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ABSOLUTE POSITION SENSING IN AIRCRAFT CONTROL SYSTEMS USING 3D MAGNETIC SENSORS

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Abstract: *This paper proposes an absolute position sensing methodology for aircraft electromechanical actuators using 3D Hall effect sensors as a replacement for traditional, complex LVDT systems. While traditional sensing technologies often face limitations regarding mechanical wear, electromagnetic interference, and system complexity, the proposed approach leverages multi-axial magnetic field mapping to determine position as a proportional angular vector. Experimental validation across wide temperature range demonstrates reliable performance under extreme environmental conditions, establishing this non-contact method as a durable and viable alternative for short-stroke actuator applications*

Keywords: Absolute position estimation, Hall sensors, 3D magnetic sensors, Electromechanical actuator

1. Introduction

The primary objective of this project was to modernize an electromechanical actuator by replacing a brushed DC motor drive with BLDC (brushless DC) and appropriate motor control. Furthermore, the project necessitated replacing potentiometer-based measurement with LVDT (linear variable differential transformer) position sensing and a suitable LVDT driver and other signal conditioning circuitry. Although this still represents an ongoing project, work on an alternative sub-project has been initiated.

Its primary goal is to consequently also replace the LVDT position sensing utilising high-frequency analog signals and complex processing circuitry (both prone to future EMI/EMC (electromagnetic interference/compatibility) problems) by a feasible alternative based on magnetic field mapping of a displaced neodymium permanent magnet. Additionally, practical objective is also to reduce spatial footprint and manufacturing costs of the entire device.

Hence, the merit of this contribution is to evaluate how precise the absolute position estimation for a given electromechanical actuator could be, considering the range of environmental conditions in which the device must be capable of reliable operation.

2. Overview of position sensing in electromechanical actuators

The use of the Hall effect for position detection currently represents an established and well-documented method. The principle itself was discovered as early as 1879 by physicist Edwin Hall. A key milestone for the widespread adoption of Hall sensors was the development of semiconductor technologies and their integration onto silicon chips in 1960s and 1970s, which enabled deployment in the fields of automation, computing, and the automotive industry as stated in work of Ramsden (2001).

Compared to conventional technologies, such as electromagnetic resolvers or potentiometers, Hall effect-based sensors offer a number of critical advantages. Among the most significant is the non-contact nature

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of the measurement, which eliminates mechanical wear and ensures high durability even in demanding operating conditions, while maintaining compact dimensions and low weight as described by Yenuganti et.al. (2025) and Crescentini et. al. (2020). These properties can be utilized when replacing standard industrial resolvers to reduce operating costs Kang et. al. (2020), or for precise spring deformation measurement of control wheel forces in internal pipe inspection devices by Jezny and Čurilla (2013). Currently, Hall effect sensors are also being intensively researched for the precise measurement of the speed and position of permanent magnet synchronous motors (PMSM) for example by Akrami et. al. (2023) or Du et al (2018).

Despite these benefits, the wider implementation of Hall sensors in the aerospace industry, especially in critical systems such as electromechanical actuators (EMA) for primary or secondary flight control remains limited. This limitation stems from stringent requirements for data integrity and electromagnetic interference (EMI) resistance. Another challenge is the influence of external conditions, where rapid temperature changes associated with the aircraft's ascent and descent can negatively affect sensor accuracy; this issue is addressed in detail by a Zhong et. al (2025) study utilizing advanced optimization models. The possibilities of integrating Hall sensors directly into the motor of an aerospace actuator (BLAC type) have already been explored in a Toman et. al. (2014) study.

3. 3D Hall Sensors Application and Idea Execution

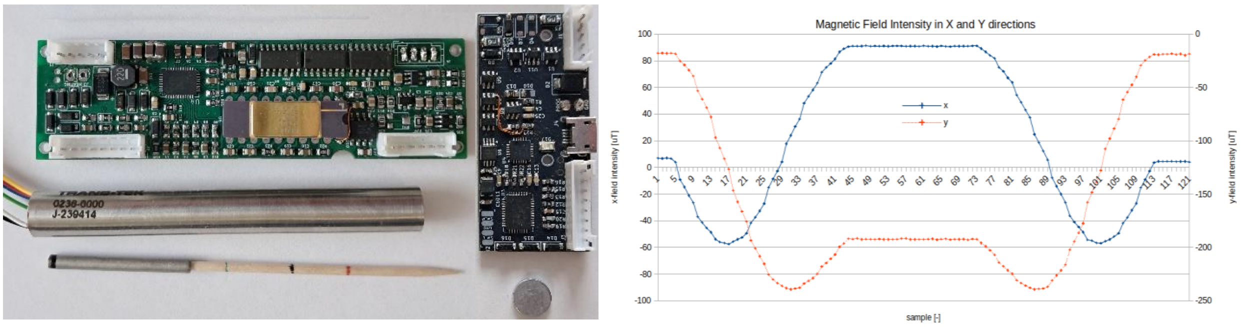

Fig.1: New and newer proposed electronics design (left), magnetic field intensity when extending and retracting the actuator's arm (right).

Fig.1 (left) shows the core and the LVDT transformer used for accurate position sensing and the developed electronics for the modernisation of the actuator (green PCB, left) while on the right there is the newly proposed solution with three 3D HALL sensors and the sensing neodymium magnet which is to be mounted onto the extendable electromechanical actuator's arm.

3.1 Absolute Position Estimation from the Magnetic Field

The principle of position estimation is the change of the magnetic field along with the extension/retraction of the arm. The measured magnetic field intensity values in X and Y axes can be seen in the Fig.1 (right). The Z-axis is omitted from this analysis because its variations are negligible (there is no movement along the Z axis and also measured magnetic field is too weak due to physical magnet orientation). This chart depicts a single extension followed by retraction of the actuating rod and shows how the intensity of the magnetic field transitions with the movement.

The absolute position is determined by calculating a two-dimensional vector rotating around a predefined center-point in the magnetic field intensity plot. The principle can be seen in Fig.2 (left). We chose a center-point A from which a vector in the magnetic field is calculated. Point B represents the initial position of the actuator's arm (retracted in this case) while its extension is represented by rotation of the vector anticlockwise over point C (middle/central position) up to point E where the arm is fully extended. Retraction of the arm then goes backwards along this C-shaped curve over the arbitrary position D into a fully retracted state marked by the letter B. Shape of this c-curve is determined by the physical geometry of the device under test while also the initial positions B and final position E are given by position of the magnet on the actuator's arm. The absolute position of the arm is then directly proportional to the angle formed by the vector with the positive direction of the X axis - the position angle φ.

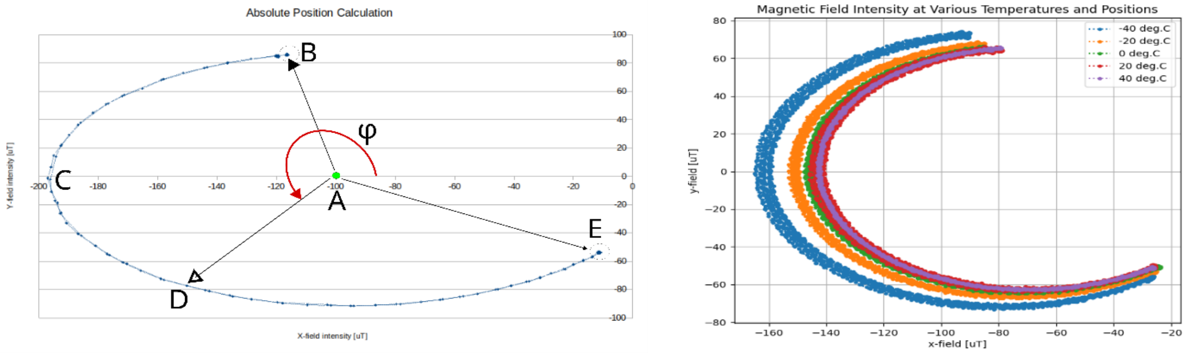

Fig.2: Principle of the position angle φ calculation (left), temperature drift of the C-curve used for position estimation (right).

3.2 Validation

As application of this project is targeted into DO-160 required temperatures range (from -55°C to +70°C), our concern was how will the evaluated magnetic sensors withstand these conditions. The following data originate from experiments conducted in a thermal chamber with focus mainly onto the lower of the temperature range (to validate reliability and survivability of the used electronic components) while tests from the higher ranges were limited due to used reference measurement equipment limitations. Hence the explored temperatures varied from -60°C to +40°C as monitored and controlled within the environmental chamber. Discrepancies are evident in the upper temperature range, resulting from inaccurate factory calibration of the magnetic sensor's thermometer subsystem.

Arrangement of this experiment was as follows: The actuator was set to its central position and remained stationary. The centre of the attached neodymium magnet which moves along with the actuator position was located in the y-axis of the hall sensor (the magnetic field in the x-axis was at its peak) while the field along the x-axis was symmetrical.

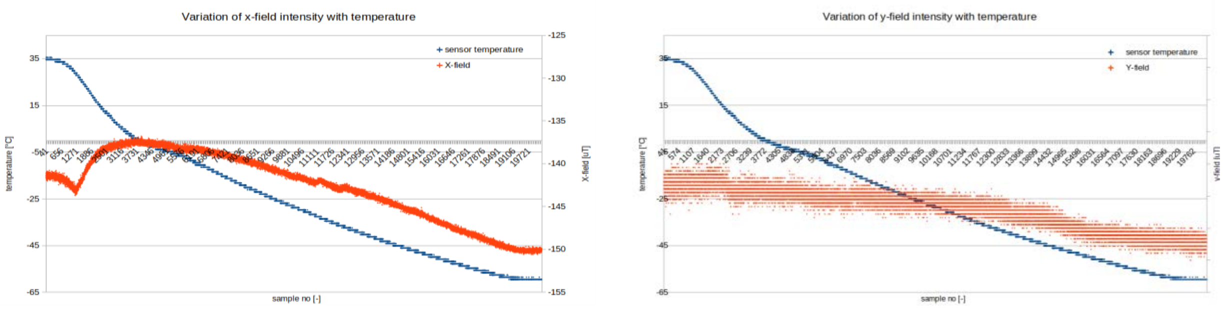

Fig.3: Temperature variation of the X and Y magnetic fields.

The charts on the Fig.2 (right) show impact of thermal drift on magnetic field intensity measurements across a broad temperature gradient. As the ambient temperature decreases, both the X and Y axes exhibit a clear negative correlation between temperature and measured intensity, indicating that the sensor's response is highly dependent on its internal thermal state. This phenomenon, often attributed to the temperature coefficient of the sensor's physical components, introduces systemic errors that may severely compromise the accuracy and repeatability of the data if not properly compensated for.

Besides the temperature variations in field measurement there is a secondary factor that might play a role in the absolute position estimation - noise of the magnetic sensor (Fig.3 and Fig. 4, red lines). While initial observations suggest high raw noise, it ultimately does not impact the position angle φ and resulting absolute arm position. Temperature drifts have the tendency to shift the arcuate trajectory in both dimensions. Estimates of the end positions (retracted (0% and extended 100%, points *A* and *E*) have moved slightly (which can eventually be compensated for) but the position angle φ along the movement track does not experience any such dramatic changes (Fig.2 right).

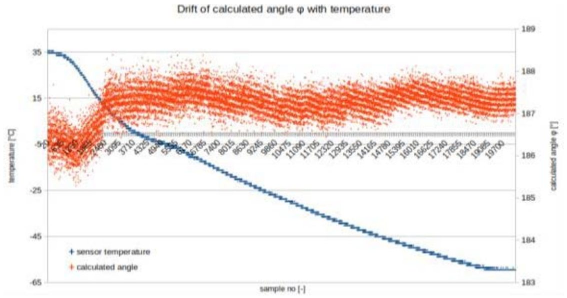

Fig.4: Drift of the calculated angle and absolute position with temperature.

3.3. Limitations

The usable magnetic field of the used neodymium magnet is limited. The specimen depicted in Fig.1 has a maximal measurable range around 2 cm. Depending on the available physical space a stronger / larger magnet could be used. If such an option is not feasible, we propose to use multiple sensors along the measuring edge (note the three identical ICs at the top edge of the black PCB) which can be switched among as needed or a specific data-fusion algorithm can be used to estimate the absolute position accurately along greater distances.

4. Conclusions

Absolute position estimation via magnetic field mapping represents a viable alternative to LVDT sensing. LVDT position sensing. Even though it encounters certain influences from temperature variations and inherent sensor noise, our proposed approach could serve as an alternative especially for short-stroke actuators. In comparison to potentiometer-based position measurement the magnetic approach offers virtually unlimited life-span for the device and less complexity and EMI problems than the LVDT approach. The limitations of short magnetic field ranges can be mitigated by utilizing multiple sensors which can be switched between or the data can be fused.

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