Precise adjustment of mechanical and optical components by linear stroke actuators

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Introduction

The experience that is easier to precisely change the position of an object by using a slight tapping instead of a constant pushing force is applied daily in the realm of manufacturing and optics. Traditional, the positioning of mechanical and optical objects (e.g. work pieces, components, lenses) is activated manually by hammer. Stability and success of such an adjustment process depends highly on the skills of the operator. Nevertheless, misalignments resulting from the subsequent fixation process are inevitable. However, in most cases objective position adjustments need to be made systematically and cost-effectively.

Alternative adjustment method

At the Fraunhofer Institute in Jena, Germany, the manual position adjustment was developed further and replaced by providing an effective and automated adjustment method applied in precision engineering and micro-optical applications. The movable parts of electro-magnets and electro-dynamic actuators transfer measured strokes (momentum) directly to the component which needs adjustment or indirectly on its mounting. The transfer of momentum (intensity, number and direction of strokes) is in feedback control by a computer and a measurement device /1/. Major advantages of the alternative adjustment method are:

- In contrast to conventional methods, this approach immobilizes the components with a pre-stressing force before the adjustment process starts.
- Furthermore, the equipment expenditure are reduced to cost-effective guides, clamps, frames and other adjusting device.
- After the adjustment operation the linear stroke actuators can be used for the next adjustment task.

The design of the pushing magnet is shown in Fig. 1.
In the framework of the joint DFG (German Research Society) project with the University of Stuttgart a linear stroke actuator, as shown in Fig. 2, has been developed and built /2/.

Theoretical and experimental investigations

The theoretical investigations focus on the calculation of motion behavior of such pushed components under consideration of pre-stressing forces and friction /1/. A model of motion was developed utilizing classical collision theories based on the law for rigid bodies. The derived equations of motion for our model takes static and sliding friction forces in place of clamping into account. The conducted experiments aim for an explanation in friction and impact behavior for different specimen. The experimental results confirm the capability of the hypothetical model of motion and the correctness of simplification assumptions made, as shown in Fig. 3. Hence, the amount of motion of fixed (pre-stressed) objects after transfer of momentum can be calculated in good approximation to performed experiments. Such derived equations, characteristic curves and practical experience are be used to enhance algorithms for the automated and fast adjustment of components. Based on theoretical and experimental results, constructive guidelines and parameters can be proposed for usage in alternative adjustment methods.

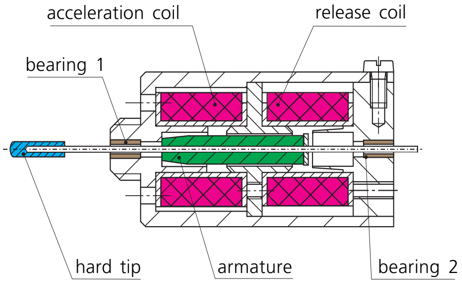

Fig. 1:
Setup of the electro-magnet /1/.

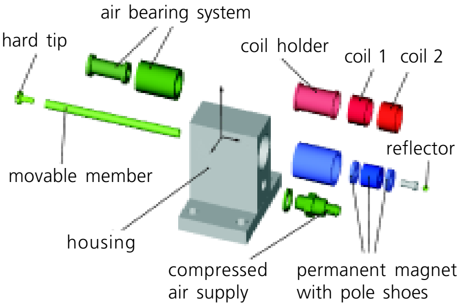

Fig. 2:
Exploded view of the electro-dynamic actuator with air bearing system /1/.

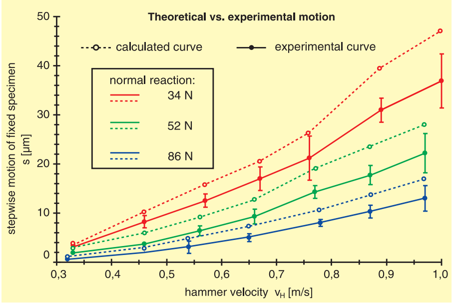

Fig. 3:
Comparison of the theoretical and experimental motion /1/.
pairing: stainless steel
mass: $m_H = 4{,}5$ g, $m_S = 40$ g
friction: $\mu_{stat} = 0{,}25$, $\mu_{kin} = 0{,}18$

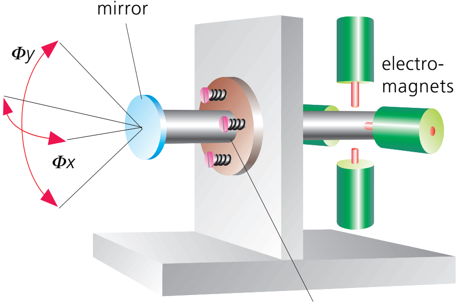

Fig. 4:
Mirror adjuster with four electro-magnets.

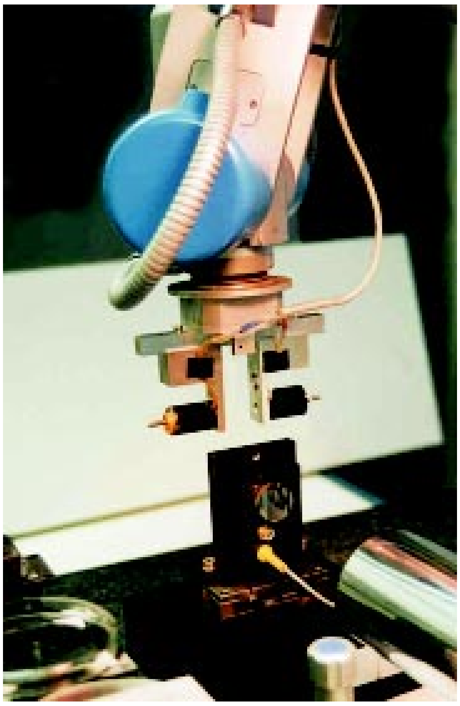

Fig. 5:
Two actuators attached on the endeffector of robot in operation /1/.

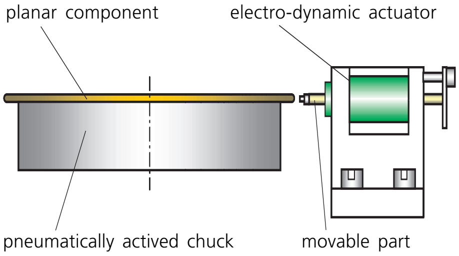

Fig. 6:
X, Y, Z-aligning of planar components.

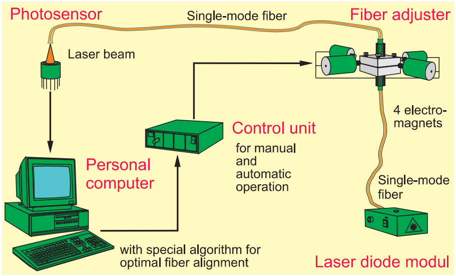

Fig. 7:
Schematic illustration for a fiber optic adjustment /1/.

Applications

This method enables linear and angular adjustment of mirrors, lenses, prisms, fibers and other components in operation.
Various prototypes for optical and micro-optical applications have been investigated and optimized:
The setup of a demonstrator for pitching and yawing of a mounted mirror by four electro-magnets is shown in Fig. 4. Positioning accuracies better than 1.0 arc sec can be achieved in wide range of adjustment.
An interesting and useful application is the adjustment of components using an assembly robot. Two pushing magnets attached on the endeffector enable the exact aligning of a mounted mirror, as shown in Fig. 5. Robots with small positioning accuracy can be used for such positioning task.
In a further application four electro-dynamic actuators make an exact positioning of planar component possible whereas the components are immobilized by the pneumatically activated chuck (shown in Fig. 6). The planar component is exactly aligned to an optical marking in the x, y and z direction using an image processing system /2/.
In another case, a prototype for an automated adjustment of glass fibers in the sub-micrometer range was developed. Four electro-magnets are able to adjust fiber optics by first aligning the fibers to each other. Intensity, number and direction of strokes are controlled by an algorithm and a sensor testing decrease or increase of insertion loss. The complete adjustment process takes only several seconds. A schematic arrangement for the performance of coupling of single-mode fiber is shown in Fig. 7.
An exceptional application for precise aligning of components being in motion is a CNC-lathe with a centering device /3/. The special purpose machine was developed in collaboration with Jenoptik AG. The production process splits into 3 steps. In first step optical lenses are cemented in their housings. The second step involves correction of the centering errors between optical and mechanical axis by two pushing magnets. The final step is turning the cylindrical and plane surfaces of the housing by a conventional precision turning operation. The benefit: Centered and turned lenses can be put in to a cylindrical and finely ground and polished guide tube (barrel) with no additional alignment.

References

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/2/ Pröger-Mühleck, R. Gebhardt, A., Guyenot, V., Schinköthe, W., Siebenhaar, C. „Aerostatisch gelagerter Impulsantrieb zur Präzisionsjustage in der Mikrotechnik“ GMM-Fachtagung, Innovative Klein- und Mikroantriebe, Mainz 2001
/3/ Guyenot, V., Siebenhaar, C. “Centering of optical components by using stick-slip effect” SPIE-Proc., Bellingham/Wash.: Optical Fabrication and Testing Bellingham, Wash.: SPIE, 1999 (SPIE Proceedings Series 3739) p.404–410