Control of a long range high-precision positioning system

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A dual stage actuator (DSA) is a combination of two actuators along an axis: fine and coarse actuators. The fine actuator has high accuracy and high bandwidth although its stroke is very short. In order to extend this limited motion range, the base frame of the fine actuator is mounted on the coarse actuator, which has a long stroke with accuracy poorer than the fine actuator.

Among a variety of actuators, Lorentz actuators are often used as fine actuators in DSA systems under an environment where disturbances are expected at fine actuators' base. Their advantage is that they show an almost ideal zero stiffness characteristics, which is that disturbances from bases do not transmit to the moving parts [1]. Such zero-stiffness DSA systems have been applied to wafer scanners for lithography [2]. However, since movable parts need to float, these setups tend to be heavy and bulky with granite plates and air feet for pneumatic levitation or require relatively complicated sensing and control for magnetic levitation with multiple Lorentz actuators [3]. In addition, heavy moving parts are under constraint of the mass dilemma of precision positioning systems, which is that the mass of a moving part is determined by a compromise between the achievable acceleration and the sensitivity for disturbance [1]. Thus the dilemma restricts the performance of the dual stage system, limiting either its operational speed or accuracy.

In this presentation, we propose a low stiffness actuator in a DSA system. A low stiffness actuator has mechanical supports to suspend its moving part. Nevertheless, its low transmissibility between the base and moving part reasonably reduces the disturbance effects on positioning. Using such an actuator as the fine actuator, we demonstrate that a low stiffness DSA system can realize long range positioing with precision on the nanometer scale without extra vibration isolators, by minimizing the moving mass of a DSA system. The aim of this light load is to broaden the actuator's bandwidth such that all the remaining disturbances can be compensated and the mass dilemma is bypassed. In order to implement this concept, a CD/DVD laser pickup is mounted as the fine actuator on a linear motor. Our experiments demonstrate that this dual stage system is able to position in a total range of 0.5 meters with $\pm$ 15 nanometer accuracy at a settling time of 1.72 seconds.

[1] Schmidt, R.M.; Schitter, G.; van Eijk, J.: The Design of High Performance Mechatronics: High-tech Functionality by Multidisciplinary System Integration, Delft University Press, 2011.

[2] Butler, H.: Position Control in Lithographic Equipment [Applications of Control], Control Systems, IEEE, vol. 31, no. 5, pp. 28-47, 2011.

[3] Hollis, R.L.; Salcudean, S.E.; Allan, A.P.: A six-degree-of-freedom magnetically levitated variable compliance fine-motion wrist: design, modeling, and control, Robotics and Automation, IEEE Transactions on, vol. 7, no. 3, pp. 320-332, 1991.