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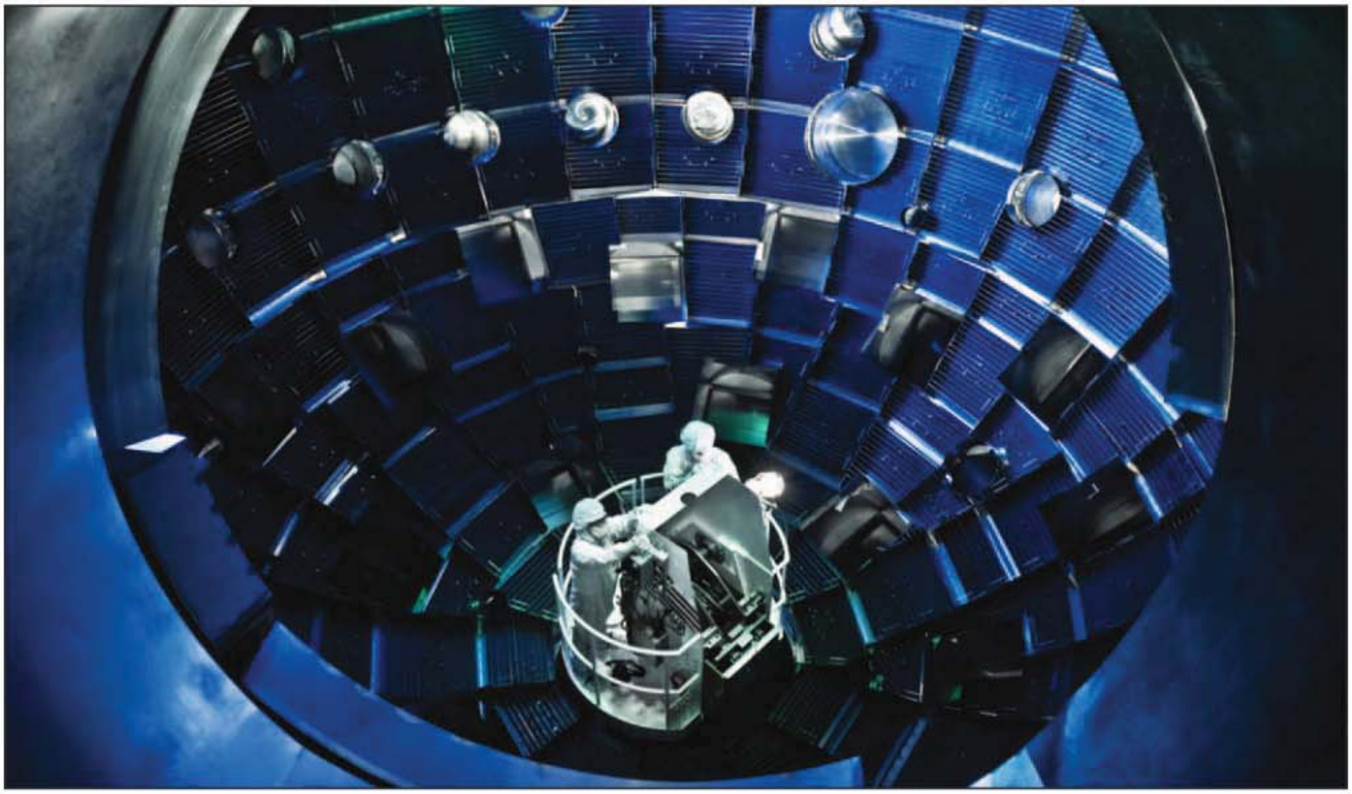

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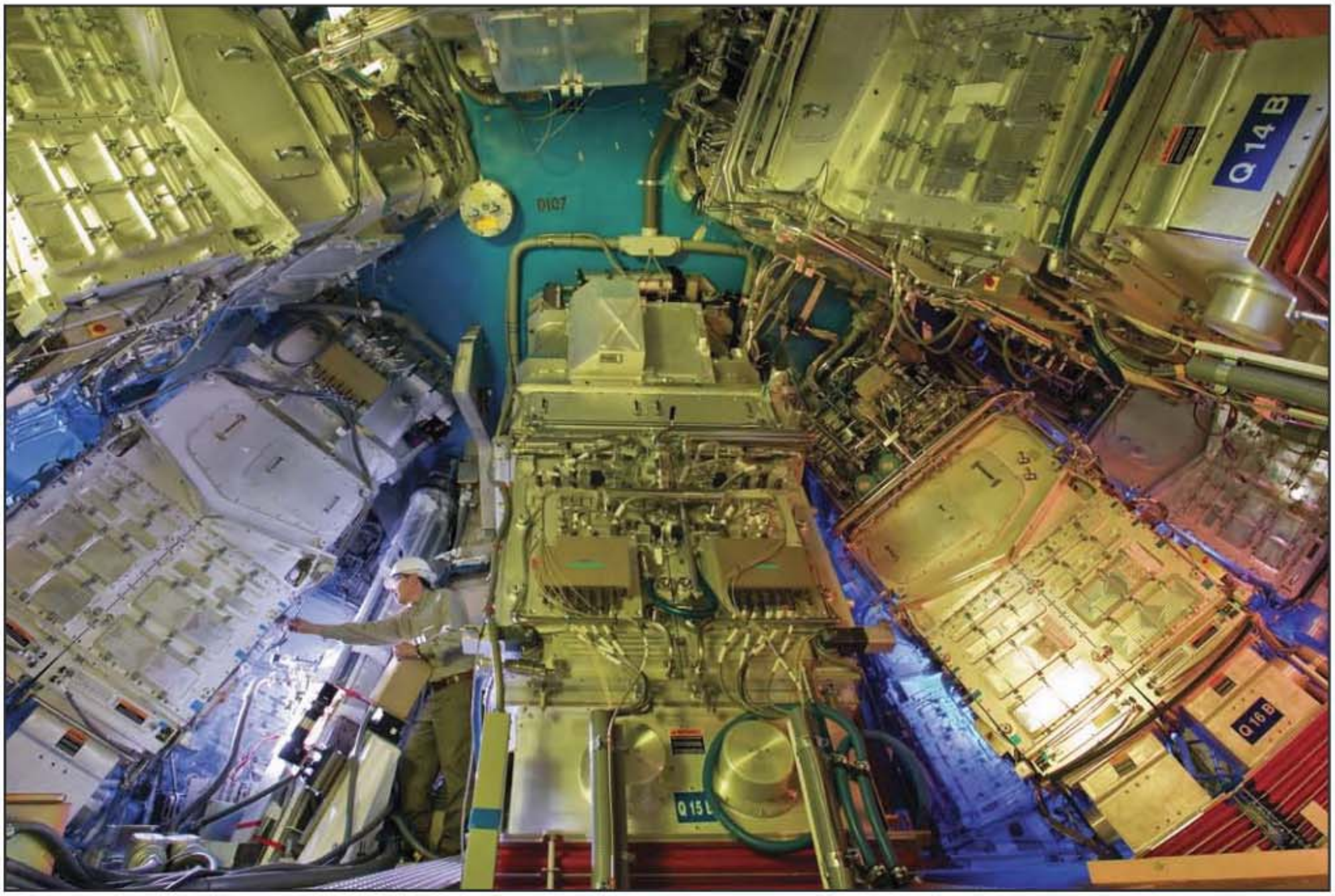

National Ignition Facility: Drive Diagnostic Kinematic Mount Assembly Plate System Characterization, Alignment, and Installation

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The National Ignition Facility (NIF), a program of the U.S. Department of Energy's National Nuclear Security Administration (NNSA), will focus the intense energy of 192 giant laser beams on a BB-sized target filled with hydrogen fuel, fusing the hydrogen atoms' nuclei and releasing many times more energy than it took to initiate the fusion reaction. NIF, a facility one football field wide and two football fields long, could be considered one of metrology's "wonders of the world" because of the stringent precision alignment of mechanical components, optics, and subsystems. In addition, NIF has a precision network accurate to three hundred microns, (3σ) over the entire stadium-size facility.

Out of these subsystems are the many diagnostics producing enormous amounts of data before, during, and after shot operations. (Shots last only two millionth of a second.) One such diagnostic is the Drive Diagnostic (DrD). The purpose of the DrD is to measure the power and wavelength of the 3ω light of all 192 beams entering the 10-meter-diameter spherical target chamber by sampling off a fraction of a percent of energy.

The DrD is installed indirectly onto the target chamber beam ports. Each port directing four of the 192 beams, 48 ports in total. Each DrD has a minimum of 12 precision optics and sensors per beam, totaling ~2,300. The DrD optic/sensor assemblies, called line replaceable units (LRUs), are affixed to the chamber using kinematic mount assembly (KMA) plates attached to calorimeter spools (Calspools), totaling 96 KMA plates for the 48 ports, with each KMA plate having 12 kinematic mounts on which to mount the LRUs. There are eight LRUs per port, four on top and four on the bottom (two for each beam), as seen in figures 1 and 2.

MECHANICAL CONFIGURATION

NIF is formally in a Cartesian coordinate system (CCS), and all NIF mechanical assemblies are driven by optical configura-

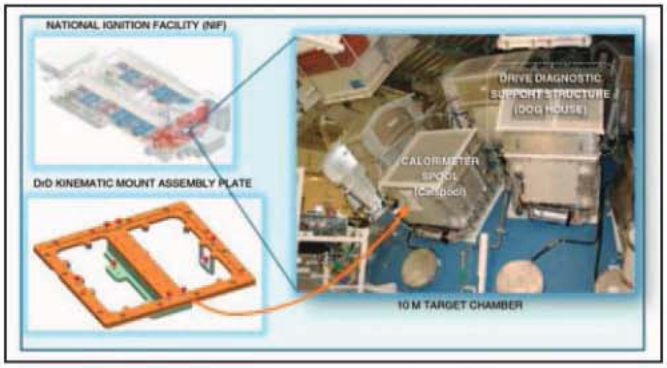

Figure 1. National Ignition Facility (NIF) 10-meter target chamber

Figure 2. NIF target chamber beam lines and beam ports

tion drawings (OCD), with the mechanical assemblies designed around the positional and alignment requirements these drawings dictate for optic placement. On a large project such as NIF, from time to time there will be a location where measurements and coordinate analysis are precarious at best. NIF's location is at the 10-meter-diameter spherical target chamber.

Formally assembled and designed in a CCS, because of the spherical shape of the target chamber, it would have been irrational not to employ a spherical coordinate system (SCS) integrated to the CCS. Moreover, NIF also employs hundreds of lower-level parametric coordinate systems called local coordinate systems (LCS). The reference to "parametric" simply means that the NIF CAD model has a top-level assembly (called "NIF Project") in which reside hundreds, perhaps thousands, of local parametric coordinate systems. When a subassembly is begun for design, the CS for that specific location is "passed down" from "NIF Project" to that subassembly to build around that CS. Once it is completed it is then "copied up" back to "NIF Project" and integrated into the top assembly. Upon release of a new revision, the top assembly is then "regenerated" and the components and all its features are now linked "parametrically" together. This was how tens of thousands of NIF installation coordinates were quality controlled and generated to an accuracy of 1 μm, moreover, this was how NIF could confirm that coordinates generated from the top assembly down to the subassemblies were 100-percent reliable. The coordinate generation for installation of the DrD employed this compilation and use of the parametric CS just described.

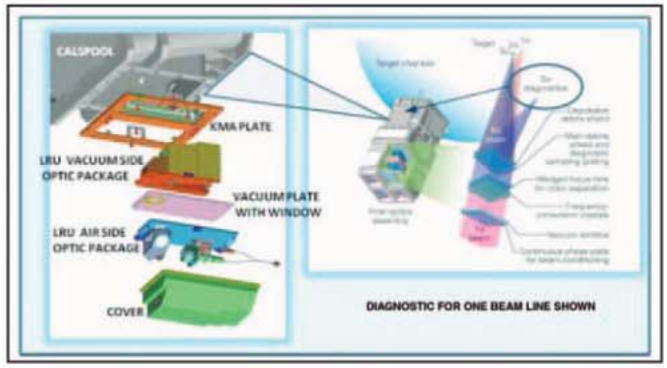

Figure 3. Beam line diagnostic

OBJECTIVE

The goal of the installation was an alignment of a precision optical subassembly—the DrD LRUs—onto an improperly installed upper-assembly Calspool mounted onto the 10-meter-diameter spherical target chamber to within +/−125 μm flawlessly 96 times, as seen in figure 3.

The Calspool interfaces (spacers) attached to the target chamber (48 in total) were machined incorrectly—an imperfection that compounded the difficulty of the precision installation. This corrective spacer designed to machine-out profile and plane imperfections was intended to create an orthogonal vector from the center line of the Calspool to the center of the chamber. At the time when the error was mitigated (to prevent beam clipping), it was believed that the modification was sufficient and would pose no future problems to subsequent subassembly integrations. This conclusion would later prove false.

The Calspool mitigation at the time was adequate to overcome beam clipping and pointing concerns; in summary, it minimized the maximum errors with respect to clear aperture; which in the local CS defined the x and y axes to be critical, leaving z to be understood as the soft axis.

It was later discovered that the z axis was in fact not soft; in addition, it was also critical to the DrD, which would be housed inside the Calspool. The DrD source energy (for sampling) is provided by the wedged focal lens (WFL, pronounced "wiffle"), as seen in figure 4.

The focal distance from the WFL to the DrD was critical to the pointing and centering of the energy to accurately hit the DrD optics. This was necessary for the DrD to get the energy required, and equally important, to not damage the diagnostic package components. The WFL is part of the Integrated Optics Module (IOM), which is hard-mounted to the Drive Diagnostic Support

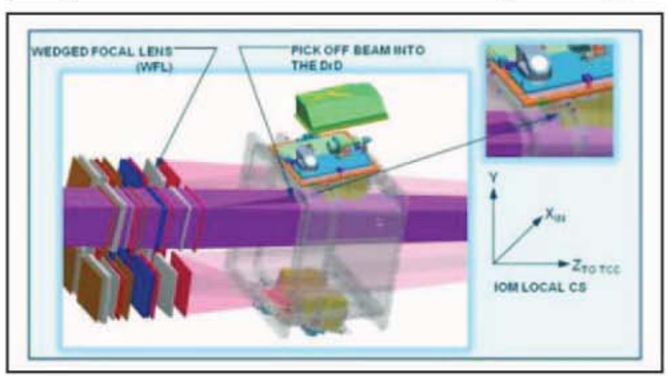

Figure 4. WFL

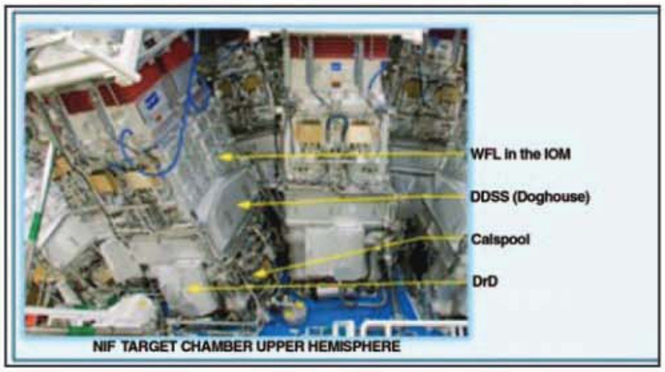

Figure 5. WFL mounted into “The Doghouse”

Structure (DDSS, also known as “The Doghouse”), which is in turn hard-mounted to the Calspools, as seen in figure 5.

The Calspools were thought to be in tolerance where they were in z (along the beam line) to other assemblies where z was soft, but to the WFL, where z was critical, the axis was out of tolerance. Therefore, in a global CS sense, the Calspools were good enough, but in a local CS sense (as a subassembly relating to the WFL) all 48 were out of spec in z. Moreover, it was questionable if the KMA plates could be accurately positioned in the local CS x and y, since the clear aperture tolerance was looser than the DrD positional tolerance. In the Calspools' current position, if the DrDs were installed in the global CS, the installations would be too far in z from the WFL; meanwhile, x and y were unknown.

The original alignment strategy involved installing the KMA plates onto the Calspools and aligning each of the 24 kinematic mounts individually; 12 on top and 12 on the bottom. Lines of sight (LOS) of the more logistically difficult ports would involve looking through some of the Calspools and Doghouses, predominantly those near the north and south poles. The flaw of the strategy was the inability to obtain adequate LOS to both the control network and each of the 12 kinematic mounts on each plate. As the DrD was postponed, this became obvious when in many cases the target building was being populated with other scheduled assemblies obstructing LOS to the network and to the KMA plates. The new strategy would need to overcome the LOS obstacle and be robust enough to logistically not impede the installation of other mechanical subsystems already scheduled in with the scaffolding and rigging needed to install the KMA plates.

The best solution was a “plug-and-play” strategy, which would require a compilation of as-built-and-designed data to employ reverse engineering. Moreover, for quality control of the flow of data, the calculations and coordinate transformation would need to be both flawless and seamlessly traceable back to the OCD for the DrD to successfully complete commissioning for operation. Any mistake in the calculations would cause the whole process to become suspect and halt the alignments and installations; thus, there would be no diagnostic for the 3ω light just before it entered the target chamber. To avoid postponing laser experiments, data quality control was paramount.

THE ALIGNMENT STRATEGY

The solution to the spacer concern was to relate the installation of the DrD to the WFL and generate the design and as-built coordinates in the IOM local CS, treating the relationship of the DrD to the WFL as two subassemblies integrating into an upper assembly in situ, as opposed to the DrD installing into the top assembly global CS. In summary, the solution was to employ a “relative alignment.”

To accomplish the goal of a plug-and-play installation while not impeding other scheduled installations, the KMA plates were pre-aligned in six degrees of freedom offline and simply brought into their quad location and bolted in to within +/–125 μm of their positional requirements.

To quality-control the generation of the design data, a parametric local CS of the IOM and the Calspool interface was used to translate from port to port. Here the local CS could be rotated and pointed to the target chamber center. By using the IOM local CS, and orienting it in this attitude and vector, an increase in quality control of the design data and acquisition of the as-built data was obtained, due to the symmetry of the coordinate data related to the mechanical configuration. As the metrology teams moved from port to port in the local CS, the values would reveal a symmetric pattern and assist in error detection as familiarity with the naming convention and its associated coordinate values became repetitive.

The alignment strategy used for the installation was designed to use the as-built condition of the critical interfaces on the Calspools side to generate the offline pre-alignment coordinates of the KMA plate side of the interface for alignment on a coordinate measuring machine (CMM).

The vertical adjustments of the mounts were related to the plane interface of the Calspools (the primary datum adjustment); their adjustments were controlled by the threaded shafts below the mounts and secured by a lock nut at the base. The lateral adjustments were related to the openings of the Calspools (the secondary and tertiary datum adjustments); their adjustments were controlled by eccentric cam hard stops and secured by four lock screws, as seen in figure 6.

ACQUISITION OF THE AS-BUILT DATA

First the critical features were identified and assigned a naming convention. Once the features and naming convention were complete, the global coordinates were generated and transformed to the IOM local CS. The verification process validating resulting values was then completed with associated drawings and procedures. The metrology teams were sent out into the target building and given the local coordinates with the origin along the port center line. As these teams moved around the chamber taking data, they would reacquire the global CS network and transform to that

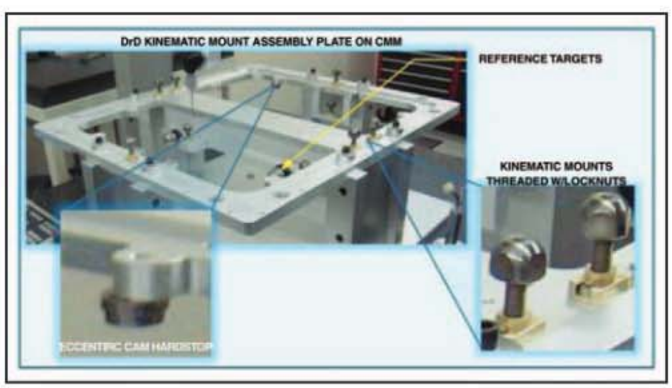

Figure 6. Vertical mount adjustments

specific port's IOM local CS. By working in the IOM local CS, the metrologists gained familiarity with the numbers, increasing possible error detection when correcting for target thicknesses. In addition to measuring the plane, the bolt-hole centers were also targeted. Characterizing the bolt centers assured that there would be enough lateral translation within the through-hole's diameter.

If, during later analysis, it was discovered that more adjustability was needed, the through-holes could be opened up to their least material condition, freeing more lateral adjustment.

Mimicking the cam interfaces with the metrology targeting also proved invaluable. During the field measurements it was discovered that the design of the eccentric cams required modification. Around the openings of the Calspools, weld puddles were discovered encroaching into the cam interface envelope; in addition, during characterization in the target building the metrology teams were instructed to select as the secondary plane the gravity side of the Calspool DrD opening. The KMA plate weighs 64 pounds; therefore, using gravity during installation would prevent the plate from sliding as it would had the upper interfaces been used, as seen in figure 7.

As data were collected, implementation to modify the as-built distances from the WFL began. This new data set would now be used to pre-align the KMA mounts and adjust the cams to the hard interface of the opening of the Calspools.

The calculations involved determining the height adjustment of each of the 12 kinematic mounts and the lateral adjustment of each of the three cams per KMA plate.

CALCULATING THE HEIGHT ADJUSTMENTS OF THE KINEMATIC MOUNTS

The objective was to perfectly calculate the exact height of the 576 mounts while at the same time, due to scheduling pressures, to ensure the quality of data delivered from the target chamber, catching errors real time, particularly with respect to how the target thicknesses were removed. To do this, a local part CS was created using the feature controls designed into the KM plate. The part's primary datum was used because it was also related to the primary interface to the Calspool. For the secondary and tertiary datums, two of the KM centers were used in the lateral directions and on the plane of the primary datum to the Calspool. Using this technique removed all the error in the secondary and tertiary datums within the manufacturing process because the secondary

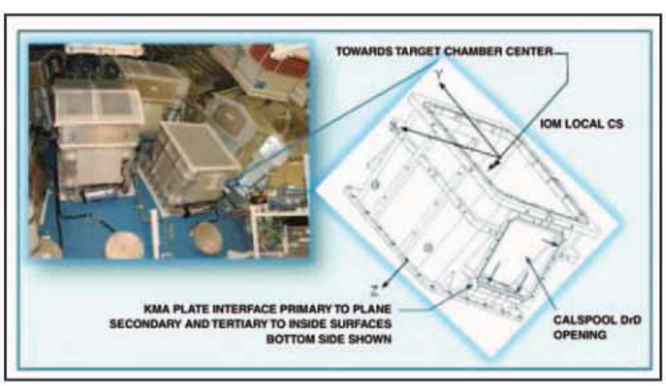

Figure 7. KMA plate

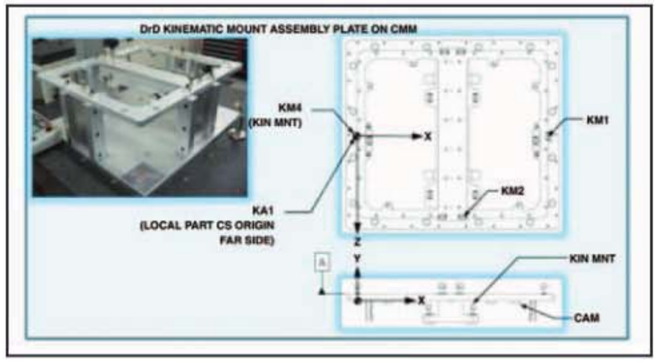

Figure 8. DrD kinematic mount

and tertiary datums were now at two of the 12 critical interfaces, as seen in figure 8.

When the best-fit was applied the IOM local CS, design data fitted to the KMA local-part design data and the plane as-built-data from the field metrology floated along with the fit. This technique provided two important data sets: the delta vertical adjustments for the mounts and the quality assurance of the Calspool plane measurements. The planes had a machined tolerance, therefore an out-of-tolerance condition (a quality assurance check that was designed into the data analysis) would have meant a possible error in correcting for target thickness. This check scrubbed out a handful of errors that, if undetected, would have led to positional errors and possibly hardware damage.

The second part of the process was to calculate the translation offsets to be applied to the cams. The as-built data of the Calspool DrD openings from the target chamber would tell where the cam hard interfaces were by best-fitting the IOM local CS into the part-local CS, thus creating the new part-local values. These newly created values allowed reverse engineering to be applied to create the new design values for each port location. Just as in the case of the plane fit for the KM height adjustment, a quality assurance calculation was included to detect any errors in removing target thicknesses and/or any other correction for which the field metrologists needed to correct. Once again the quality check calculations detected a handful of errors and were corrected in real time.

ALIGNING THE KINEMATIC PLATE OFFLINE

The field metrology was separated into two tasks: upper target chamber hemisphere and lower. Upon the completion of the first task, the data for offline alignment was created. At this point it's notable to mention that a master KMA plate was created and aligned to design values within 25 µm. This master plate was sent to the LRU facility in Boston, where the integrated optics were pre-aligned. After installation of the KMA plates, the pre-aligned LRUs could then be placed on any quad on the target chamber and be ready for operation. This is the main point of the LRU design; an LRU can be placed anywhere on the chamber provided that the KMs are properly aligned.

The production KMA plates were sent to a metrology lab in southern California and pre-aligned using a CMM. The KMA plates were set up on the CMM using a custom fixture designed by the metrology lab to mimic the hold down of the plates onto the Calspools.

Figure 9. First article inspection

(A duplicate tool was produced as well and kept at NIF for verification purposes.) Reference targets were also installed onto the plates. These reference targets were characterized at final inspection and were later used to verify the position of the KMA plates relating the KMs to the reference targets after installation, as seen in figures 9 and 10.

THE INSTALLATION

The installation onto the target chamber was flawless. The plug-and-play alignment strategy was a success. As the KMA plates were received from Southern California, they were immediately installed. The KMA plates would interface to the plane of the Calspool, rest on the two cams on the gravity side and slide over to the remaining cam to stop; primary-secondary-tertiary, an elegant strategy. When the LRU was ready for installation, it was ready to bolt up onto the kinematic mounts. As the KMA plates were installed, quality assurance verifications were performed by sampling the first few installed; their positional errors were on average 80 µm. Engineering was convinced and sampling discontinued. For the most part, all 192 diagnostics performed well within specifications.

Figure 10. Completed installation