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Design of a Continuously Varying Electro-Permanent Magnet Adhesion Mechanism

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Abstract

The most common adhesion mechanism used in mobile robots, which are used for inspection tasks in ferromagnetic structures, is the magnetic adhesion mechanism. Magnetic adhesion can be produced by Permanent Magnets (PMs) or Electro-Magnets (EMs). Both of them have intrinsic limitations such as: a fixed magnetic force for PMs or the need of a constant electric power supply for EMs. These restrictions have a substantial impact on the performance of the mobile robot when manoeuvring in intricate structures, evading tough obstacles or energy consumption. Nevertheless, the work in this paper presents a novel approach to overcome these restrictions by employing Electro-Permanent Magnet (EPM) technology in the adhesion mechanism design. By simply applying a short electric pulse it is possible to switch On and Off the adhesion force. Furthermore, by controlling the amplitude of the pulse the magnetic force can be driven to a desired value between On and Off states, enabling the continuous variation of the magnetic force. The results validate the feasibility of the proposed design and consequently the potential use of EPM for adhesion mechanism in mobile robots.

Keywords Electro-Permanent Magnets; Magnetic Adhesion; Climbing Robots.

1. INTRODUCTION

Adhesion mechanisms, for the particular case of ferric structures, have been constrained due to the lack of an efficient, continually adaptable adhesion mechanism, which allows the Unmanned Vehicles (UV) to manoeuvre in complex structures and overcome difficult obstacles. Even though different types of adhesion technologies can be employed for attaching to complex structures [1–4], these present several disadvantages when compared to magnetic technologies [1–7]. Hitherto, most of the magnetic climbing UVs have been designed to perform specific tasks, in a particular environment. This is mainly due to the limitations of current available adhesion mechanisms [8]. These magnetic adhesion mechanisms are divided into passive or active.

The passive mechanisms use Permanent Magnets (PM) as the source for the adhesion force, resulting in a constant magnetic attaching force. This constraint makes it difficult for the mobile robot to move in a complex environment and avoiding different types of obstacles. On the other hand, an alternative approach for overcoming the PM constraint is the use of Electro Magnets (EM) -active mechanism- instead, which would allow continuous variation of the magnetic adhesion force, where needed [6]. The down side in the use of EM is the constant power supply needed to keep the mobile robot adhered to any surface. This results in a fast drain of the batteries, for the case of cordless UVs, or the necessity to use an energy supply cord, thus, limiting the manoeuvrability and range of the UV. However, by implementing the EPM technology in the magnetic adhesion mechanism, the efficiency, performance and size of any previous mechanism, active or passive, is improved considerably.

Therefore, the main contribution of this paper is the introduction of a novel active, continuously varying, control of the adhesive force for complex ferromagnetic structures, which is achieved by means of just a single short electrical pulse, minimising the power consumption. In addition, depending on the amplitude of the electric pulse, a specific value between the minimum and maximum adhesive force values can be selected, thus enhancing manoeuvrability.

2. DESIGN, SIMULATIONS AND EXPERIMENTS

2.1. DESIGN

The model design used to perform simulations and experiments consists of a set of three Neodymium-Iron-Boron (NdFeB) PMs and three Aluminium-Nickel-Cobalt (AlNiCo5) PMs. Each single PM has a diameter of 5 mm and 20 mm length. AlNiCo5 PMs are coiled with 250 turns of 32 AWG insulated copper magnetic wire. Two 1008 steel discs of 20 mm diameter and 5 mm width, placed at both ends of the PMs, act as keepers for the EPM. Finally, a gap of 1 mm was left between the wheel and the steel 1008 target plate, to simulate a possible coating or dirt present - *c.f.* Figure 1.

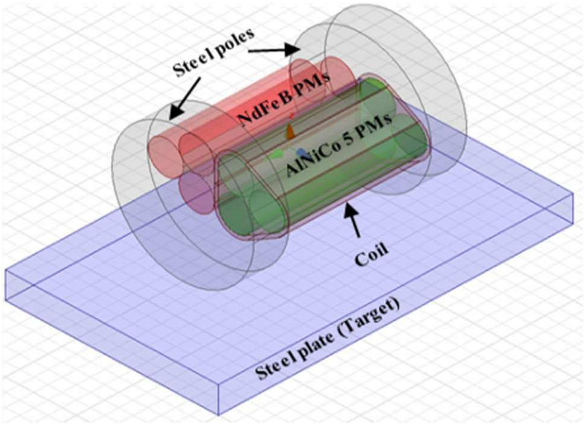

Figure 1. EPM wheel design and main components, (Red) NdFeB PMs, (Green) AlNiCo5 PMs, (Copper) Enamelled wire, (Purple) Steel keepers and steel plate target.

2.2. SIMULATIONS

Finite Element Method (FEM) was employed to model the magnetic field density interactions of both types of PMs for the Off, On, and continuously varying configurations. The simulations were performed using ANSYS Maxwell-3D.

A series of increasing voltage pulses were applied through the windings. The applied voltage magnitude was set from 8V to 20V with 0.5V increment steps (previous simulations showed that below 8V there was no effect to the magnetic force). The width of each pulse was 10ms with 5ms spacing between each other. Results shown in Figure 2 show the input voltage increment steps (red) and their corresponding magnetic force output (blue), exerted to the target. It can be seen that the magnetic force output increments monotonically between 11V and 19V. Any voltage pulse below that range is meaningless since the magnetic field intensity generated by the coil is not strong enough to remagnetize the AlNiCo5 PMs. On the other hand, any voltage pulse above it does not provide further final magnetic adhesion, due to the fact that AlNiCo5 PMs reached saturation.

2.3. EXPERIMENTS

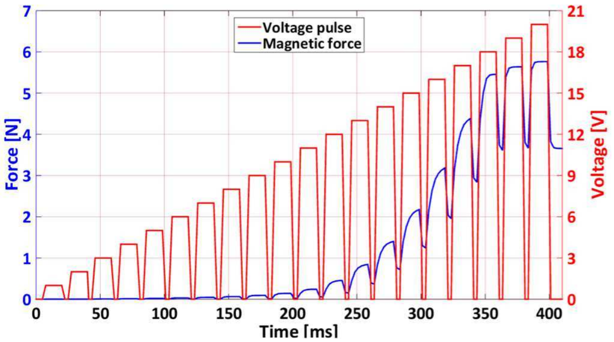

Figure 2. Comparison of the increasing magnetic force (Blue) vs the corresponding voltage pulse (Red).

Following the same procedure as the simulations, a set of experiments were performed to validate those results from simulations.

The results obtained through these sets of experiments, Figure 3, show that applying a single pulse the transition from Off to On state can be achieved. Even if further pulses, and bigger amplitudes are applied, no increase in the final magnetic force will be obtained. This behaviour is due to that the AlNiCo5 PM, for this particular design. For a bigger magnetic force the size of the PM's poles must be increased. Moreover, it is observed that when the voltage is removed the magnetic force drops to a lower level, this is due to that the magnetic force generated from the coil is much bigger than the one from the PMs. The magnetic field from the coil must be much bigger than the magnetic field of the PMs in order to alter it.

3. CONCLUSIONS

The work presented in this paper proposes a novel continuously varying magnetic adhesion mechanism to be implemented in mobile robots, used for inspecting complex ferromagnetic structures. The use of EPMs as the core technology for the adhesion mechanism was proven and validated through corresponding simulations and experiments. Even though, the work was performed in a magnetic wheel design, the same approach can be applied to most of the other locomotion mechanisms (i.e. legged or tracked). The use of this novel approach of EPM technology, as adhesion mechanism, enhances the mobile robot capability to overcome different types of obstacles and allows it to manoeuvre in complex environments, by just a fraction of the power need for EMs

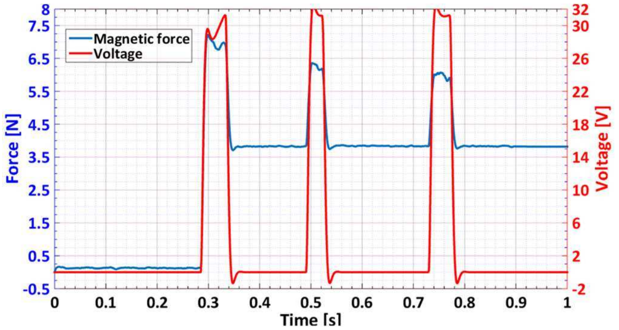

Figure 3. Transition from Off to On state as. Maximum magnetic force (Blue) vs the input voltage pulses (Red).

4. ACKNOWLEDGEMENTS

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