

A Position Sensor for a Micro-Actuator

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Summary: A position sensor for a micro-actuator is being developed. The sensor operates by sensing the change in inductance and coupling factor between two coils, as the piston moves in the actuator. The presented sensor is extremely small; it only adds 0.4 mm to the diameter of a φ 1.6 mm actuator. The sensor can measure the position of the invar core with an accuracy of ± 10 µm over a stroke that equals the total length of the actuator.

Keywords: Position sensor, Displacement sensor, Actuator

1 Introduction

The ongoing miniaturization and continuing integration of functions are the driving force behind the development of a new generation of microrobots. These so-called “agile microrobots” will exhibit a high number of degrees of freedom, a large workspace and a high workload, all in a restricted volume. To realize this, several major issues remain to be solved. The presented work is part of a project that addresses one of these issues: the development of intelligent micro-actuators with a high power density. The hydraulic actuator aimed at, has a diameter of about 1 mm, a stroke of about 10 mm, a speed of 10 mm/s, and a force in the Newton range. To be able to realize accurate closed-loop controlled actuation, position sensing with a precision of about 10 µm is necessary. The application in a micro-actuator imposes that the dimensions have to be minimized. Ideally the position sensor should increase neither the diameter nor the length of the actuator. This paper tries to maximally exploit the available space by modifying the well-kown LVDT principle.

2 Measurement principle

Inductive systems are excellent for measuring linear displacement [1,2]. They offer a nearly infinite resolution, only limited by the data acquisition system, and they are highly reliable and robust due to the contactless measurement principle. The DVRT (differential variable reluctance transformer or half-bridge LVDT; fig. 1.a) and the LVDT (linear variable differential transformer; fig. 1.b) offer excellent linearity and therefore are the most frequently used linear displacement sensors. However, for the position sensing in a micro-actuator, it is an important drawback that both use a series connection of 2 coils (series opposed configuration in case of the LVDT). This implies that the stroke is limited to half the length of the sensor, leading to an unacceptably low stroke-to-length ratio of the actuator. Therefore in this paper we investigate the single-ended counterparts of the DVRT and the LVDT, as shown in fig. 1. c and d.

![Fig. 1. Overview of inductive displacement measuring systems: DVRT(a), LVDT(b) and their single-ended counterparts (c and d).](image)

The variable reluctance transformer (fig.1.c) is based on the change of the coil inductance with the position of the core. Its application to sense the rod position in a hydraulic cylinder has already been described in [3]. The change in inductance is the net result of 2 counteracting effects: 1) When a high permeability rod is inserted in the coil, the magnetic reluctance decreases, resulting in a higher magnetic flux, and thus in an increase of the coil inductance. 2) When a conductive rod is inserted in a coil that is driven with an AC current, eddy currents will circulate in the opposite direction, reducing the magnetic flux in the coil and thereby its inductance. In this paper, a high permeability invar rod is used, so the first effect is dominant in frequency range of interest.
The improvement proposed in this article, allows to increase the performance of the variable reluctance transformer with a factor 8. This is achieved by adding a second coil in parallel, as shown in fig.1.d. Suppose both coils are evenly spread over the cylinder length, and a high permeability core is inserted into the cylinder. The magnetic coupling factor between both coils will then increase nearly linear with the insertion of the core.

If the primary coil is driven at a constant amplitude with a low impedance driver, both effects described above add up. Inserting a core increases the voltage \( V_p \) due to the resistive division with the source impedance \( R_s \), and simultaneously increases the coupling factor with the secondary coil, increasing the voltage \( V_s \) even faster.

3 Measurement results and discussion

The concept described above was tested with an aluminum cylinder (\( \Phi 1.6 \text{ mm} \) and matching invar core (see fig.2). To simplify the coil winding, a single wire consisting of 4 strands of \( \Phi 40 \mu \text{m} \) was used. One strand is used as the primary coil, the others are connected in series to increase the output voltage.

In a first measurement, the primary coil was connected to the output of a network analyzer and the voltages on the primary and secondary coil were measured (see fig.3); both without core, and with a 1 cm long core fully inserted. It can be seen that the voltage on the secondary coil is more sensitive to the presence of the core. A frequency of 30 kHz was chosen, as a trade-off between sensitivity and signal magnitudes.

To measure the position of the core in the actuator, the primary coil was connected to a function generator (sine wave, 5 V amplitude, 30 kHz, \( R_s=50 \Omega \)). The signal on the secondary coil was buffered, amplified (20 dB) and its amplitude was measured. The core was extended and retracted 10 times. Fig.4.a shows the average output voltage as a function of the insertion of the core in the coil. No significant hysteresis was observed. The repeatability standard deviation on the output voltage is shown in fig.4.b. After calculating the sensitivity of the sensor, for each rod position the standard deviation can be converted to the 95% confidence interval in terms of position. For each rod position, the result is within ± 10 \( \mu \text{m} \).

Future work will focus on the actuation mechanism and the extension of the position sensing principle to dual acting actuators.

![Fig. 2. Photograph of the actuator, with sensor coil, and invar piston.](image)

![Fig. 3. Sensitivity of the sensor as a function of frequency.](image)

![Fig. 4. a) Measured output voltage as a function of core insertion into the coil. b) Standard deviation of the output voltage. c) Repeatability in terms of position.](image)

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