Highly accurate passive actuation system

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Abstract

This paper describes an alternative method to drive and control the fine positioning (short stroke) stage of a precision positioning device. The short stroke actuators are replaced by a pair of passive magnetic springs. Now the control forces are determined by the relative displacements between the long-stroke (coarse positioning) and short-stroke modules, while it eliminates large actuators and power dissipation in the short-stroke. This approach requires a special control effort for the long-stroke actuation system.

Introduction

Precision positioning stages commonly consist of a combination of a coarse positioning module with limited accuracy (long-stroke), at which a fine positioning module (short-stroke) is cascaded. Figure 1 illustrates this principle. The precision of the system is achieved with a fast linear short-range actuator, while the coarse positioning module keeps the short-range actuator in its optimal working range.

Accurate positioning relies on accurate control and effective reduction of disturbances. Both positioning modules use electromagnetic actuating systems. Especially the actuator for the fine positioning module must generate high forces at high accuracy, which is a contradicting requirement.

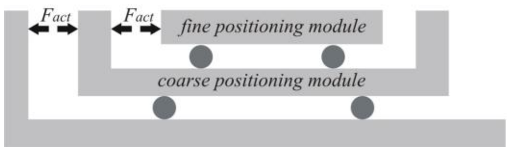

Figure 1 *Cascaded modules*

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Over the past decades a steady increase in required accuracy and speed is observed with a proportional increase of accelerations. This requires the actuators to be large and heavy while a substantial amount of heat is dissipated, significantly affecting the thermal stability of the application and jeopardizing the system's positioning accuracy, since it leads to unwanted structural deformations.

1 Passive Drive System - Theory

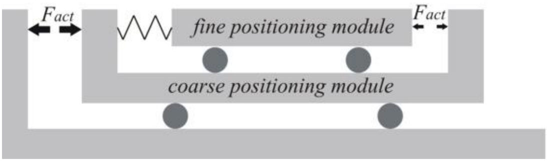

Figure 2 *Spring element between cascaded modules*

This paper investigates the possibility to make use of the actuators of the coarse positioning module to accelerate the fine positioning module as well, thereby reducing the heat load of fine positioning actuators. The force is transferred by an inserted spring element between the coarse and fine positioning modules as shown in Figure 2 as proposed in [1]. Main advantage of a spring is that most of the force is delivered by the spring. Now only a small, lightweight actuator is needed for counteracting unknown disturbance forces.

1.1 Contact less non-linear spring

The most straight-forward implementation would be an ordinary mechanical spring, but that would lead to too large disturbing forces between the coarse and fine positioning module. Therefore a magnetic, nonlinear, contact-less spring is proposed for this development as shown in Figure 3. This spring consists of two pairs of repelling permanent magnet arrays.

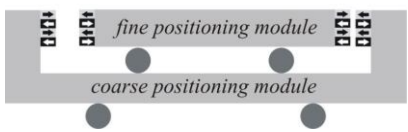

Figure 3 *Magnetic arrays*

The benefit of such a non-linear magnetic spring element is the minimum stiffness behavior in the mid position of the spring as can be concluded from the force-stroke-characteristics shown in Figure 4. At its neutral position (mover displacement equals 0 mm) the force is zero and also the slope of the graph (which represents the

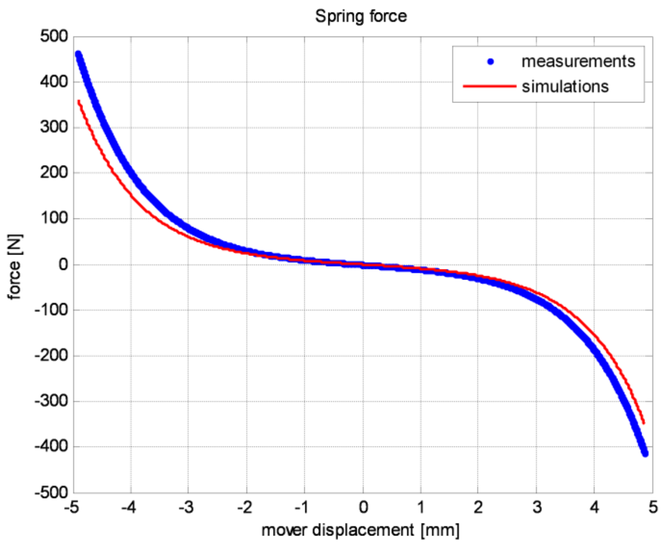

Figure 4 *Force-stroke-characteristics, both measured and simulated*

stiffness) reaches its minimum value. This configuration effectively reduces the disturbance forces transmitted by the coarse positioning module around the neutral position.

1.2 Control strategy

Driving this system requires a renewed control strategy [2]. With a regular electromagnetic actuator the force on the fine positioning module is linear proportional to the current through the actuator. For this application, the force is depending on the relative position of the fine positioning module with respect to the coarse positioning module. The fine positioning module has to track a certain set-point and the corresponding trajectory for the coarse module can be computed using an inverse model of the (non-linear) spring. For a standard set-point, the required trajectory for the coarse positioning module will exceed the constraints on actuator forces. A strategy is developed to derive a set point that minimizes the time from initial to end state, satisfying dynamic model equations and respecting the limitations on force, velocity, acceleration, jerk and snap of the coarse positioning module [4].

2 Passive Drive System - Practice

Figure 5 shows the hardware for the prototype of the design [3]. The fine positioning module is suspended by a 5-DOF air bearing system. The position measurement between fine and coarse positioning module is accomplished by an optical encoder. The coarse positioning module was mounted on two powerful linear actuators (not shown in the picture).

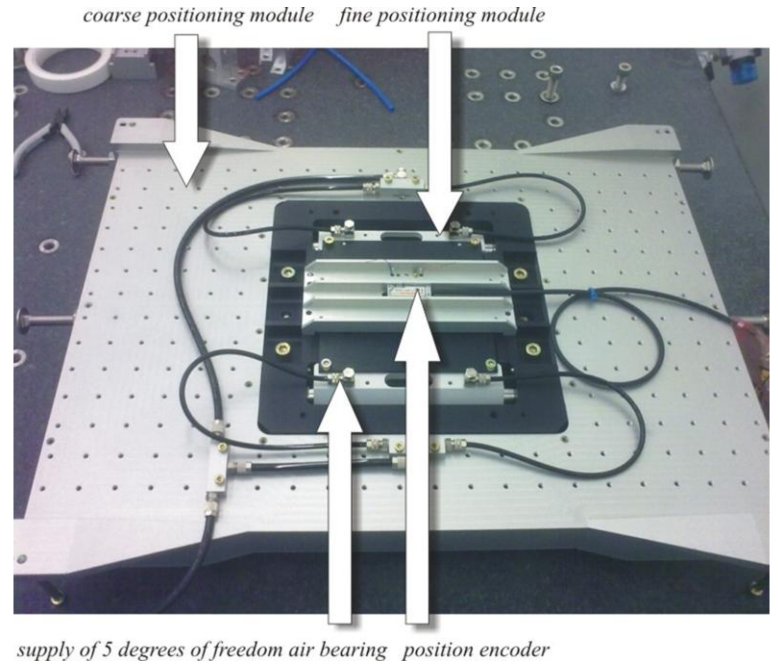

Figure 5 *Hardware*

The system has been subjected to a repetitive motion profile with a peak velocity of 1 m/s and peak accelerations of 100 m/s^2. The tracking error of the fine positioning module during constant velocity was less than 2 micrometer as shown in Figure 6. This is equal to the noise level of the used sensors to measure the position. Therefore the measurement system is currently being improved. This system shows high potential to even reduce its tracking error significantly to the nanometer range.

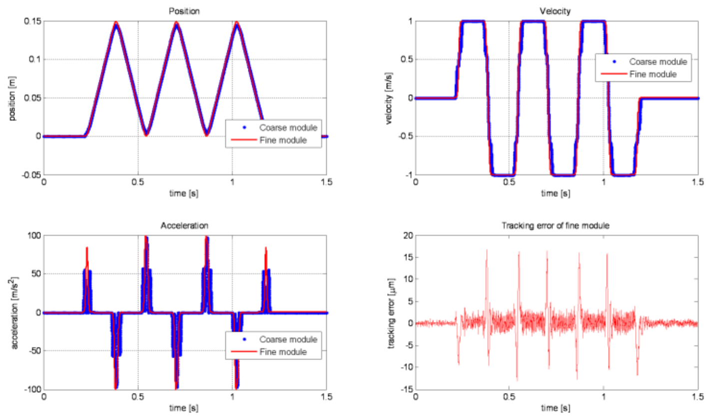

Figure 6 *Systems response to motion profile*

3 Conclusions

In this project has proven that transfer of driving forces from a coarse motion system to a fine positioning module can be done with passive elements. This has been proven by theoretical modelling and measurements on a prototype implementation.

Additionally, the non-linear spring, created by opposing permanent magnets, is well suited for this purpose. Finally, suitable trajectories for the motion elements can be derived and excellent motion performance can be obtained.

References:

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