Stabilization Methods for Force Actuators and Flexure Hinges

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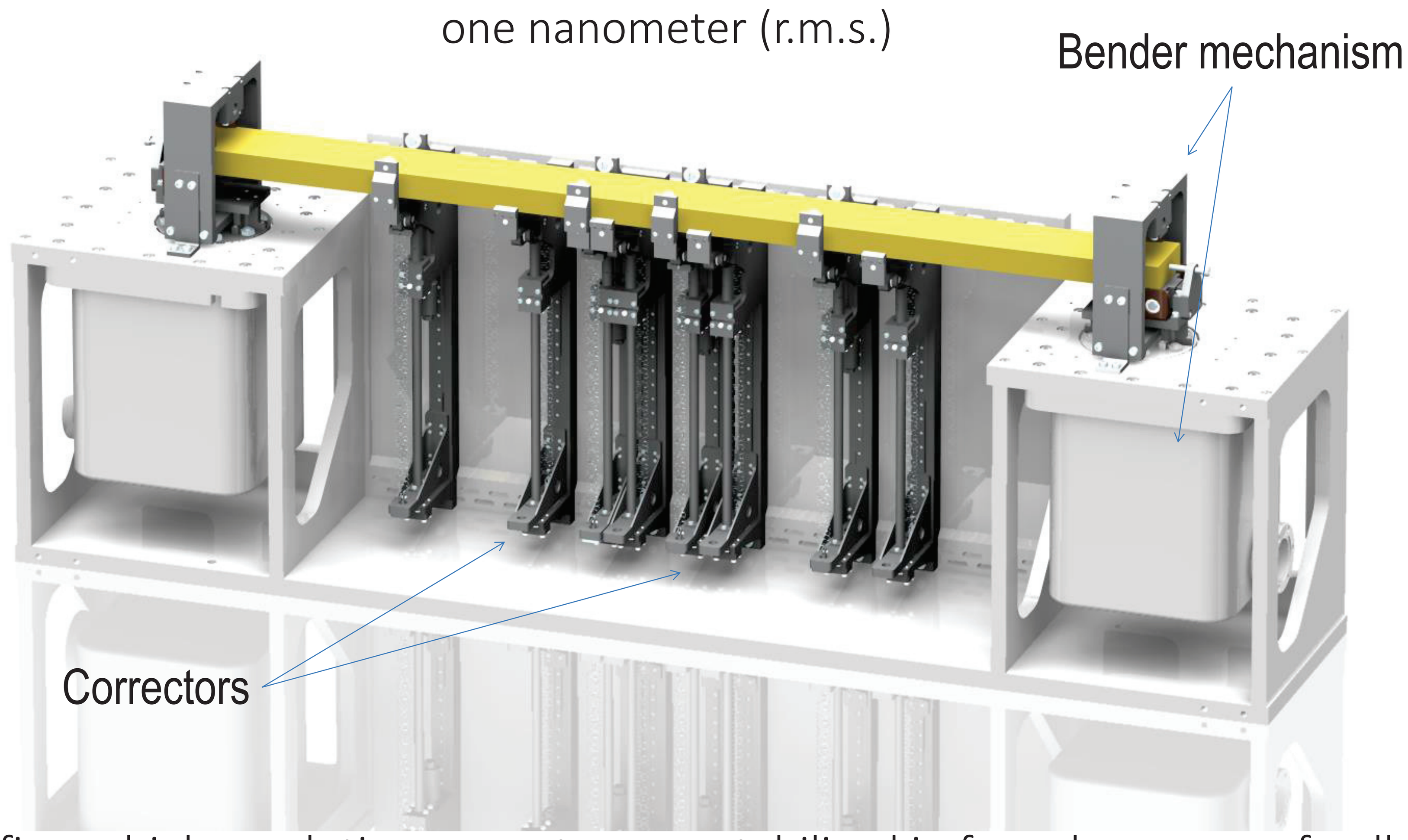
Abstract

A stabilization system for spring-based force actuators and flexure hinges has been conceived in the framework of the design of an adaptive optics x-ray mirror bender with correction resolution below one nanometer. The actuator force resolution is better than 10^{-3} N. Since the actuator must preserve the force at this level and provide both pulling or pushing force the spring force is transmitted by a lever arm which was initially pivoting about a bearing articulation. The friction of the bearing limits the force stability and resolution, Alternatively, a flexure hinge, is too stiff and limits the stability of the system. We present a novel method to stabilize the force exerted by the corrector at the same time that minimize the residual stiffness of a flexure based-articulation. It consists in combining magnets that contributed to the total force, but have opposite sign dependence on movements of the application point. The system is able to introduce a forces within a range of 30 N, and keep them stable within 10^{-2} N in a range of positions of the application point of about 1 mm. The frictionless articulation, is torque-free in the range of 1 degree.

Nanobender

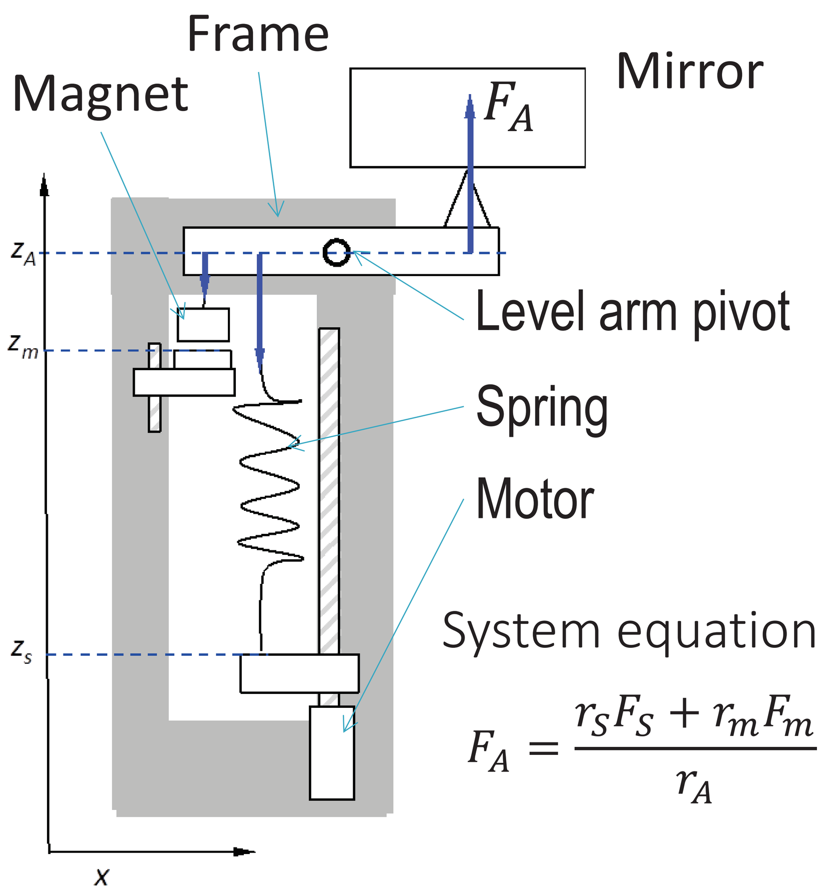
The Nanobender is a X-Ray mirror bender able to deform the mirror up to the desired curvature while correcting residual figure errors to less than one nanometer (r.m.s.)



Its figure high resolution correctors are stabilized in force by means of null equivalent k spring-magnet systems

-k Spring corrector

The attraction force between magnets is inversely proportional to their gap. In a narrow range this is equivalent to a negative stiffness spring.



System equation

$$F_A = \frac{r_S F_S + r_m F_m}{r_A}$$

Magnet Force (approx.)

$$F_m = -\frac{F_{max}}{d/d_m + 1}$$

Spring-like magnet description

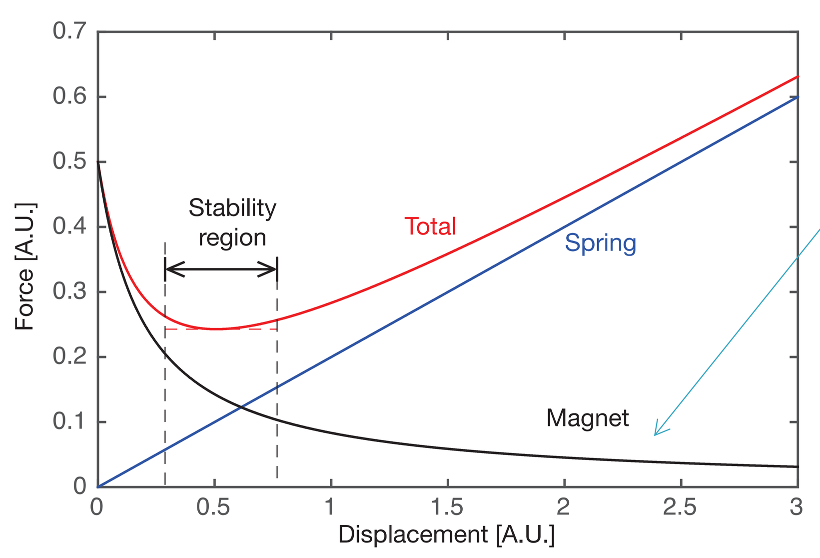
Taylor expansion

$$F_m = F_{m0} - k_m(d - d_0)$$

$$F_{m0}(d_0) = -\frac{F_{max}}{d_0/d_m + 1}$$

$$k_m(d_0) = -\frac{F_{max}}{d_m}\frac{1}{(d_0/d_m + 1)^2}$$

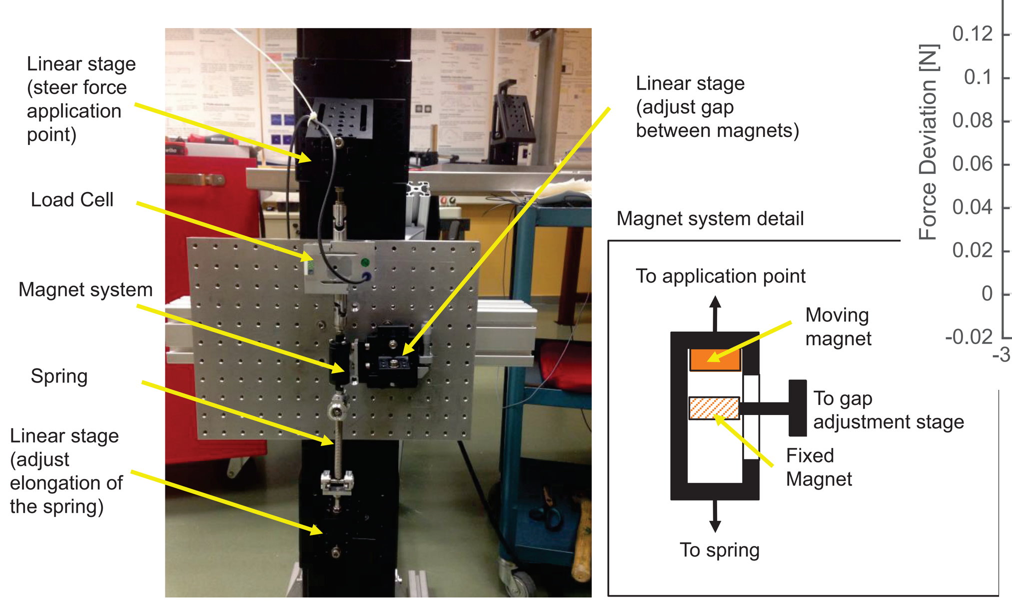
k_m has units of spring constant, and unlike elastic systems, it takes negatives values

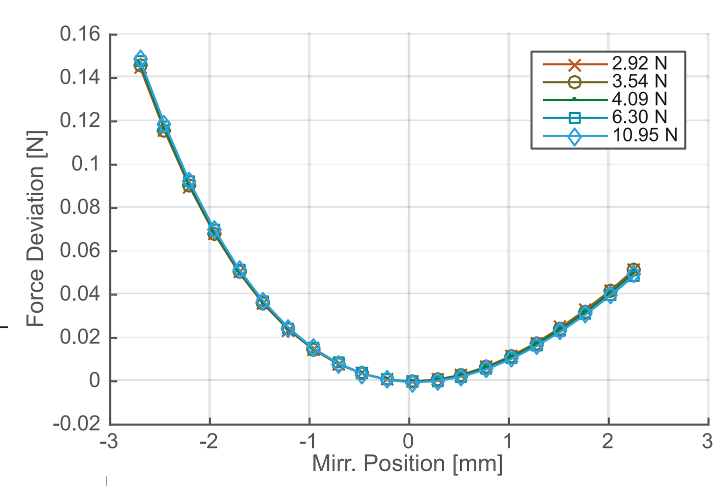


$$\delta z_A = d_m \sqrt{\frac{k_{m,max}}{k_m(d_0)}} \sqrt{\frac{\delta F_m}{F_m(d_0)}}$$

Larger stability ranges are obtained by using strong magnets and relatively large gaps.

Experimental set up



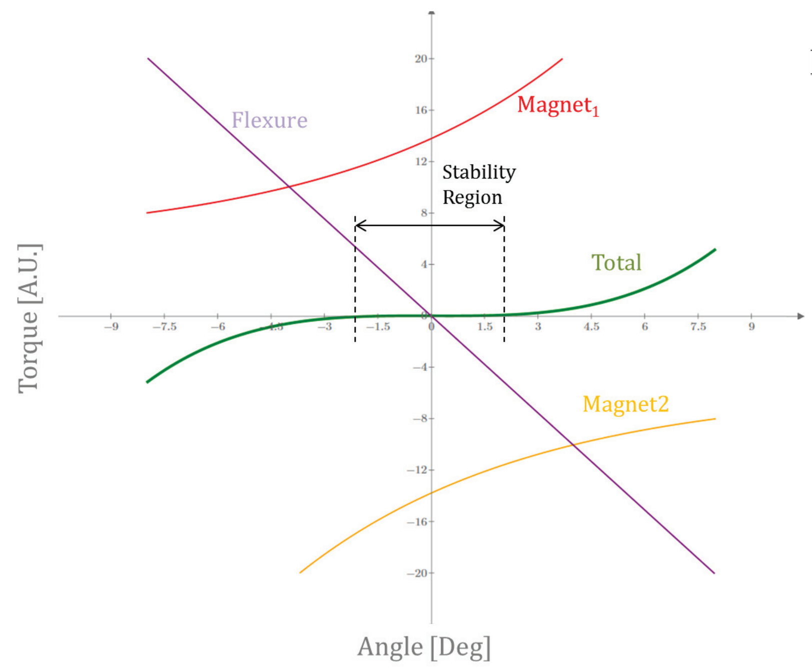


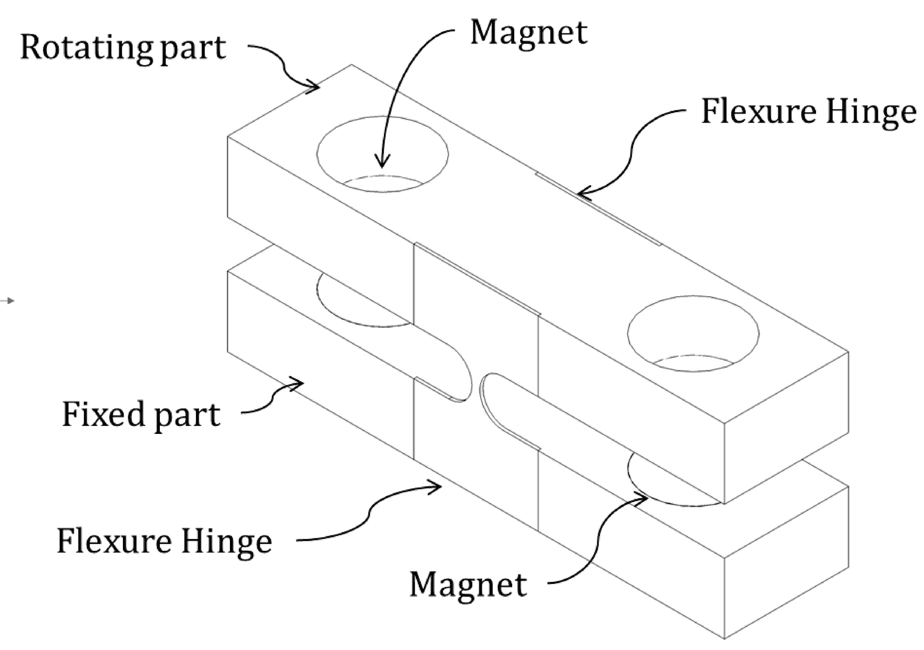
The stabilization is the minimum in which there is only a variation of 0.02 N for a range about 2.3 mm and is independent of the nominal force.

ES Patent: **P201630506**

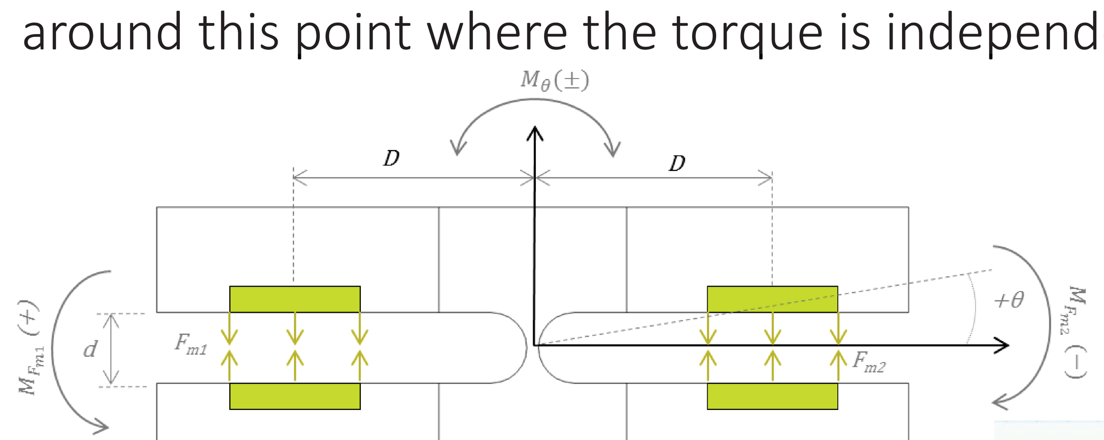
Zero torque & frictionless articulation

In order to eliminate the friction of the bearing, it is replaced by a flexure articulation compensated with magnets.





The flexure torque has a linear dependence on the angle while the magnetic force is given by an inverse law. The sum of the three torques is zero around its nominal position and it is stable in an angle range around this point where the torque is independent of the angle.

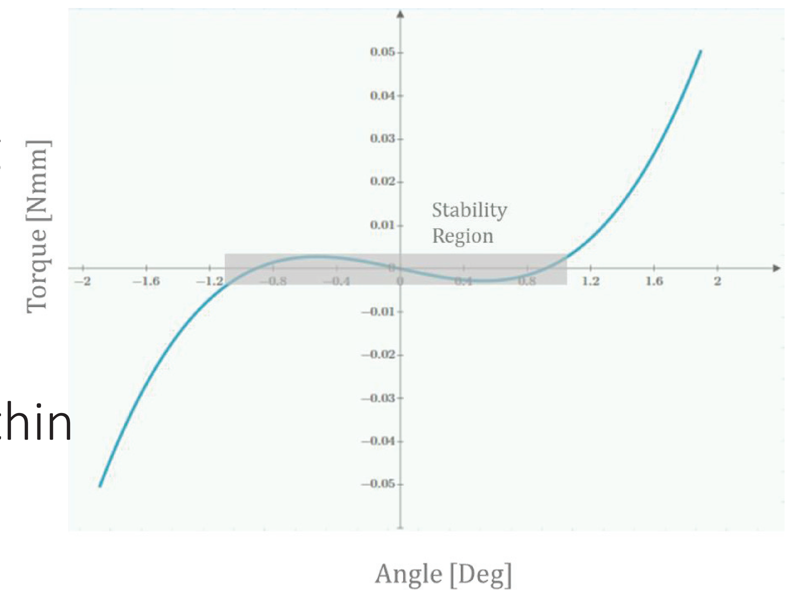


System equation

$$T(\theta) = M_{F_{m1}} - M_\theta + M_{F_{m2}}$$

Taylor expansion yields to the following expression:

$$T(\theta) = -2\, k_m D^2 Sin\theta - k_\theta \theta$$



This implementation is stable within 0.005 Nmm in a range of about ±1.2º.

ES Patent: **P201631142**

Conclusions

By combining spring and magnets it is possible to stabilize a force actuator and make it insensitive to the position of the force application point.

By combining a flexure and magnets it is possible to stabilize a flexure hinge, eliminating the torque in a range around its free position and turning it into a frictionless, torque-free articulation.