voltage graph versus armature position shows adequate linearity with a nonmagnetic conductive armature, comparable to that of a magnetic Ferrite armature. Increasing frequency enhances the sensor's sensitivity with a nonmagnetic conductive armature. The real and imaginary components of voltages are obtained relative to the excitation coil current as a reference signal.

The design, analysis, and measurements of a novel LVDT position sensor were presented. The presented sensor features only one pickup coil, which simplifies manufacturability and enables a cost-effective position sensor. The shape and dimensions of the pickup coil have been optimized to extend the linearity range and reduce nonlinearity error below 1.0% using 3D FEM. Optimizing the pickup coil shape and armature length can increase the linearity range to ± 25 mm and ± 30 mm with low nonlinearity error. The proposed position sensor features a structure with an external armature, isolating the coils from the moving armature. It makes a suitable position sensor for various industrial applications in a harsh environment.

References

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