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Novel in-situ fine adjustment system with contactless energy transfer

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Abstract
Highest precision devices often require the adjustment of very sensitive units to achieve their maximum performance. An effective adjustment can only be performed in-situ under the intended working conditions. Avoiding any disturbances is critical for ensuring the quality of the adjustment and function of the unit. This paper presents the design and optimization of a novel in-situ fine adjustment system with low disturbances. The system is mounted directly on the sensitive unit and is controlled via contactless energy transfer. The fine adjustment motion is realized via a combination of a piezoelectric actuator and a compliant mechanism. The transfer subsystem is optimized to minimize stray fields, heating and external parasitic forces. A lock mechanism holds the position of the output stage securely and free of energy input. When the adjustment actuator is energized, an electrical switch is activated, powering the release actuator of the lock. The return motion is achieved by a controlled discharge of the main actuator via an optical switch and a shunt resistor. Discharging the release actuator in the same way secures the position again, while the adjustment actuator returns to its initial position. Therefore, no disturbances exist after the adjustment.

Keywords: adjustment, contactless energy transfer, low disturbance, piezoelectric actuator

1. Introduction

Highest precision devices, such as nanomeasuring machines [1] and mass comparators [2], are designed for maximum sensitivity to functionally relevant quantities, while minimizing the effect of disturbances. External influences are often avoided by operating inside hermetically sealed rooms under controlled conditions up to even vacuum. Remaining systematic deviations are managed with different methods such as computational correction, compensation, innocent design, etc. If these are not sufficient to achieve the required performance, very sensitive units of the device must be adjusted. Fine adjustments are operations, often mechanical, to set function parameters of a unit to the required values for its intended application. Typical examples are the alignment of lenses in precision optical systems to eliminate the effect of manufacturing deviations.

Adjustments are often done manually under atmospheric conditions using fine adjustment screws before setting the device up for operation. In highest precision devices, an effective fine adjustment requires rather to be performed in-situ under the intended working conditions. This allows a verification of the adjusted state in real time, further increasing the performance of the device. Remotely-controlled motion stages are favoured in such cases. However, their associated side effects are not compatible with the use in very sensitive units. Particularly, the electric cables for energy transfer introduce unstable parasitic forces and torques, hindering the quality of the adjustment as well as the subsequent function of the unit.

The following paper presents a novel in-situ fine adjustment system with contactless energy transfer. Due to the elimination of the external mechanical coupling by the cable connection, no parasitic forces and torques are transmitted to the sensitive unit after the adjustment. Previous investigations have shown that disturbances must be kept under permissible values during the adjustment to avoid deviations of the adjusted parameter [3]. The novel system is designed for application in the weighing cell presented in [4], where a trim mass is positioned vertically to adjust the stiffness of its mechanical structure.

2. Functioning principle

The functioning principle of the novel adjustment system is shown in Figure 1. To minimize disturbances at the adjustment location, the system is driven by built-in piezoelectric actuators under quasistatic operation. The adjustment motion is realized by a main actuator in combination with a transmission lever. Position of the adjustment unit is secured powerlessly via a friction lock, which is released by a second actuator for the adjustment motion. The required clamping force is exerted by a preloaded spring. The forward motion of each actuator is achieved by storing energy transferred to a built-in coil via inductive coupling. Releasing the stored energy using a shunt resistor controlled by a phototransitor and light source produces the return motion. The circuit for the release actuator is initially open until the contact elements on the lever and guiding carrier close the circuit during the motion of the main actuator.

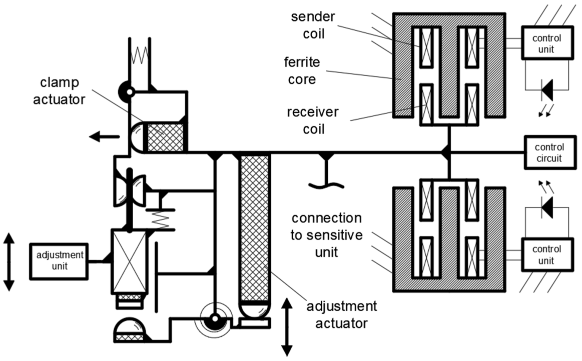

Figure 1. Functioning principle of novel fine adjustment system

Figure 2 shows the adjustment motion sequence. In the initial state (a), there is no energy flow and all elements are secured. When the main actuator is energized and the contact element of the transmission lever enters in contact with the output stage (b), the release circuit is closed and its actuator is powered (c). Then, the adjustment unit can be freely positioned in either direction (d). The achieved position is secured by discharging the release actuator (e). Finally, the main actuator is discharged (f), eliminating any disturbances due to self-discharge afterwards.

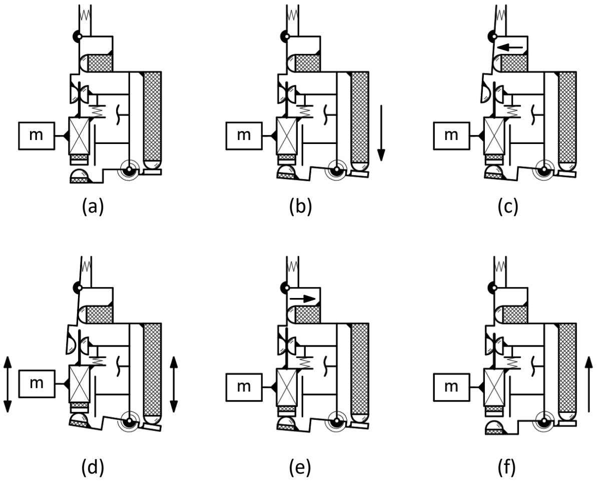

Figure 2. Adjustment motion sequence

3. Embodiment design

Based on the principle in Figure 1, a fine adjustment system for positioning masses up to 40 g over a range of 100 µm vertically is designed. The embodiment design focuses on the minimization of disturbances during the adjustment process. Figure 3 shows the motion subsystem. The mechanical structure is designed as a compliant mechanism to avoid kinetic friction and backlash. Leaf springs are used as compliant elements to reduce restoring forces, and thus, clamping forces. Suitable materials have also been selected for the contact pairings.

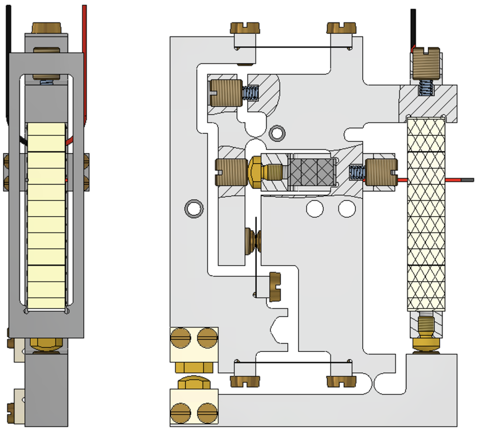

Figure 3. Embodiment design of motion subsystem

To achieve the voltages (>100 V) to control the piezoelectric actuators contactlessly, while minimizing electromagnetic and thermal disturbances, the energy transfer subsystem has been optimized using finite element (FE) simulations in ANSYS Maxwell (see Figure 4). High voltages under low current are achieved by working at a high frequency range (100 kHz) and maximizing inductances. A ferrite core is necessary to minimize stray magnetic fields and heating due to eddy currents. In comparison to conventional wireless transfer units, no ferrite material is mechanically attached to the receiver coil. Thus, no parasitic magnetic forces are transferred to the sensitive unit after the adjustment. The magnetic force on each coil during energy transfer amounts to approximately 40 µN. Their influence on the sensitive unit is reduced by orienting the coils in a direction of low sensitivity as well as through compensation by a symmetric arrangement of the interfaces around the unit. The transfer subsystem can also be placed on a location of low disturbance sensitivity independently of the motion subsystem to further reduce its influence.

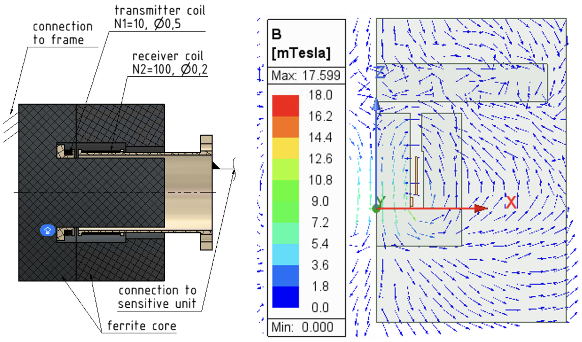

Figure 4. Energy transfer interface: (a) design, (b) FE simulation

5. Conclusion

This paper presents the design of a novel fine adjustment system for the application in highly sensitive units. Unstable external forces and torques brought by electric cables are completely avoided by using contactless energy transfer. Disturbances during the adjustment process have been minimized by a targeted design process and model-based optimization. Also, disturbances are completely avoided after the adjustment is concluded.

Verification of the capabilities of the system on a prototype represent the current work. In addition, further reduction of the disturbances by reducing the energy requirements of the system through the use of in-situ energy storage is under investigation.

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