ACTIVE MAGNETIC GRAVITY COMPENSATORS ENABLING SEMICONDUCTOR MANUFACTURING EQUIPMENT

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INTRODUCTION
High precision semiconductor manufacturing equipment is confronted nowadays with increasingly though requirements with respect to accuracy, throughput and wafer size footprint.

While the Moore’s law is continuously increasing the required accuracy the chip manufacturers’ economics make them ask for higher productivity by higher number of exposed wafers per hour and by larger wafer size.

Consequently the semiconductor equipment manufacturers are facing the requirement of positioning larger (mass and footprint) stages with higher acceleration and speed while achieving better accuracies.

These conflicting requirements are placing a heavy burden on the gravity compensators used to hold the various positioning modules within such manufacturing equipment. On one hand they must increase in size and force in order to keep up with the larger positioning modules footprint. On the other hand they have to continuously improve (reduce) their parasitic effects like stiffness and damping in order to limit damaging the positioning module accuracy due to disturbance sensitivity.

In the paper a short overview analysis of various types of magnetic gravity compensators applied to high precision semiconductor manufacturing equipment will be made emphasizing their specific working principle and their advantages and disadvantages. Finally some examples and results of internal developments within Philips Innovation Services will be discussed.

GRAVITY COMPENSATORS
High precision semiconductor manufacturing equipment has long valued the benefits of gravity compensators in order to eliminate the need for dissipating power while holding the positioning stage against gravity.

Mechanical (spring-based) and pneumatic gravity compensators have also been used in the past but they have as main drawback a high (positive) stiffness. This effect is mostly unwanted within high precision semiconductor manufacturing equipment for two main reasons: the increased sensitivity to external disturbances and the extra force needed from the positioning actuators when adjusting the position.

MAGNETIC GRAVITY COMPENSATORS
The paper will discuss different types of magnetic gravity compensators emphasizing their specific working principle, advantages and disadvantages. Extra attention will be devoted to examples and recent developments within Philips Innovation Services.

Passive magnetic gravity compensators
The simplest magnetic gravity compensators are the passive ones where two types can be distinguished: based on a permanent magnet interacting with a soft ferromagnetic material and based on permanent magnets interacting with each other. The paper will discuss both of them.

Reluctance based
A basic form of passive magnetic gravity compensator is to have a permanent magnet attract a ferromagnetic material target against gravity. Due to the nonlinearity of the attraction force with the gap (displacement) the negative stiffness will not only be high but will also vary a lot with the displacement. One example with improved linearization of the force-gap relationship (to achieve a constant negative stiffness in the region of interest) is shown in Figure 1.
One interesting characteristic of this type of gravity compensation which will be discussed in the paper is the possibility to combine it with a mechanical spring. The spring positive stiffness will be able to compensate the intrinsic negative magnetic stiffness such that tunable (desired) remaining stiffness can be achieved. Tunability of both stiffness and gravity compensation around the operating point will be discussed in the paper.

**Permanent Magnet based**

Simply holding two permanent magnets against each other while facing with the same pole will also deliver a rejecting force which can be used to compensate gravity (see Figure 2).

![Figure 2: Passive magnetic gravity compensator using two magnets against each other.](image)

However clearly this configuration will inherently retain an undesired high positive stiffness as discussed above. Over the past decade magnetic design workarounds (one example shown in Figure 3 and [1]) have been implemented to address this issue.

**Active magnetic gravity compensators**

Passive magnetic gravity compensators are 6DoF position unstable as have been proven by Earnshaw theory. In order to stabilize their position within semiconductor manufacturing equipment usually separate forcers are used which are already available in the system for stage positioning purposes. However in the recent past coil-embedded versions of the magnetic gravity compensators have occurred. In this way actuating functionality have been added to the magnetic gravity compensators making them active. The paper will present two examples of active magnetic gravity compensators discussing their specific working principle, advantages and disadvantages.

**Reluctance based**

One example is to integrate gravity compensation type shown in Figure 1 with a typical Ecore reluctance actuator (see Figure 4). Simultaneously the introduced force offset (gravity compensation) also enables bidirectional actuation.
FIGURE 4. Magnetic gravity compensator combined with bidirectional reluctance actuator (see [2]).

Permanent Magnet based

Various configurations (an overview of which will be briefly shown in the paper) in the literature show the combination of embedded coils with the permanent magnets involved in magnetic gravity compensation in order to add actuation functionality.

One recent development within Philips Innovation Services incorporating an example active magnetic gravity compensator (see figure 5) based on permanent magnets will be discussed in the paper.

To be added after company clearance in the extended abstract

FIGURE 5. Active magnetic gravity compensator/actuator based on permanent magnets.

CONCLUSIONS

A comparison will be done in the paper of the different types of magnetic gravity compensators against a set of criteria in the view of current and future requirements applicable to semiconductor manufacturing equipment.

REFERENCES


[3]