MEDSI 2004 proceedings

NOVEL DESIGN OF PEEMIII 5 AXIS SAMPLE MANIPULATOR

Daniela Cambie, Robert Duarte, Nicholas Kelez, Alastair Macdowell, Howard Padmore, Karl Peterman

Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA

Abstract

The PEEM3 microscope currently under construction at the ALS requires a UHV sample manipulator that has an X, Y motion of +- 5 mm, Z motion of 5 mm, and tilt of the sample around both the X, and Y axis of +- 2 deg. The sample requires heating to 900 K, cooling to 90 K, electrical isolation of 25 kV, and stability of 1 nm for 1 hour. The approach taken is to use an orthogonal six strut system that allows each axis of motion to be controlled directly from the sample stage through a flexible link to it's corresponding manipulator that is attached directly to ground. This allows all of the motions to be controlled from outside of vacuum eliminating heat sources or magnetic fields from the sample area, and also gives direct access to the back of the sample stage to outside of vacuum to facilitate heating and cooling of the sample. A preliminary design of the motion system has been completed and a larger scale prototype has been built. The first step is to correlate FEA data for the modal analysis to the actual components, then other design options will be tested for motion and stability. A description of the design and the results and future directions will be discussed.

This paper is a status report and a discussion of several of the options looked at for the design of the PEEM3 sample manipulator. It also describes the origins of the design with the use of a 6 strut system at the ALS and possible configurations for this application. All current results are based on analysis, no measurements are available at this time.

1. Use of the 6 strut system at the ALS:

Since the beginning of the ALS most support system design has been based on the use of 6 orthogonal struts. Our seismic requirements dictate that all components be fully constrained in the event of an earthquake, all designs are required to be able to handle a minimum .7g lateral load. The six strut system accomplishes this for us. There are more than 550 six strut systems in use at the ALS and has proven itself by holding its position for 8 years of operation and to remain stable even through seismic events.

The 6 strut system has been used at the ALS both in orthogonal and Hexapod (Stewart platform) configurations. In cases where a full 6 degrees of automation are required the hexapod geometry is often preferable. In case of manual adjustments such as for alignment, or for automation of only a few of the motions the orthogonal approach is most often used. The orthogonal six strut system has been used at the ALS to support such diverse components as the 12 storage ring girders and all the individual magnets located on them, to individual mirrors in UHV and sample positioners[1], [2], [3].

The orthogonal 6 strut system is intuitively easy to adjust and any required motion can be automated for a limited range of travel by mounting the anchor point of the corresponding strut to a linear stage. The large motions are typically handled by the regular strut adjustments and the smaller precision motions are controlled by the stage [figure 1]. This doesn't require a high quality stage since the only motion that is transferred to the system is parallel to the strut but for the highest stiffness the loads are often applied on axis with the lead screw to minimize the compliance of the stage system.

The approach of using a linear stage at the anchor point is not as appealing with the hexapod geometry since the extended lines of the struts cross each other at the base. In the case of large motions, it is preferable if the strut itself changes length. There are several good examples of this type of strut design such as those used at the ESRF [4], or those used on smaller manipulators manufactured by PolytecPI [5], and Alio industries [6]. While the orthogonal 6 strut can also take advantage of these strut designs it is typically not required since having the combination of manual alignment on top of smaller automated adjustment of desired motions usually solves most of our needs.

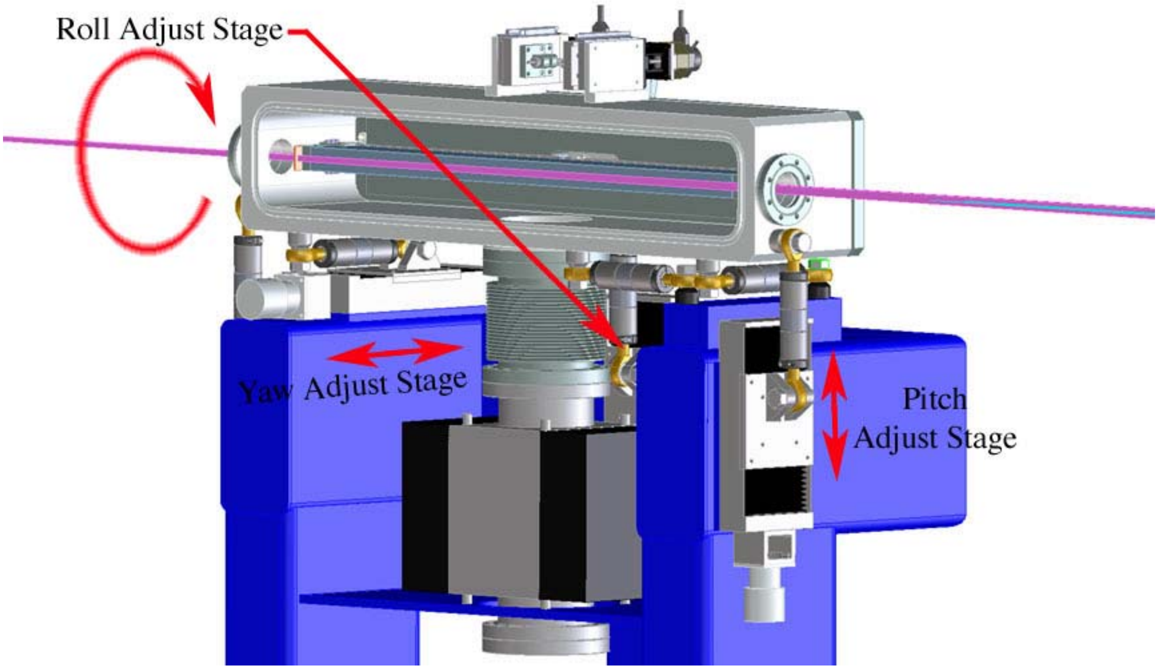

Figure 1 – Mirror Tank with 6 Strut Mount and 3 Axis Remote Adjustment

2. PEEM 3 Microscope

The PEEM 3 microscope is an aberration corrected photoemission electron microscope currently under construction at the ALS [Figure 2]. The resolution of conventional PEEM microscopes is limited by the spherical and chromatic aberrations of the round lenses. Since the lens aberration coefficients are always positive, aberrations can only be minimized by adjusting the geometry of the electrodes but not eliminated. Up to now, the lateral spatial resolution of the state-of-the-art X-PEEM can reach to 20nm such as PEEM2 currently in operation at the Advanced Light Source. Aberrations must be compensated in order to remove their deleterious effects on the imaging properties of the microscope. A well-designed electron mirror can have different sign aberration coefficients from that of round electron lenses so that the aberrations can be cancelled out and the resolution can be improved.
The stability and performance of the sample manipulator will affect the ultimate performance of the microscope. This is a look at one of the design options currently under investigation and some of its variations.

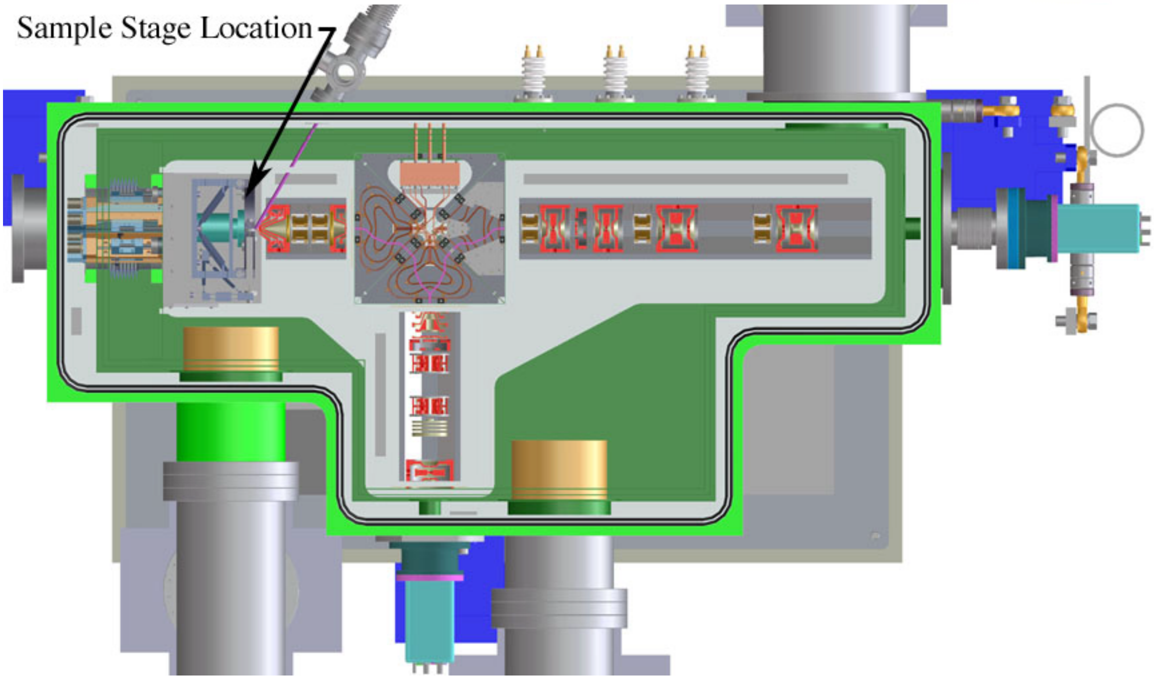

Figure 2 - PEEM 3 Microscope

3. Six Strut Manipulator and variations

3.1 Stage options

The original layout for this design was based on the goal of locating all the positioners (motors, stages and encoders) outside of vacuum through one bellows. It is based on a standard orthogonal 6 strut system [figure 3]. The geometry consists of a 6 inch diameter by .75 inch aluminum stage, the struts consist of 4.375 long by .025 inch diameter stainless steel wires with a 3.5 inch long aluminum stiffener in the center. This ratio of rigid to flexible components on the struts was chosen to keep the flexible link below yielding at maximum travel. The actual stage will be considerably smaller but this size was chosen for ease of assembly and flexibility in the test phase. Analysis shows that the natural frequency of the basic structure with ideal mounting of the fixed end of the struts is 349 Hz. It is important to note that the compliance of a 6 strut system typically comes from the mounting or the support structure. Due to the various mounting locations of the struts in the orthogonal geometry it is typically more difficult to build a rigid mounting frame than with a hexapod geometry where both ends of the struts have a circular mounting pattern [Figure 4]. The natural frequency of the hexapod with the basic geometry (same diameter mounting circle top and bottom) shown is 274 Hz. To optimize the hexapod geometry for this application the base circle could be increased, this increases the frequency of the first and second lateral modes and lessens the third mode vertical modes [Figure 5].

In this case, the choice to use orthogonal over hexapod geometry for the PEEM sample manipulator was due to the required 5 axis motion that allowed us to eliminate one drive, this would not be possible with a hexapod since all struts must move to achieve any of the desired motions. In the case of a Hexapod where the strut typically changes length, the strut contains the drive, the stage, and the encoder, significantly adding to the sprung mass of the system which becomes quite significant when the payload is small such as in this case.

Figure 3 – 6 Strut Stage Test Model

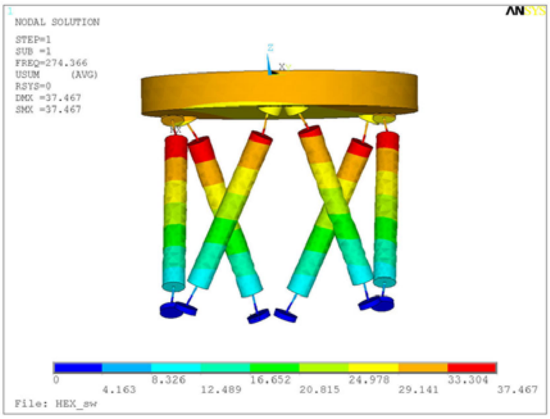

Figure 4 – Hexapod Platform geometry

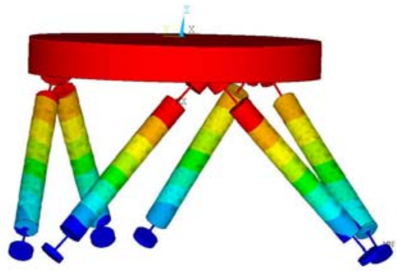

Figure 5 – Hexapod widened base

3.2 Stage with Bellcrank actuation.

Since there is no rotation of the stage required for this application we could add a 7th strut. This extra strut leads to an over constrained system which is typically a not a good idea where long term stability is important. This is only done to give a symmetric mounting for the bell crank flexure and allow for all the linear drivers to be located in one location [Figure 6, 7]. The addition of the 7th strut doesn't change the natural frequency of the ideal system and will be eliminated if in-vacuum drivers are adopted [figure 9].

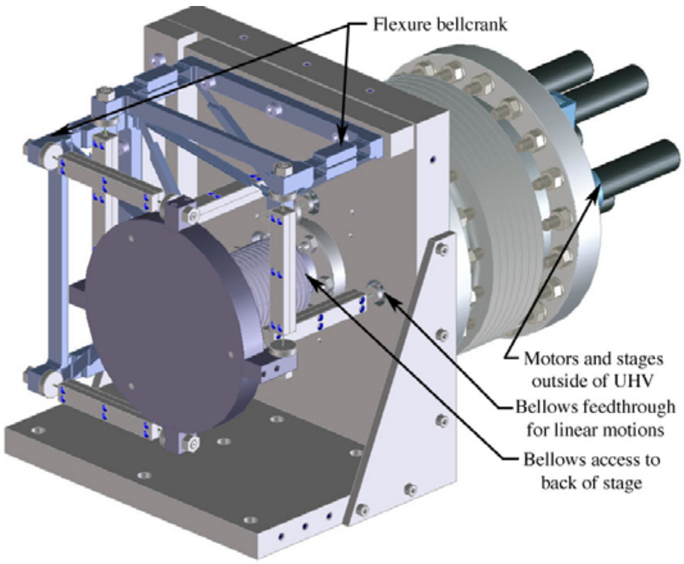

Figure 6 – Stage with bellcranks and linear feed through

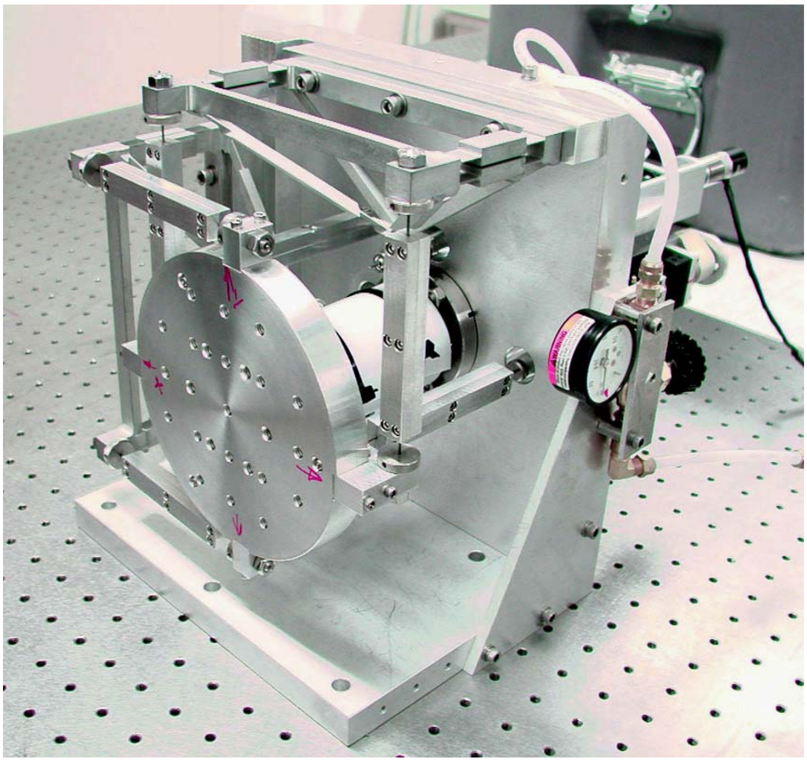

Figure 7 – Assembled test Stage with 90 degree flexures and linear drives outside of vacuum

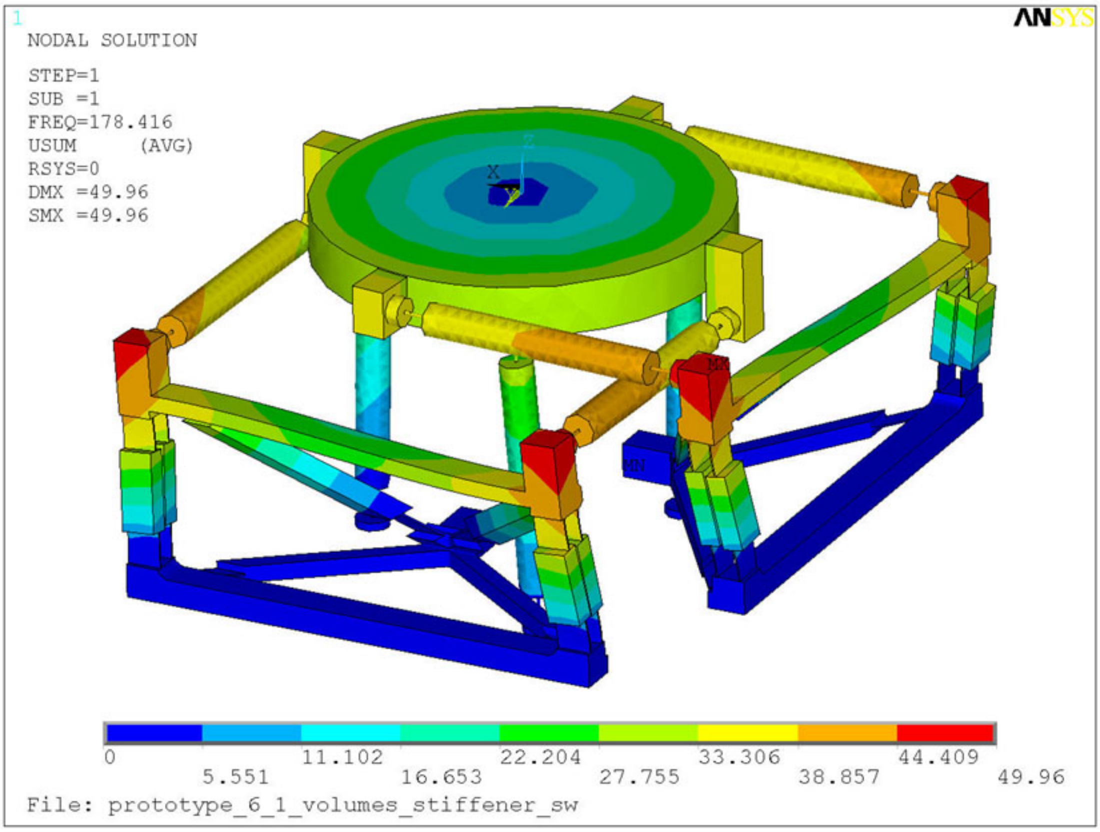

Figure 8 – Stage with Bellcrank Modal Analysis

The compliance in the bell cranks reduces the natural frequency of the assembly to 178 Hz [figure 8], which is similar to the advertised value of some commercial in vacuum hexapods we investigated. At this time we have been unable to measure the stage without adding apparatus with significant mass that dramatically degraded the expected performance, but based on preliminary measurements and past experience we do not expect a large deviation from the theoretical model. The actual requirement for the natural frequency of the stage is not a hard number. The goal would be to make it as high as practically possible, it is believed that all of the options discussed are likely to be acceptable. The primary requirement is long term stability, which was another motivation for moving all of the drivers outside of vacuum to eliminate possible heat sources that could cause thermal drift.

3.3 Stage with in-vacuum actuation

In the original PEEM 3 microscope design the large bellows that surrounded the motors and stage was needed to balance the vacuum load that existed at the opposite end of the in-vacuum table for the detector. A change in the design to decouple the detector from the in-vacuum table means that we would also like to eliminate the vacuum load from the stage end as well. This has allowed us to give up the requirement to co-locate the drivers in one location outside of vacuum, and to eliminate the bell cranks which were the major source of compliance in the system.

We are now designing a new in-vacuum stage version that uses Nanomotion UHV compatible linear drivers, [7] and titanium in-vacuum stages. This component choice is based on the need for no residual magnetism near the sample and to not generate any magnetic or electric fields during operation of the microscope. The Nanomotion stages are capable of maintaining 70% their holding force when powered off and we are testing UHV compatible encoders to determine if the fields generated are acceptable [Figure 9].

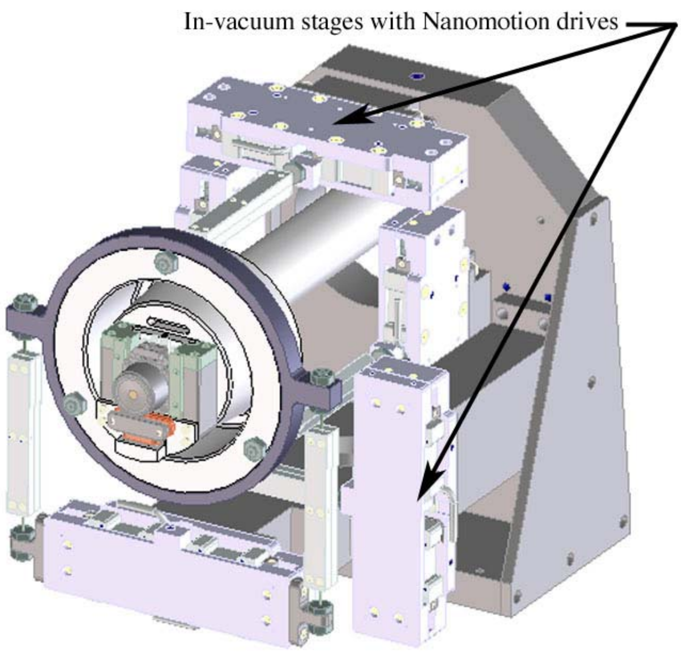

Figure 9 – All In-vacuum Stage Assembly

4. Conclusion and work to be done

At the time of the writing of this paper we have changed our design focus to using in-vacuum nanomotion stages, and we are testing the vacuum compatibility of some encoders. The measurement facility was not complete to be able to measure the natural frequency and the affects of the various components on the stability of the stage. This should be complete in the next few months. The stage with all in-vacuum motions is being designed and will be measured and results compared when the assembly is completed.

References

[1] J. Tanabe, T, Lauritzen, M. Kritscher, "Magnet Supports, Forces in the Support Struts", LBNL engineering note #M7127 (LSME-393)

[2] J. Tanabe, , "Magnet Supports, Natural Frequencies of Support Systems", LBNL engineering note #M7703 (LSME-746)

[3] Nancy Yu, Tom, Swain, "Strength and compliance of Beamline Struts", LBNL engineering note #M7272 (LSME-499)

[4] Philippe Marion, et all, "Hexapods at the ESRF: Mechanical Aspects, Results" Medsi 2004

[5] Polytec PI, http://www.polytecpi.com/hexapod.htm

[6] Alio Industries, http://alioindustries.com/

[7] Nanomotion Ltd., http://www.nanomotion.com