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Early testing of a coarse/fine precision motion control system

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This abstract presents a brief overview of key components of a motion control stage for accurate nanometer level positioning for scanning specimens over an area measuring 50 mm x 50 mm. The completed system will utilize a short-range, third generation 6 degree-of-freedom fine motion control platform (4 microns, 160 micro-radians) carried by a long-range, two-axis *x-y* positioning system (50 mm x 50 mm). Motion of the controlled platform relative to a measurement frame will be measured using a heterodyne laser interferometer and capacitance sensing. The final stage will be mounted onto an isolation table in a vacuum chamber, itself on isolation supports mounted to a granite slab on bed rock and isolated from the main floor of the building. This whole system is housed in a temperature-controlled laboratory.

It is envisaged that the current system will provide the ability to "pick and place" at nanometer levels and be used for long range scanning of specimens (including biological specimens), micro- /macro-assembly, lithography and as a coordinate measuring machine (CMM). Furthermore, the system performance will be compared with other comparable systems at international locations such as, National Physical Laboratory (NPL) in the UK, Technical University of Eindhoven (TUE) in the Netherlands, Physikalisch-Technische Bundesanstalt (PTB) in Germany, and our own sub-atomic measuring machine (SAMM) [1, 2] at UNC-Charlotte.

Critical requirements of the system are as follows:

- Vacuum compatible to better than 20 mPa
- Range of 50 mm $\times$ 50 mm $\times$ 4 microns
- Maximum translation velocity of 5 mm$\cdot$s^{-1}
- Sub-nanometer resolution
- System accuracy of better than 10 nm.

Dual axis coarse stage

The dual-axis long-range stage of the final design is shown in Figure 1. The stage is used to achieve translations of 50 mm in *x*- and *y*-axes. Motion of the slideways is obtained by a ultra-high molecular weight polyethylene (UHMWPE) nut with an 80 threads per inch feedscrew. Control of the screw is obtained using vacuum compatible, frameless motors (Aerotech™ models S-50-39 and S-50-52) with MicroE™ encoders for position feedback.

The two, stacked orthogonal moving carriages slide on thin film UHMWPE bearing [3] against Zerodur® optically flat counter faces. Evaluation of control strategies and operation of drive mechanisms has been performed on a simpler single-axis stage (included a single DOF fine motion control actuator) and demonstrated the reduction of feedback error at the nanometer level [4].

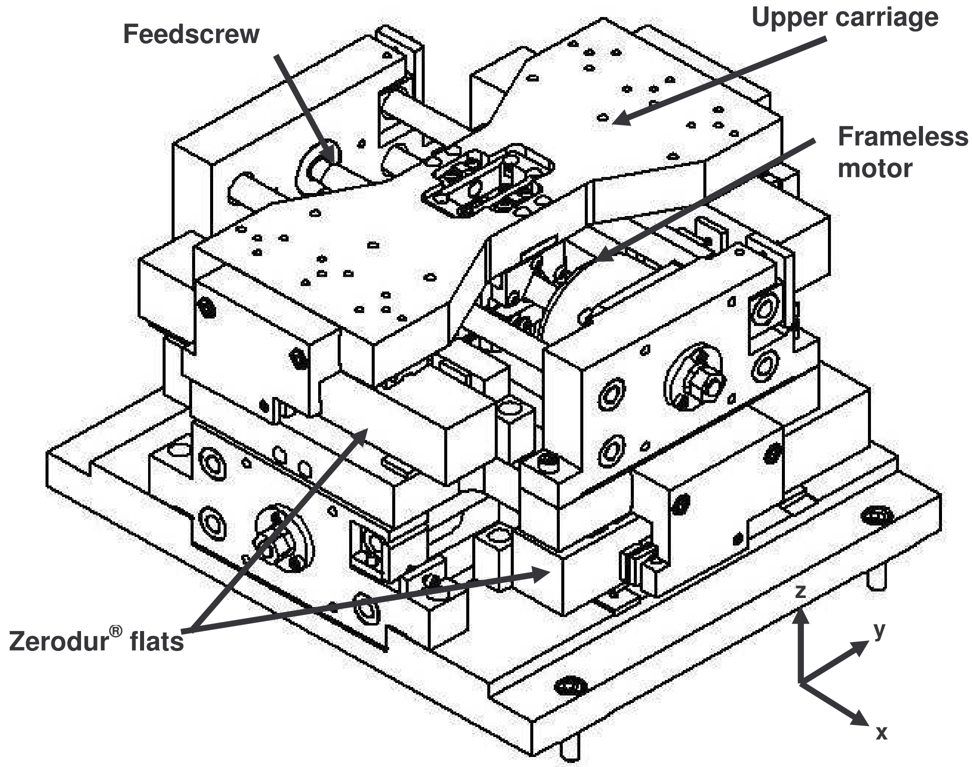

Figure 1: Line diagram of dual–axis, long-range stage.

6 degree-of-freedom fine motion stage

To achieve nanometer positioning accuracies a third generation 6 degree-of-freedom fine motion stage (DOF FMS) is utilized to reduce positioning errors of the long-range stage and is depicted in Figure 2[5]. To achieve translations of the stage 6 single crystal piezoelectric tubes are utilized in a 2-2-2 configuration (2 actuators in each axis) providing translations of approximately 4 μm and rotations of 160 μrad. The initial 6 DOF FMS positioning system has a gravest mode natural frequency at 162 Hz and very low damping resulting in a high *Q*. Through successive designs the gravest mode frequency was increased to 440 Hz with a substantial damping factor increase from the initial positioning system with little detectable damping to a damping ratio of approximately 0.016 in the second design and 0.028 at the 3rd generation. Resonant frequency was measured with a 0.65 kg load placed on top of the 6 DOF FMS, see Figure 3.

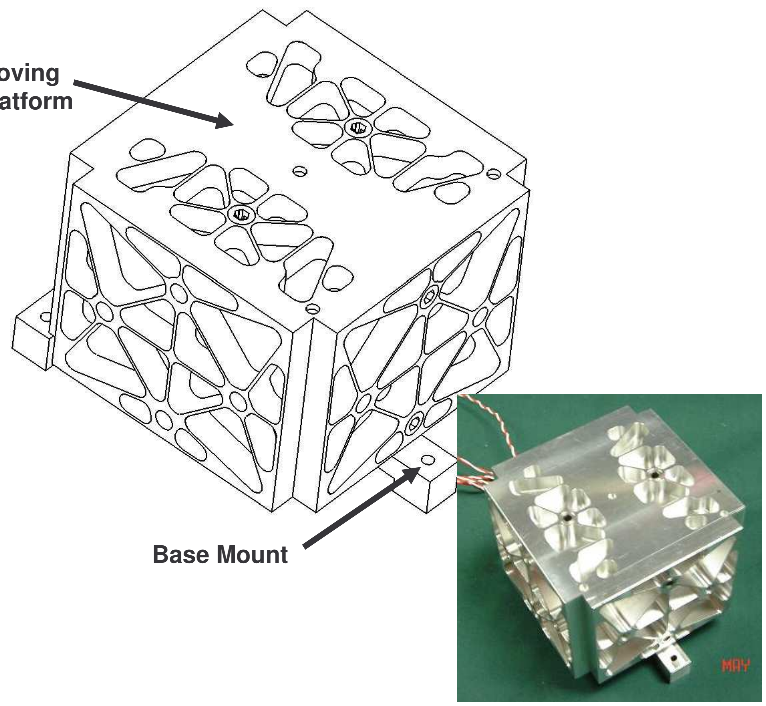

Figure 2: 3rd generation 6 DOF fine motion control system.

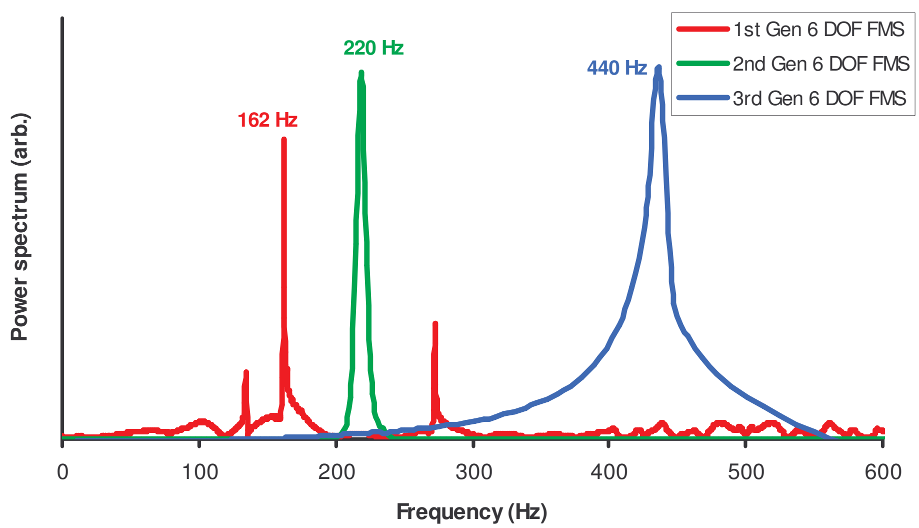

Figure 3: First resonant frequencies of the 1st, 2nd and 3rd generation 6 DOF FMS with a 0.65 kg payload.

Metrology Frame

Measurement of the specimen mounted onto the fine stage platform of the coarse/fine stage will be a combination of laser interferometry and capacitance gages. Motion of the *x*-, *y*-axes (in the plane) and rotations about the *z*-axis will be performed using a 3-axis, 2-pass laser interferometer (Zygo DMI), while motion in the z-axis and rotations about the x- and y-axes are measured by capacitance gages. A complete system with the surrounding metrology frame and instrument support structure is shown in figure 4.

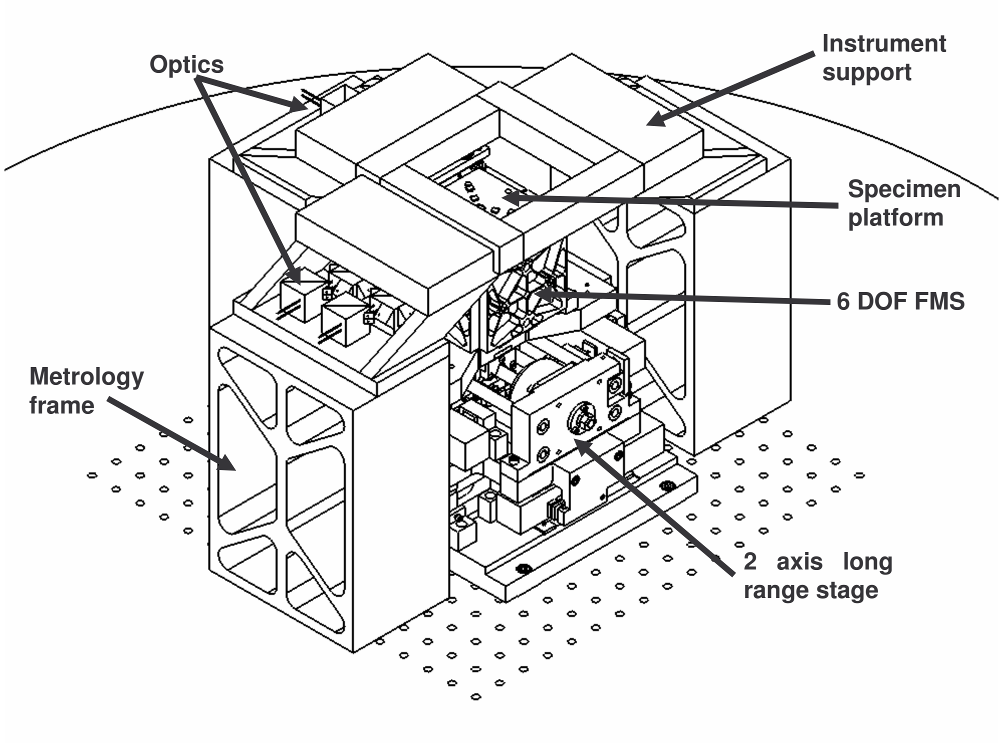

Figure 4: Complete positioning stage along with metrology frame.

Future work

As of writing, the final components of this system are being manufactured with subsystem components being assembled. It is envisaged that early performance characterization of the complete stage will be completed and results of the working system presented at the annual conference.

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