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Investigation of a positioning mechanism for adjustments with minimal side effects

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Abstract

High-precision devices often require the adjustment of highly sensitive units to achieve their intended performance. Deterministic adjustment demands high motion accuracy as well as verification under the intended operating conditions. In applications involving hermetically sealed environments, remote control and automation of the adjustment process are essential. Off-the-shelf positioning stages are commonly employed for this purpose. However, high functional sensitivity of the unit to be adjusted also implies high sensitivity to disturbances. A systematic assessment of the side effects introduced by the adjustment system is often lacking. Previous investigations have identified permanent cable connections as critical sources of mechanical disturbance due to their unstable and unpredictable behavior. Wireless energy transfer or temporary detachment of the cable connection represent possible mitigation strategies. Nevertheless, the in-situ positioning system can introduce non-neglectable side effects and therefore requires similar consideration. This contribution analyzes the disturbances generated by the positioning system, which subsequently serve as the basis for the design of a mechanism enabling low-side-effect adjustments. The positioning performance of the proposed mechanism is investigated experimentally, demonstrating submicrometer resolution and position stability over multiple days.

Keywords: adjustment, side effects, disturbances, positioning mechanism

1. Introduction

High-precision devices, such as those used in mass metrology [1], nanomeasurement technology [2] or semiconductor device manufacturing [3], demand extremely high functional sensitivity while remaining highly insensitivite to disturbances. External influences are often avoided by operating in hermetically sealed environments where conditions are strictly controlled. Residual systematic deviations are addressed for by low-error design, compensation strategies or computational corrections. If these measures prove insufficient, the adjustment of highly sensitive units becomes necessary.

A deterministic adjustment demands not only high accuracy, but also verification under the intended operating conditions. This imposes requirements on remote operability, a high degree of automation as well as environmental compatibility of the adjustment system. Electrically-actuated fine positioning stages are therefore commonly employed, with a broad spectrum of commercially available solutions.

However, electrical energy transfer, its conversion into mechanical energy, and associated energy storage (maintaining of the achieved state) inherently introduce side effects that degrade the adjustment stability. While concepts for low-interference energy transfer concepts have already been proposed in earlier studies [4,5], there is still a lack of a systematic assessment of side effects caused by the positioning system itself.

This contribution analyses disturbance effects of fine positioning systems and presents a mechanism designed for low-side-effect adjustments. The analysis focuses primarily on mechanical, thermal and electromagnetic disturbance effects, while other effects, such as the emission of particles, are not investigated exhaustively. Finally, the positioning performance of the proposed mechanism is investigated experimentally.

2. Side effects in adjustment

In precision devices, adjustment refers to the controlled displacement of a component to achieve the intended device function [6]. The adjustment parameter is measured and compared with a target value, whereupon energy is transferred to the adjustment device, converted into a displacement, and subsequent fixation of the achieved position. This closed-loop sequence is repeated until the target value is reached.

Controlled displacement is typically realized through a combination of an actuator or drive, a transmission and guidance elements. Their side effects are transmitted to both the sensitive unit and the adjustment unit. Heat is mainly generated by losses in the drive and depends strongly on the actuator principle. Actuators may also produce magnetic or electric fields, causing parasitic forces or electromagnetic couplings. Drive operation and its control can induce vibrations or impact loads. Friction at contact interfaces of moving elements under such conditions promotes wear, i.e. particle liberation. Material selection is also associated with particle release and magnetic interactions. Figure 1 shows relevant factors limiting a deterministic adjustment.

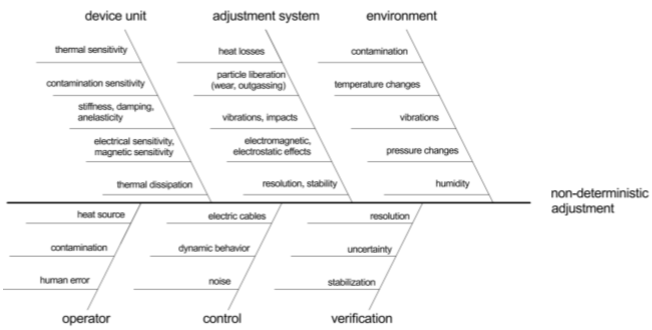

Figure 1. Representation of influences hindering the adjustment.

3. Design of positioning mechanism

Based on the previously discussed side effects, a positioning mechanism for low-side-effect adjustments is proposed (see Figure 2). The intended application is the vertical positioning of trim masses in precision weighing cells [1]. The system combines piezoelectric actuators with a compliant mechanism that fulfills both transmission and guidance functions. Due to the compliant design, friction and wear are largely avoided. However, sliding friction remains at the contact interfaces between moving elements. By operating the actuators in a quasistatic regime, heating becomes negligible and vibrations are minimized. Appropriate material selection further prevents undesired magnetic interactions and minimizes wear and outgassing.

The adjustment motion and its securement are functionally separated, as piezoelectric actuators are not self-locking. The adjustment motion is generated by a first actuator and amplified by a transmission lever. A second actuator, initially decoupled, opens a normally-closed friction locking mechanism prior to the adjustment motion. The locking mechanism consists of a pretensioned spring and a lever that clamps a leaf spring on the output stage.

To reduce the locking force, drive force and its associated friction forces, an initial gap between the output stage and the adjustment lever is introduced. This allows the restoring force of the flexure guide to partially compensate for the weight of the adjustment unit. After the adjustment, the locking actuator is returned, closing the locking mechanism. The adjustment actuator can be then released, thereby securing the adjusted position without need for a continuous power supply. Undesired deformations are avoided by maintaining short force loops and loading structural elements in a mechanically favorable manner.

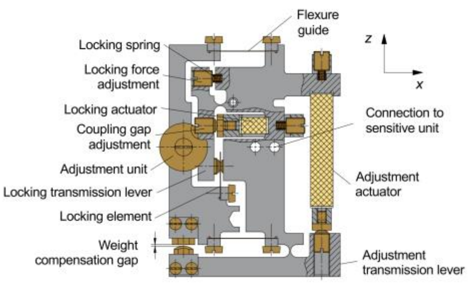

Figure 2. Embodiment design of positioning mechanism.

4. Positioning performance

The positioning performance of the proposed mechanism defines the quality of the adjustment. Figure 3 shows the displacement of the output stage at different input voltages to the adjustment actuator. Due to the hysteresis originating from the piezoceramic material and presence of sliding friction, input voltage and output displacement are not strictly proportional. The theoretical positioning resolution is approximately 25 nm for a voltage resolution of 25 mV at the point of highest sensitivity. However, the locking process induces a backlash motion that displaces the output stage by up to 0.3 µm. This effect can be attributed to misalignments on the leaf spring as well as an initial one-sided contact.

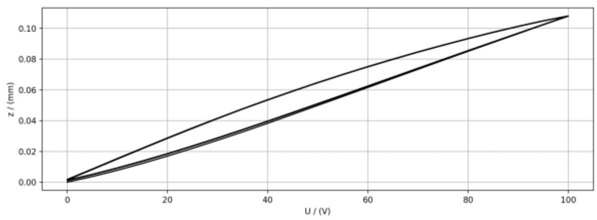

Figure 3. Characteristic curve of proposed mechanism.

Another requirement for the adjustment is a high position stability. Figure 4 shows the change in the position of the output stage over three days inside a temperature-controlled laboratory environment (±1 °C), evaluated at the position of maximum deflection (z = 113.7 µm). A correlation with the temperature drift was observed and a correction was applied. After correction, a stability better than ± 0.5 µm was measured.

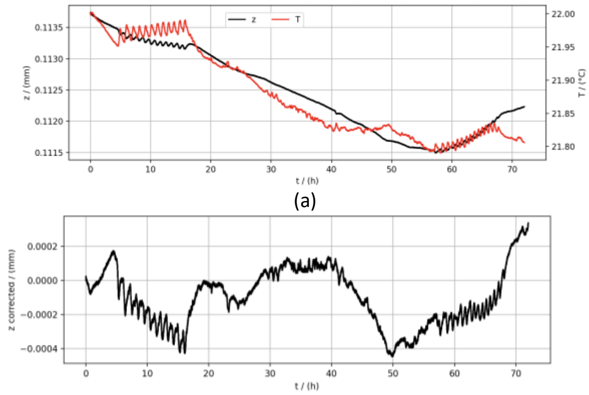

Figure 4. Position stability over three days: (a) without temperature correction, (b) with temperature correction

5. Summary and future work

This papers proposes a positioning mechanism for low-side-effect adjustments based on a systematic assessment of the ocurring disturbances occurring during the adjustment process. Mechanical, thermal and electromagnetic disturbances are considered and minimized through a deliberate selection of the operating principle and materials. The positioning mechanism comprises two piezoelectric actuators and a compliant mechanism. Experimental investigation of the positioning performance demonstrates that submicrometer resolution can be achieved, which is limited by the locking mechanism. In addition, a position stability better than 0.5 µm over a period of three days is demonstrated.

Due to sliding friction between contact interfaces, wear cannot be completely avoided. The use of lubricants compatible with the application environment, e.g. PTFE grease, may reduce friction and trap wear particles. However, in applications where contamination is unacceptable, where static friction is functionally required, e.g. for position securement, or where any loss of mass or volume is impermissible, low-particle adjustment strategies becomes necessary. Future work will therefore focus on investigating novel solution approaches to eliminate particle emissions during the adjustment process.

Acknowledgements

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