Active Gravity Compensation Actuator Using the Multistability of Magnetic Shape Memory Actuators

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Abstract:

An active contactless gravity compensation system is presented, using multistable magnetic shape memory (MSM) actuators to adjust permanent magnet forces. MSM-alloys are smart materials, which can be activated by a magnetic field to generate force and motion based on a solid state effect. Due to the solid state effect, very low wear is generated. This makes the system beneficial for high precision applications. As MSM-materials have a high strain (5 %) permanent magnet forces, which are applied to a movable object can be precisely adjusted. Thanks to the multistability of MSM-actuator, moreover, the power dissipation of the gravity compensation system can be significantly reduced.

Introduction

In precision applications where vertical actuation is required, as well as in high precision magnetically levitated systems, contactless gravity compensation is needed in order to avoid over excitation of the actuators and thus temperature rise through Joule losses. Most concepts compensate the force of gravity for one specific load or position by the use of fixed permanent magnets [1]. Magnetic shape memory (MSM) alloys are active material, which can be actuated magnetically to produce force and motion. They can be used to adjust actively the position of the permanent magnets, offering the possibility of designing adjustable gravity compensation systems. Due to the solid state effect nearly no particles are generated. On the other hand large strains of 5 % are possible with MSM-materials, which offer a high movable range. Furthermore, MSM-sticks have an internal holding force (so-called twinning force), thus different positions can be actuated and will be held without the use of external energy [2].

Concept

The concept of the weight force compensation is shown in Fig 1. The armature, subjected to the gravity force F_G, has to be kept in a constant position. The rejection of fast disturbances can be performed by fast actuators (e.g. Lorentz actuators). These actuators can be used in a position control loop with a high control bandwidth.

On the other hand, the compensation of the static gravity force can be done in other ways, for instance by the static forces generated by permanent magnets which is mounted on a MSM-stick. To compensate the static force of gravity, a permanent magnet generates an attractive force on the armature. At equilibrium, the weight force F_G is equal to the force of the permanent magnet F_{PM}. In this way no constant electric power is required from the stabilization actuators.

By actuating the MSM-sticks, strains of up to 5 % can be achieved and thus the permanent magnet force can be adjusted by means of the elongation, as indicated in the states 1 and 2 of Fig. 1. Using standard MSM-stick dimensions an adjustable range of about 1 mm can be achieved. Thanks to the multistability of MSM-alloys, after an actuation cycle, the MSM-stick (and thus the permanent magnet actuated by the stick) will remain in its position, without external energy supply.

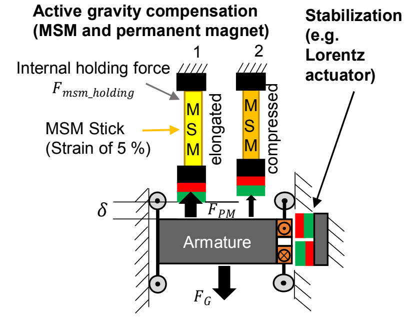

Fig. 1: *Concept drawing*

MSM-actuator design

An antagonistic MSM-actuator, based on the concept of [3] using two MSM-sticks is designed. To enlarge the movable range, a mechanical lever is adapted to the actuator as it is depicted in Fig. 2. At the end of the lever a permanent magnet is mounted for the gravity compensation. The design uses two MSM-sticks with the dimensions 3x5x20 mm. To avoid wear in the system, flexure hinges are used for guidance.

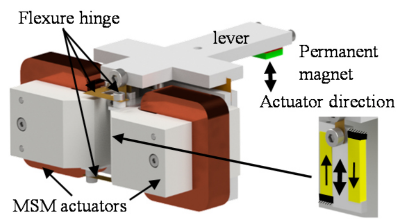

Fig. 2: *MSM actuator*

For a multistable use of the actuator, the positions of the actuator are important, which can be kept current-free and thus powerless. As depicted in in Fig. 3, a multistable positioning is achieved for loads at the end of the lever up to 200 g with a traveling range of 1.4 mm.

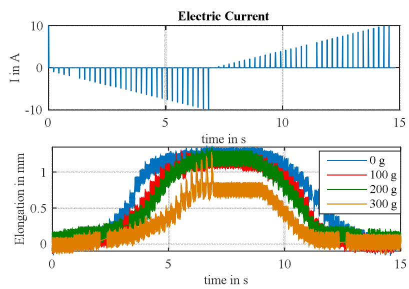

Fig. 3: *Multistable positioning of the actuator*

Control

To keep the position of the armature (see Fig. 1) at a fixed value a standard PID control for the stabilization actuators is used. The output of the PID controller, which is proportional to the current through the stabilization actuators, is fed into an additional controller, which regulates the position of the MSM-actuator and thus the gravity compensation force generated by the permanent magnet. This is indicated in Fig. 4. Using an ad-hoc control scheme, the controller of the MSM-actuator is switched off once the desired compensation is reached. The multistability of the MSM-stick is exploited, and the constant power dissipation is reduced to a value below 3 mW.

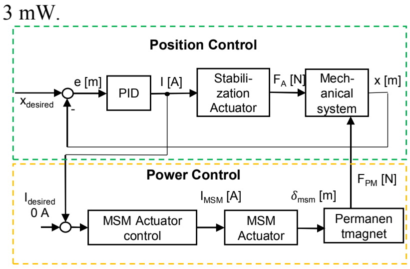

Fig. 4: *Control concept*

Conclusion

An active weight force compensation using an MSM-actuator in combination with permanent magnets was presented. With this construction it is possible to compensate variable weights between 1.4 N and 3.0 N in a range of 1.2 mm without mechanical contact. Due to the solid state effect of the MSM-alloy, no abrasion is generated in the system. Furthermore, no lubricants are required. This makes this weight force compensation applicable in high precision and vacuum applications.

Acknowledgment

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