K1DM3 Design Note

Mirror Assembly Test

Version 2.0, December 18, 2016

By Alex Tripsas, Jerry Cabak, J. Xavier Prochaska, Chris Ratliff, Jim Ward, Dave Cowley

I. Overview

Every several years, the K1DM3 mirror will be removed from its module for recoating on site at WMKO. To facilitate this process, the mirror assembly is mounted on the swing arm on 3 cone-in-groove kinematic fixtures and fastened with 6 M4 screws. This kinematic coupling is designed to insure the mirror is repeatably returned to the same position. This document describes tests which measure the precision of repeatability.

II. Test

To measure repeatability of the mirror to swing arm positioning we incorporated three LVDTs mounted to custom, removable fixtures to measure the mirror blank position at three points. We will then remove and replace the mirror assembly, taking a series of measurements.

Goals: The primary goal of this test are to measure the positioning repeatability of the mirror assembly when removed and reattached to the swing arm. Secondary, we will determine and document a preferred removal and installation procedure for the K1DM3 mirror assembly (e.g. for coating).

There is no specific repeatability requirement in the version 3.1 requirements document relating to mirror replacement. However there are repeatability requirements for the system during deployment and retraction as listed in Table 1.

Mirror in beam positioning		
Repeatability		
Decenter in the mirror plane	2.5	mm
Decenter from the telescope X and Z axes	0.725	mm, rms
Tip	11.5	arcseconds rms
Tilt	23	arcseconds rms

Table 1: Repeatability requirements for K1DM3.

We can apply the requirements outlined in Table 1 to estimate tolerances on the repeatability of mirror assembly replacement. In Appendix A, we convert the tip and tilt requirements to microns of movement in the mirror as measured by our LVDT's. The results are listed in Table 2.

Fixture	**Offset**	**Tip**	**Tilt**
On-Major Axis	1 micron	...	0.9 arcsec
Off Axis	1 micron	0.7 arcsec	0.4 arcsec

Table 2: Estimated tip/tilt from a 1 micron displacement of a kinematic fixture. In each case, only one fixture is assumed to be displaced, i.e. all others are held fixed. See Appendix A for further details.

Materials: To perform this test, we need the following materials and K1DM3 sub-systems:

- Three LVDTs with mounts
- Three hardened 440-C Stainless Steel blocks
- Agilent [NEED MODEL]
- Computer
- Crane
- Mirror and groove plate assemblies
- Swing arm assembly
- Groove-plate
- Swingarm Stand
- Guide clamps and rods

Setup:

The three LVDTs are positioned next to each kinematic on the groove-plate, and pressed up against hardened 440C stainless steel blocks providing reference surfaces of .2 microns roughness. Figure 2 shows one face of the kinematic coupling (groove-plate) and how it attaches to the mirror support structure (Figure 3). Next to each kinematic is a pair of M4 captive screws which are attached to the groove plate and fasten the mirror assembly to the swing arm. The swing arm itself is to be held by a 3-point stand designed to keep the groove plate approximately level. This stand allows access underneath to fasten the mirror support (See Appendix B).

To stabilize the system and simplify lowering the mirror assembly onto the kinematics, we designed and installed three clamps on the groove plate which holds $1/8''$ rods vertically. These rods intersect holes in the support structure of the mirror assembly and prevent sway in the system when it is lifted from the swing arm. These guides do not, however, affect the placement on the kinematics.

Figure 1 shows how we intend to hoist the mirror.

Procedure:

The procedure for this test was:

1. Hoist dummy mirror with attached support structure with crane via an eye-bolt on the dummy mirror
2. Take 5+ readings with each LVDT
3. Set mirror system down onto swing arm
4. Take 5+ readings with each LVDT
5. Fasten the system with M4 screws next to each kinematic. A specific recipe is described below.
6. Take 5+ readings with each LVDT
7. Disengage system and lift
8. Repeat 10 times

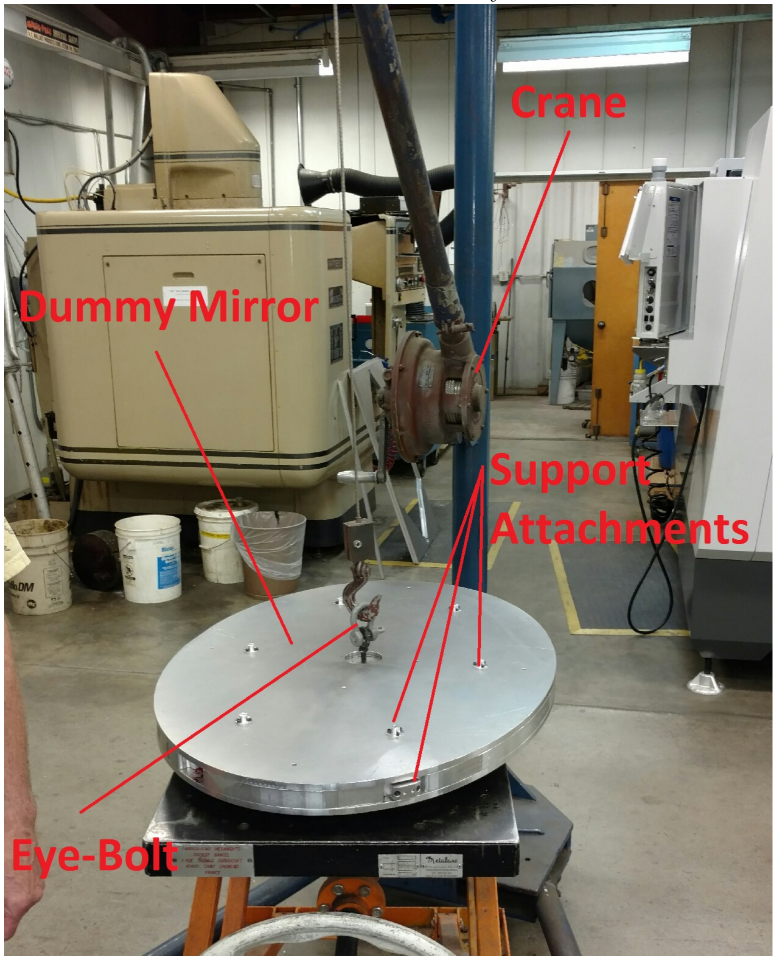

Fig. 1.— The dummy mirror held up with a crane in the instrument shop. This crane will be used to raise and lower the dummy mirror (with support structure)

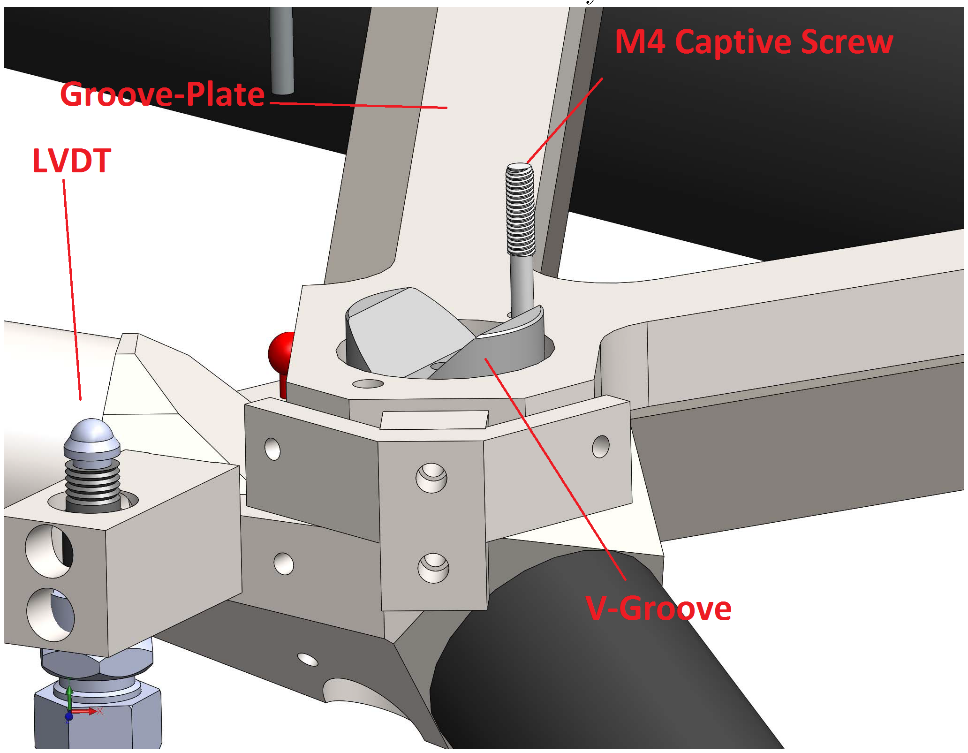

Fig. 2.— Sketch detailing one V-groove mounted to the groove plate, one of its M4 captive screws and an LVDT in its custom fixture.

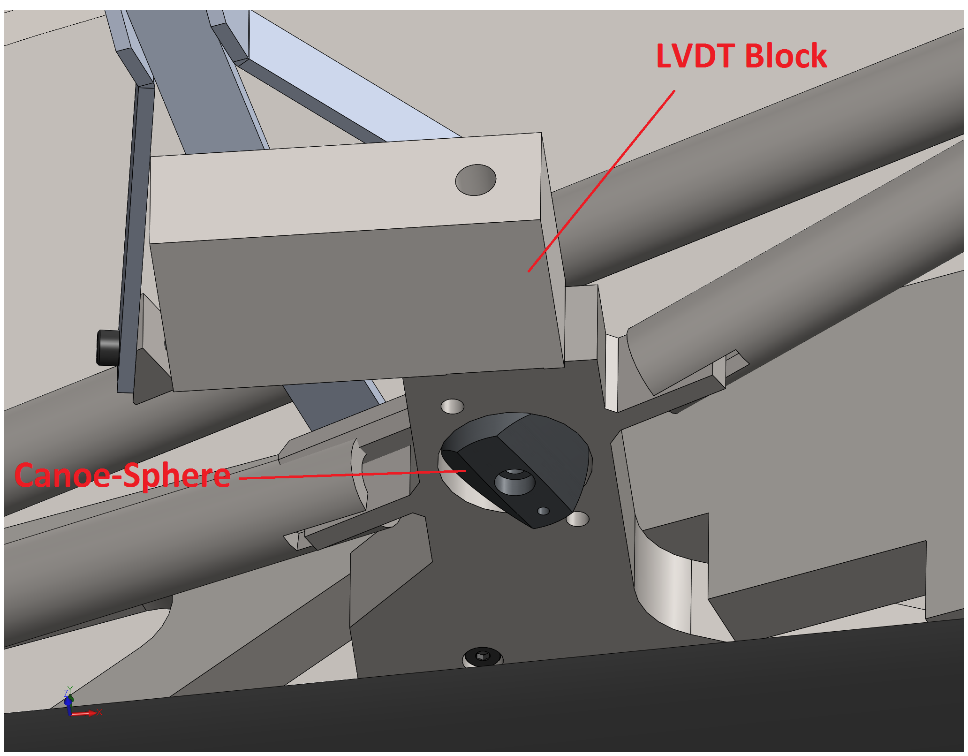

Fig. 3.— Sketch detailing the mirror support structure with kinematic and the block fixture which will contact the LVDT. The block is made of hardened 440C stainless steel to provide a smooth surface for the LVDT to press against.

III. Results

During December 1-9, 2016 we performed a series of repeatability tests on the mirror assembly system. The assembly was configured as described in the procedure above, and a sequence of lift, set, and torque steps were performed. The results below correspond to a 9 trial test performed on December 9, 2016 from 17:00-18:00 PST (recorded in file: RLO_2016dec09_17hr.csv).

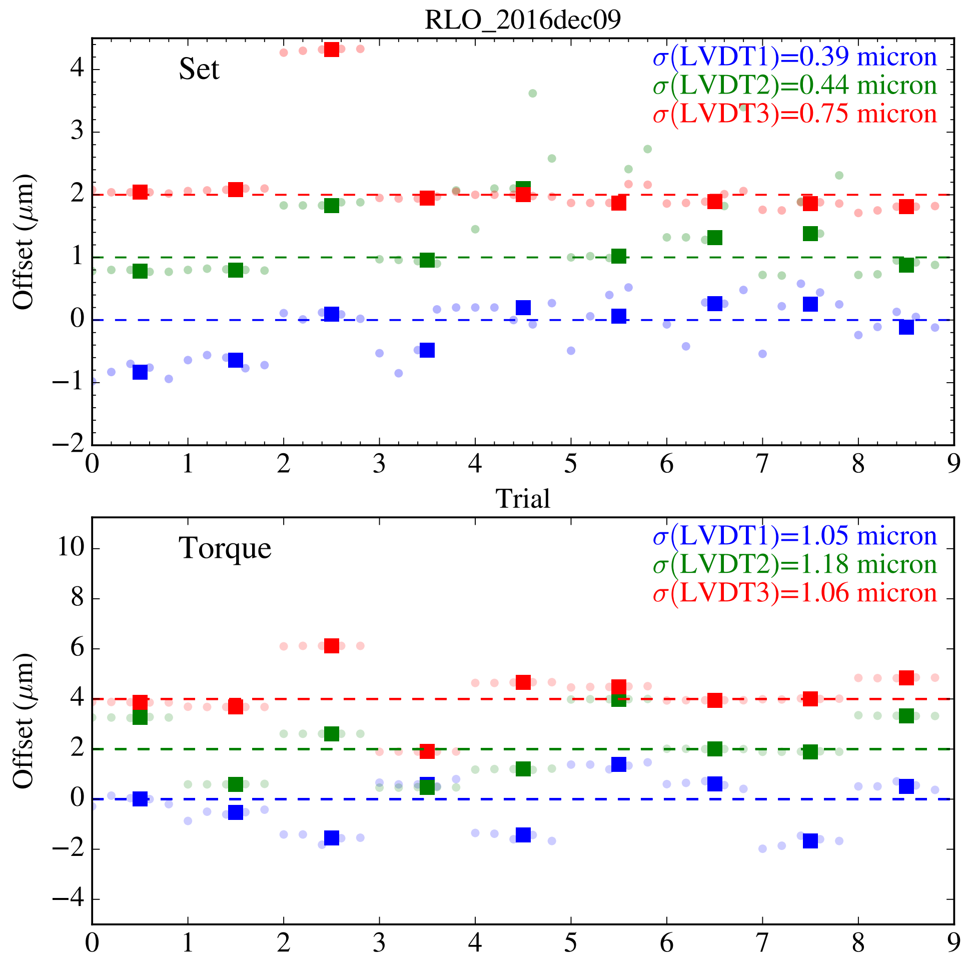

Fig. 4.— (upper) Measurements of the 3 LVDTs for the mirror assembly system when set on the swing arm *without* torquing the kinematic screws. The values are the LVDT offsets relative to the median reading from all 9 trials, in units of microns. The dark squares are the median value of 5+ LVDT measurements during the trial. (lower) Same as above, but when the kinematic screws were torqued with our preferred procedure. This has been recorded in K1DM3 drawing 872-LM4700, Mirror & Swing Arm Assembly.

The upper panel of Figure 4 shows a sequence of LVDT offset measurements (relative to the median reading) for the mirror during a repeatability test performed on December 9, 2016. These measurements were taken just after the mirror blank was lowered onto the kinematics, i.e. before tightening of the M4 captive screws. The data show that the mirror positioning is highly repeatable (RMS $< 1\mu$m) confirming that the system is kinematic. This result held throughout our testing and is nearly consistent with systematic error in the LVDTs themselves.

When the captive screws are tightened, however, the system is no longer strictly kinematic and its positioning is dependent on the procedure used. For the off-axis kinematics, the LVDT positions offset by approximately 50 microns between no-torque and torque. We expect the majority of this offset is due to flexure in the LVDT mounts because the on-axis kinematic shows only an ≈ 10 micron shift.

After some experimentation, we adopted a specific procedure for torquing the mirror to optimize repeatability (refer to Figure 5 for a schematic). It is intended to more gradually bring the system under tension, one kinematic fixture at a time.

1. Torque screws in order #1-6 with a torque wrench set to 5 inches-pounds
2. Torque screws in order #1-6 with a torque wrench set to 10 inches-pounds

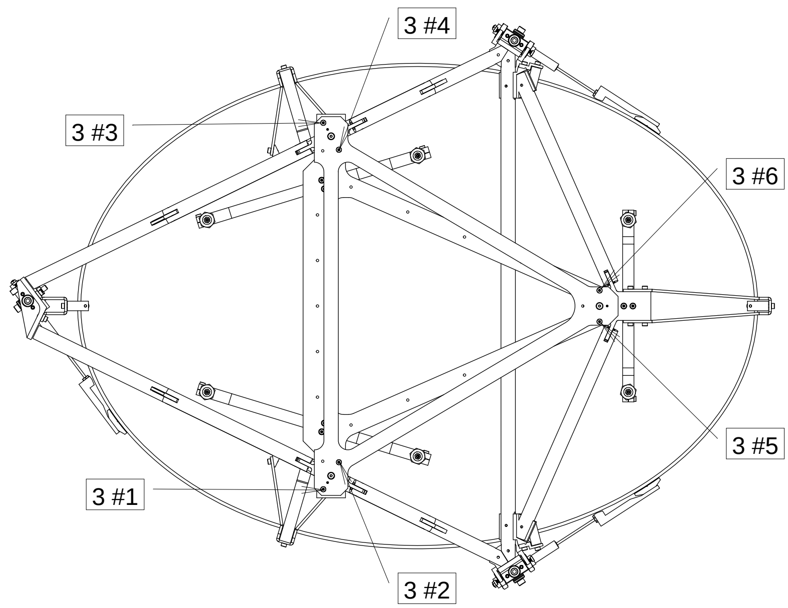

Fig. 5.— Schematic detailing the M4 captive screws, labeled #1 to # 6, as viewed from below the mirror assembly system. The numbers give the ordering for tightening down the screws.

The lower panel in Figure 4 describes the positioning offsets of the three LVDTs for the system when torqued to the final operating specifications. For the 9 trials, we measure an RMS of approximately 1 micron with a maximum excursion of approximately 2 microns.

These results easily meet the performance requirements.

IV. Lessons Learned

Below we capture a few additional findings from this series of tests:

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Appendix A: Requirements

The K1DM3 requirements document v3.1 defines Tip as rotation of the tertiary mirror around the telescope's Z-axis (Optical Axis) while Tilt is rotation about the telescope's Y-Axis. These correspond to rotations about the major and minor axes of the K1DM3 mirror, respectively.

The three kinematics are mounted in an isosceles triangle with base of 17.7 ,inches and sides of 16.563 inches. Using the Law of Cosines, the angle of the apex is $\alpha = 64.596$ degrees (and the base angles are $\beta = 57.702$ degrees). We further derive that the altitude (or height) of the triangle is $h = 14.00$ inches.

As designed the line that splits and is perpendicular to either congruent side, crosses the altitude 0.743 inches below the center of the mirror (toward the base; see Figure 6). We determine with simple geometry that that length from the base to the mirror center is $d = 4.945$ inches.

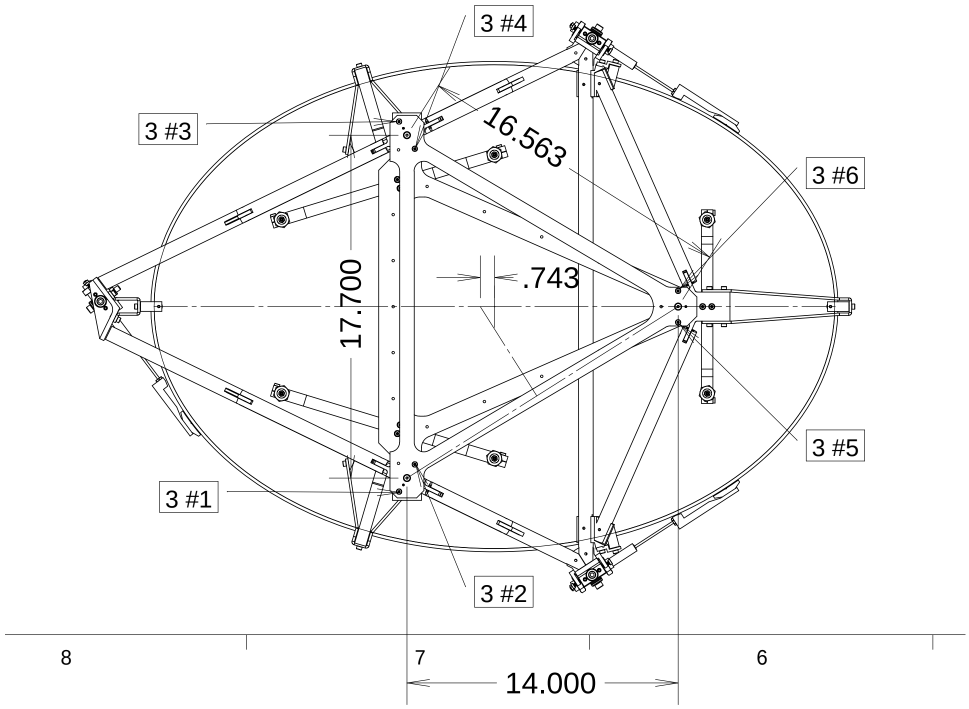

Fig. 6.— Zoom in of the K1DM3 drawing of the mirror support system with several dimensions labeled, focusing on the triangle of kinematic fixtures.

Focusing on the kinematic fixture located on the major-axis first, any offset of its position corresponds to a tilt of the mirror. Using the small angle approximation, this tilt for an offset of δ_{KO} is

$$\theta_{\text{tilt,KO}} = \frac{\delta_{KO}}{h - d} \tag{1}$$

For δ_{KO}=1 micron, we find $\theta_{\text{tilt,KO}} = 0.9$ arcsec.

The other two kinematic fixtures (using the Pythagorean theorem) is 10.138 inches from the mirror center. A 1 micron offset of one of them will be an angular rotation in that direction of 0.8 arcseconds. If this were purely along the minor-axis, the rotation would be entirely tip. However, these fixtures are ≈ 30 deg off the minor-axis and we estimate the tip as $\theta_{\text{tip}} = \theta_{\text{tilt,KO}} \cos(30)$ and recover 0.70 arcsec for a 1 micron offset. This also gives approximately 0.4 arcsec of tilt.

Appendix B: Swingarm Stand

The purpose of the swingarm stand is to hold the swing arm in a position where the dummy mirror (with mirror support structure attached) can be attached level to the ground while still being able to access the underside of the swing arm to fasten together both components. Figure 7 shows the base of the stand and how it will support the swing arm. In order to support the swing arm properly, an angle bracket was designed to use the existing screw holes on the swing arm to hold it up on the stand (Figure 8). Finally Figure 9 shows how the swing arm will be supported during testing.

Fig. 7.— Above is the base of the stand that will hold up the swing arm.

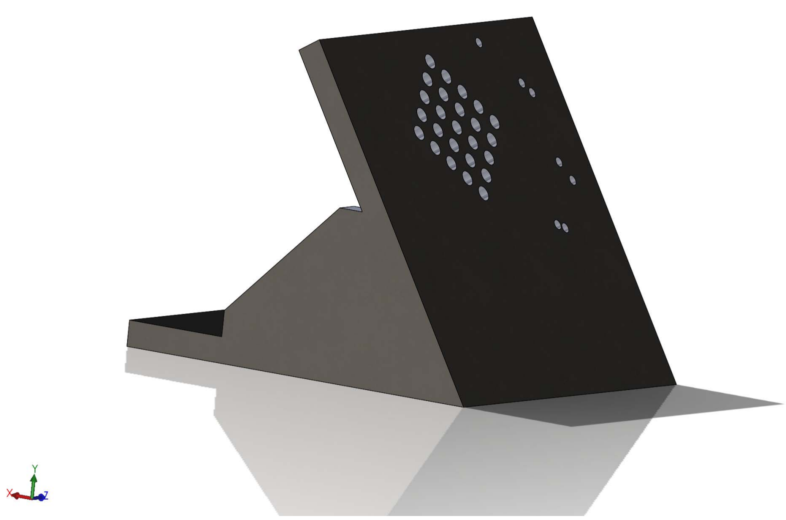

Fig. 8.— Above is the angle bracket that will be fastened to the swing arm. This will be fastened where the bracket for the kinematics will eventually go.

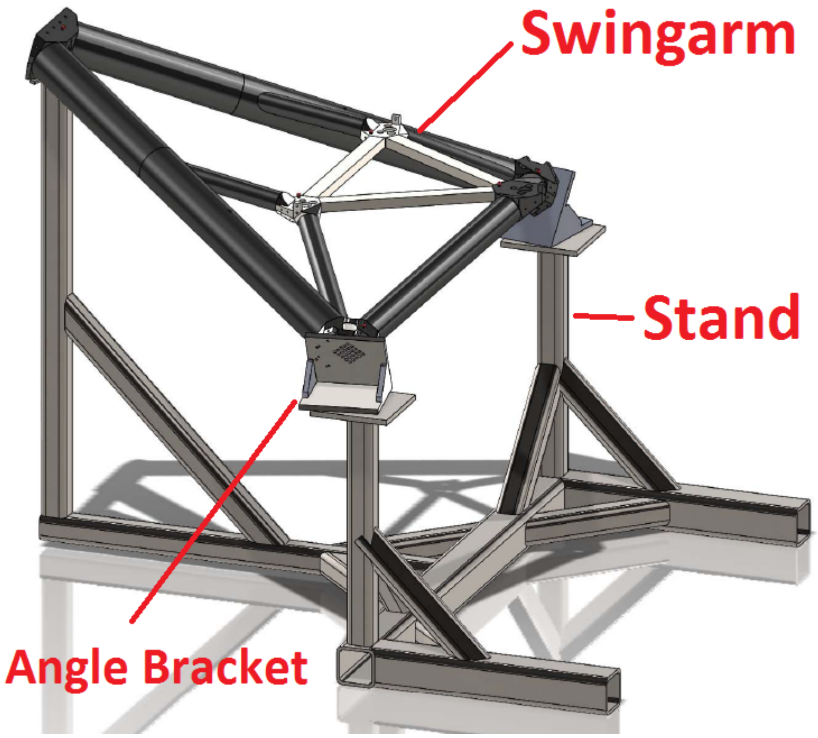

Fig. 9.— The finally assembly of how the swingarm will be positioned during testing.

Appendix C: Additional photos

Fig. 10.— Photo of the mirror blank set on the kinematics, on the swing arm, on the custom stand.

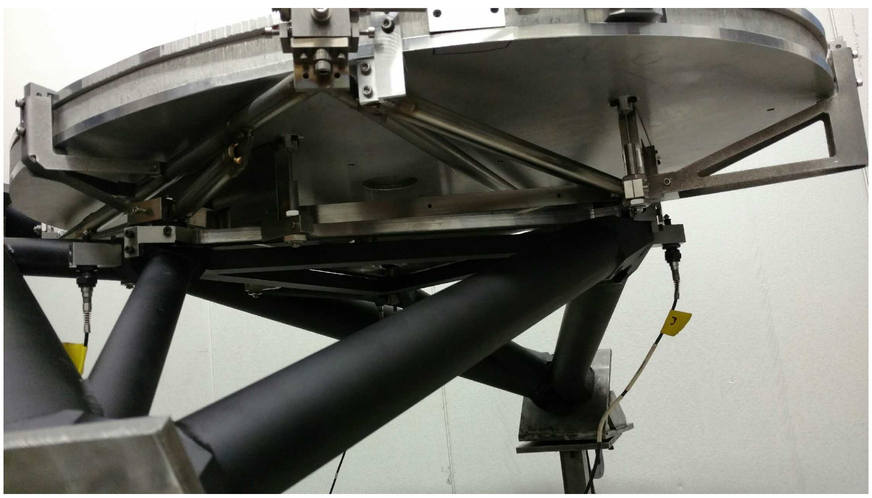

Fig. 11.— Underneath view of the mirror assembly on the kinematics. Two of the three LVDT devices are visible below.