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A Concept for Application of Hall Sensors in Measurement of Magnetic Field over Magnetic Catapult Tracks

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Abstract. The growing demand for commercial unmanned aerial vehicles (UAV) requires that innovative technical solutions for the critical aspects of UAV servicing, must be researched. The magnetic catapult discussed in this work is an interesting alternative to the existing UAV deployment or launch platforms. This paper presents the research designed to facilitate the measurement and analysis of the position of a launch truck applied in a UAV magnetic catapult with tracks. The measurement system discussed herein comprised a transducer connected to Hall sensors which were spaced evenly at the base of a superconductor pod. A displacement of the superconductor pod relative to the magnetic field resulted in the variation of the voltage output from individual Hall sensors. A proprietary algorithm was developed and controlled stepper motors which displaced the assembly of the superconductor pod with the Hall sensors along the test track of the UAV magnetic catapult.

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At the same time as the displacement was sensed by the Hall sensors, they were reading the real-time magnetic strength; it was therefore critical for the microcontroller, which executed the control algorithm, to operate at a sufficient processing frequency (speed). The proprietary control algorithm was executed by an ATMEL ATmega2560 RISC processor. The processor system read the status of every Hall sensor in the assembly and compared it to the reference voltage outputs stored in the microcontroller's memory. The difference between the voltage output reading and the reference voltage outputs, and the superconductor pod's geometry was used to determine the superconductor pod's position along the magnetic tracks of the UAV magnetic catapult.

Keywords: Hall sensors, magnetic levitation system, magnetic catapult, superconductivity

1. INTRODUCTION

An alternative to the existing UAV launch platforms is the UAV magnetic catapult analysed in this paper. The UAV magnetic catapult enabled repeatability of the launch parameters, protection of the UAV against g-loads, and operator's safety.

This paper discusses a solution comprising the application and a certain layout of Hall sensors, which were solid-state devices and provided key data by measuring the components of the magnetic field induction vector. The key data was essential to analyse the movement of a levitating launch truck of the UAV magnetic catapult. An electronic system based on an AVR ATMEGA ATMEGA2560-16AU read the status every Hall sensor in the assembly and compared it to the reference voltage outputs stored in the microcontroller's memory. The difference between the voltage output reading and the reference voltage outputs, and the superconductor pod's geometry was used to determine the superconductor pod's position along the magnetic tracks of the UAV magnetic catapult. This allowed a calculation of the levitation reaction forces and moments applied to the levitating supports at their actual positions in space.

2. UAV MAGNETIC CATAPULT

The UAV magnetic catapult assembly used in this research was built under EU FP7 GABRIEL (Integrated Ground and on-Board system for Support of the Aircraft Safe Take-off and Landing) [2, 3]. The UAV magnetic catapult comprised a take-off runway tracks formed by high-energy permanent magnets and a launch truck which levitated above the tracks by the mediation of four levitating supports (Fig. 1).

The take-off runway tracks comprised neodymium magnets, each sized 15 × 15 × 5 [mm] and with the field polarity aligned with height, being the smallest dimension. The magnet polarity alternated along the track cross-section to provide gutter-like shaped magnetic field force lines.

The geometry of the magnetic field force lines defined the stability of the levitating launch truck assembly.

The other component was the launch truck. The launch truck levitated above the magnetic catapult tracks with the aid of four levitating supports. Each support comprised a pod housing high-temperature superconductors immersed in liquid nitrogen (Fig. 2).

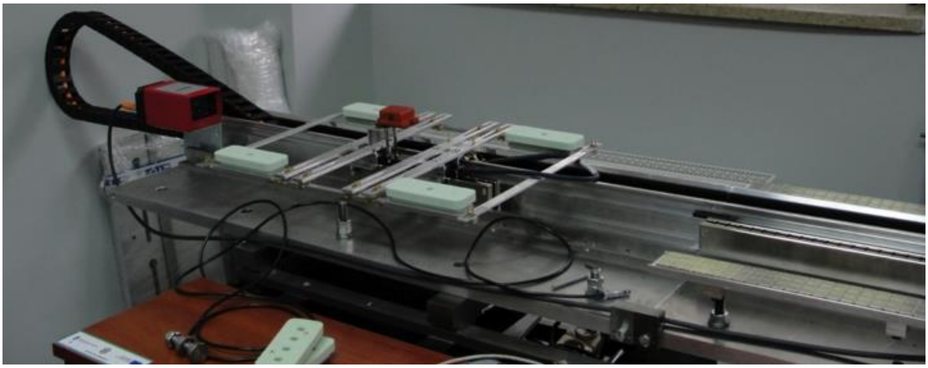

Fig. 1. Components of the UAV magnetic catapult (EU FP7 GABRIEL)

The force of interaction between the levitating supports and the tracks depended on the magnetic field strength which changed with the position of the levitating supports over the tracks. The magnetic field strength quickly reduced inversely to the distance from the tracks; the neodymium magnet configuration which generated the 'magnetic gutter' along the track generated a magnetic field gradient across the tracks [1, 2].

The magnetic field was designed to be stable along the tracks to provide a lossless translation of the levitating truck. This was a theoretical assumption; in reality, the magnetic field would be disturbed by the magnet geometry and their imperfect alignment.

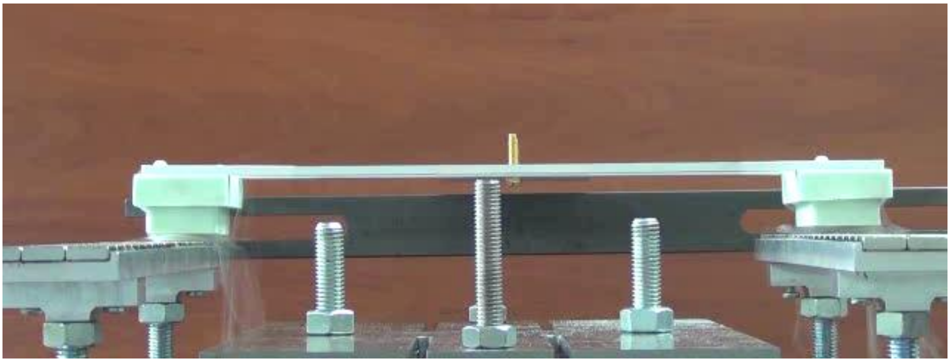

Fig. 2. Launch truck levitating supports [2]

The levitation reaction forces and moments depended on the shape and force of the magnetic field, which itself depended on the alignment of the magnets along the track. The resulting heterogeneous magnetic field was defined at every point by a magnetic field induction vector and a gradient of the vector ∇B. Force F and moment M applied to the superconductor are expressed with the following relations:

$$F = \mu \nabla B\,; \qquad M = \mu \times B \tag{1}$$

with: μ – superconductor magnetic moment; B – magnetic field induction vector.

The magnetic field form (with the tracks forming a gutter, where the magnets oriented along the tracks were in monopolar contact, whereas the magnets oriented crosswise to the tracks were in bipolar contact) stabilised the position of the launch truck. When moving along the axis of the tracks, a superconductor was exposed to an input of a moment of force striving to rotate the superconductor until the magnetizing vector was aligned with the magnetic induction vector, following which a force proportional to the product of the superconductor magnetizing vector and the magnetic field gradient should force the superconductor to the centreline in between the tracks.

3. MAGNETIC STRENGTH MEASUREMENT

3.1. Measurement system concept

A spatial measurement of the magnetic field generated by the neodymium magnets of the UAV magnetic catapult required constructing a custom test bench, whose primary component included magnetic field sensors.

The operating principle of magnetic field sensors is to process magnetic-encoded information or, by conversion of the information into electric outputs for downstream processing in electronic systems, respond to a wide range of positive and negative magnetic fields. The magnetic sensors most commonplace in science and engineering are Hall sensors. A Hall sensor senses magnetic flux and outputs a Hall voltage difference dependent on the direction and density of the magnetic flux.

The tested SS49E Hall sensor provided a voltage output linearly proportional to the applied magnetic field. This specific Hall sensor was chosen because of its relatively small size, a plastic enclosure, a linear analogue voltage output, an operating range between -40°C and +85°C, and an analogue voltage output range between 0 V and 5 V. In the tests carried out with the custom test bench, the voltage output was 0.86 V at -150 mT and 4.21 V at 150 mT.

The output from a single Hall sensor was insufficient to determine the position and orientation of a launch truck levitating support. Hence, an array of Hall sensors equidistant along the superconductor pod (Fig. 3).

Hall sensors 3, 5, 7, 11, 13, and 15 were arranged horizontally below the superconductor pod (as shown with the broken line in Fig. 5), and Hall sensors 1, 2, 4, 6, 8, 9, 10, 12, 14 and 16 were arranged vertically.

The array of equidistant Hall sensors provided much more data and enabled generating a family of magnetic field induction characteristics in the function of displacement.

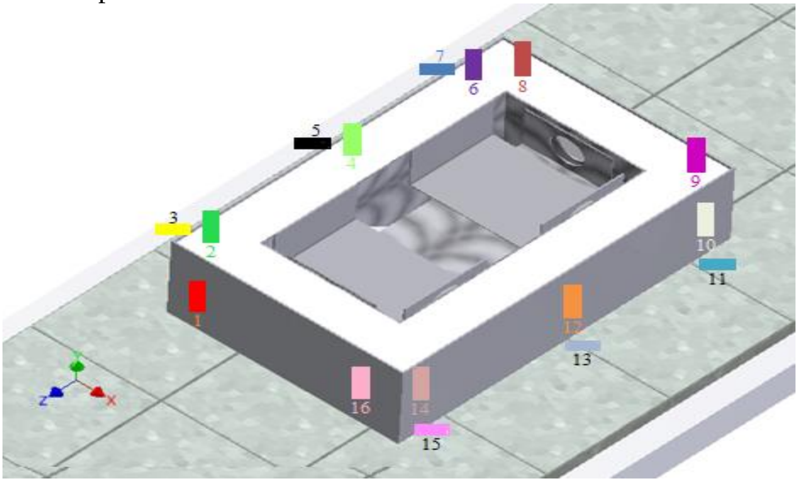

Fig. 3. Layout of 16 Hall sensors

Following an analysis of Hall sensor array application, a test bench was designed and constructed to permit measurement and position analysis of the launch truck on the UAV magnetic catapult tracks (Fig. 4). The measurement system shown herein comprised a microcontroller connected to Hall sensors which were spaced evenly at the base of a superconductor pod. A displacement of the superconductor pod relative to the magnetic field resulted in the variation of the voltage output from individual Hall sensors. A proprietary algorithm was developed and controlled stepper motors which displaced the assembly of the superconductor pod with the Hall sensors along the test track of the UAV magnetic catapult. At the same time as the displacement was sensed by the Hall sensors, they were reading the real-time magnetic strength; it was therefore critical for the microcontroller, which executed the control algorithm, to operate at a sufficient processing frequency (speed). The proprietary control algorithm was executed by an ATMEL ATMEGA2560-16AU microcontroller. The processor system read the status of every Hall sensor in the assembly and compared it to the reference voltage outputs stored in the microcontroller’s memory. The difference between the voltage output reading and the reference voltage outputs, and the superconductor pod’s geometry was used to determine the superconductor pod’s position along the magnetic tracks of the UAV magnetic catapult.

Hence, the constructed test bench enabled an experimental determination of the relationship between magnetic field distribution with the type and arrangement of permanent magnets within the track, and identification of the linear and angular position of the launch truck levitating support of the UAV magnetic catapult.

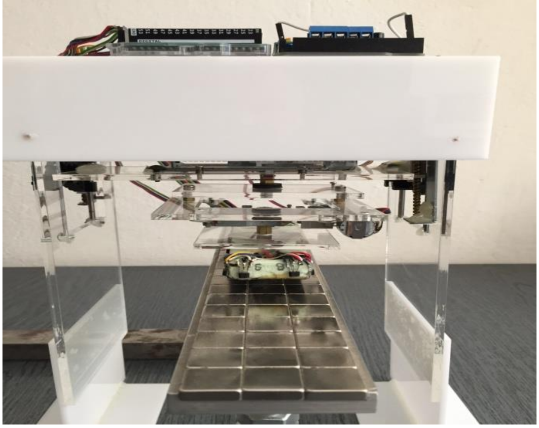

Fig. 4. Test bench for the measurement of the launch truck position relative to the magnetic tracks

3.2. Test measurement results

The paper presents the test measurement results which allowed an analysis of the response of a single levitating support beneath the launch truck on the UAV magnetic catapult.

A case was studied by which the levitating support (superconductor pod) with the Hall sensors installed was hovering 1 mm over the track with the neodymium magnets arranged to form a gutter. During the test measurement, the levitating support was displaced in the horizontal plane, first across the track (Fig. 5) and then along the track (Fig. 6). A displacement of the superconductor pod relative to the magnetic field resulted in the variation of the voltage output from individual Hall sensors. During a displacement, each Hall sensor output a voltage value linearly proportional to the magnetic field generated by the tracks. Charts (Fig. 5 and 6) show the readings from the Hall sensors arranged at the single levitating support as shown in Fig. 3.

As shown in Fig. 5, the levitating support was at the side edge of the track in its initial position. This is proven by the minimum voltage outputs from Hall sensors 2, 4 and 6. At the same time, the other side of the levitating support was located over the central row of the track magnets with the opposite polarity, as shown by the maximum voltage output from Hall sensors 10, 12 and 14.

The chart trend following the displacement shows that the horizontally arranged Hall sensors (located beneath the superconductor pod) provided extreme magnetic field indications, whereas the vertically arranged Hall sensors gave a reading with a gutter-like profile, which conformed with the orientation and layout of the track magnets which were in bipolar contact. This formed two specific extremes over the time of transition of the Hall sensors through the magnet wall interfaces.

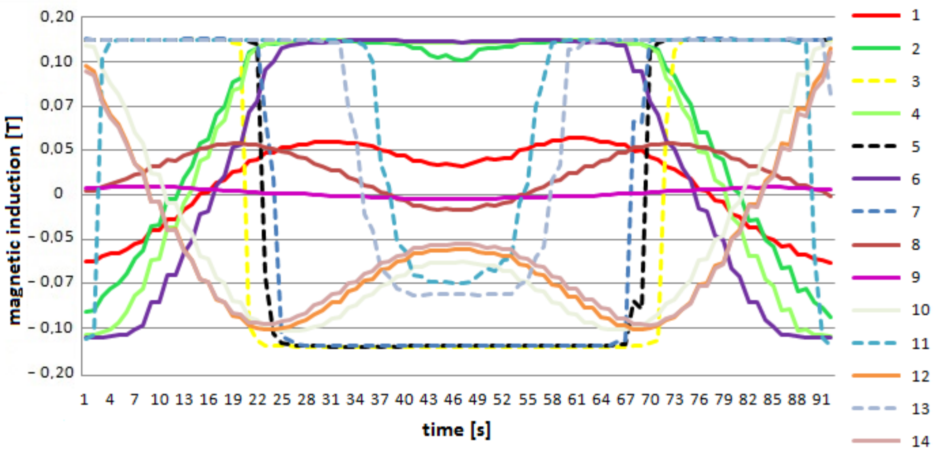

Fig. 5. Readings from the Hall sensors located at the launch truck levitating support during the motion transverse to the magnetic catapult tracks

The next chart (Fig. 6) shows the readings from the Hall sensors with the levitating support displaced along the magnetic catapult track.

According to the orientation of the magnets in unipolar contact along the track axis, the magnetic field strength in the same direction revealed a slight interference from the magnet geometric features and the imperfection of alignment of the magnets. This is confirmed in Fig. 5, where the voltage outputs from individual Hall sensors revealed small variations in time. Not unlike in the previous figure, not the symmetry of readings between Hall sensors 2, 4 and 6 and Hall sensors 8, 10 and 12, where Hall sensors 2, 4 and 6 revealed the lowest magnetic field strength. The findings suggest that Hall sensors 1, 8, 9 and 16 were at the magnet interfaces during this test measurement. An interesting finding is that the horizontally arranged Hall sensors 3, 5, 7, 11, 13 and 15 had maximum readings throughout the test measurement duration. This will be investigated further.

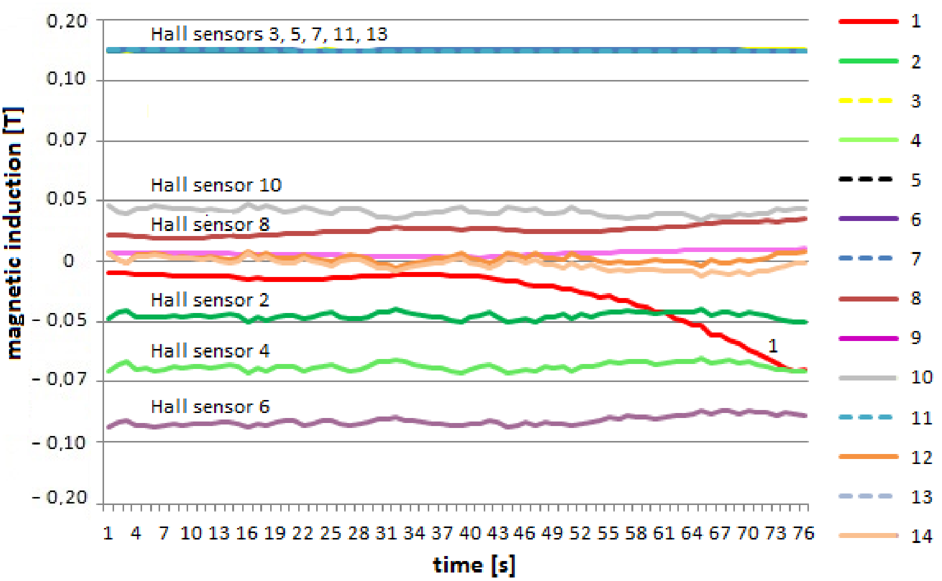

Fig. 6. Readings from the Hall sensors located at the launch truck levitating support during the motion along the magnetic catapult tracks

4. CONCLUSION

The test measurements of the magnetic field which enveloped the levitating support provided key data that are essential to any analysis of the motion (displacement) of the levitating launch truck of the UAV magnetic catapult. A correct layout of the Hall sensors which measured the magnetic field induction vector components helped identify the linear and angular position of the launch truck levitating support. This allowed a calculation of the levitation reaction forces and moments applied to the levitating supports at their actual positions in space. The position measurements of all four-levitating support of the launch truck should, at future stages of research, enable the development of an algorithm for follow-up control of the launch truck position and a precise alignment of the aircraft while loading it on the launch truck.

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Koncepcja wykorzystania czujników Halla do pomiarów pola magnetycznego ponad torami wyrzutni magnetycznej

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Streszczenie. Rosnące zapotrzebowanie na komercyjne bezzałogowe statki powietrzne (BSP) wymaga poszukiwań nowatorskich rozwiązań technicznych, związanych z krytycznymi aspektami obsługi tychże obiektów. Interesującą alternatywą dla istniejących rozwiązań jest analizowana w pracy wyrzutnia magnetyczna. W pracy zaprezentowano badania umożliwiające pomiar i analizę położenia wózka startowego wyrzutni bezzałogowych statków powietrznych (BSP) na torach magnetycznych. Prezentowany w pracy układ pomiarowy składa się z przetwornika połączonego z czujnikami Halla rozmieszczonymi równomiernie u podstawy pojemnika z nadprzewodnikami. Zmiana płożenia pojemnika względem pola magnetycznego powoduje zmianę napięcia wyjściowego poszczególnych czujników Halla. Opracowany algorytm steruje silnikami krokowymi, które przesuwają pojemnik z czujnikami względem badanego toru. W tym samym czasie czujniki odczytują wartość pola w czasie rzeczywistym, dlatego istotne jest, aby mikrokontroler realizujący algorytm działał z odpowiednio dużą prędkością. Do realizacji autorskiego algorytmu został użyty procesor RISC produkcji ATMEL ATmega2560. Układ mikroprocesorowy odczytuje stan każdego czujnika i porównuje go z danymi zapisanymi w pamięci. Na podstawie różnicy odczytu i geometrii pojemnika wyznaczane jest jego płożenie na torach magnetycznych.

Słowa kluczowe: czujniki hallotronowe, system lewitacji, wyrzutnia magnetyczna, nadprzewodnictwo