Tolerance Allocations for Automated Insertion of Optical Components in the National Ignition Facility

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Overview of the NIF

The National Ignition Facility (NIF) will achieve fusion ignition in a controlled laboratory environment early in the next century. In this facility, the size of a football stadium, 192 high power laser beams are directed toward a small fusion target after propagating through a series of optical amplification and image relaying systems. Each laser beam contains 44 optical assemblies that must be removed and replaced. There are thousands of these optical assemblies through out the facility that must be removed and replaced and these operations are, for the most part, automatic (see Figure 1). This paper address one typical optical assembly called the Spatial Filter 4 (SF4) and describes how the tolerance allocations for this automatic operation were developed, allocated, and documented.

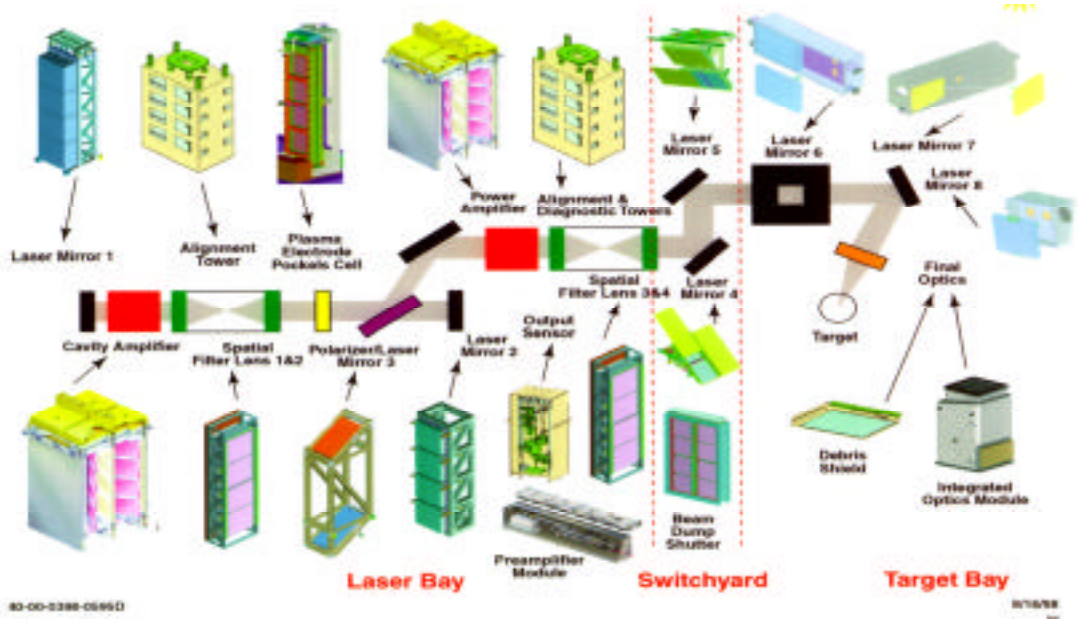

Figure 1. Pictorial of the optical assemblies in the NIF. A global coordinate system is used to precisely locate each optical assembly.

The SF4 optical assembly is inserted and removed by a bottom loading delivery system requiring the use of three sets of kinematic couplings. One set locates and secures the SF4 optical assembly in the laser beam, one set locates the bottom loading delivery system to the SF4 optical assembly, and one set locates the bottom loading delivery system to the docking structure. Four design teams were involved in developing these features: the SF4 optical assembly, the support structure, the bottom loading delivery system, and the survey team. The bottom loading delivery system is shown in Figure 2 docking to the support structure. The bottom loading delivery system consists of a canister with mechanisms for moving and placing the SF4 in the structure, and an automatically guided vehicle for delivering the canister with the SF4 to the target location.

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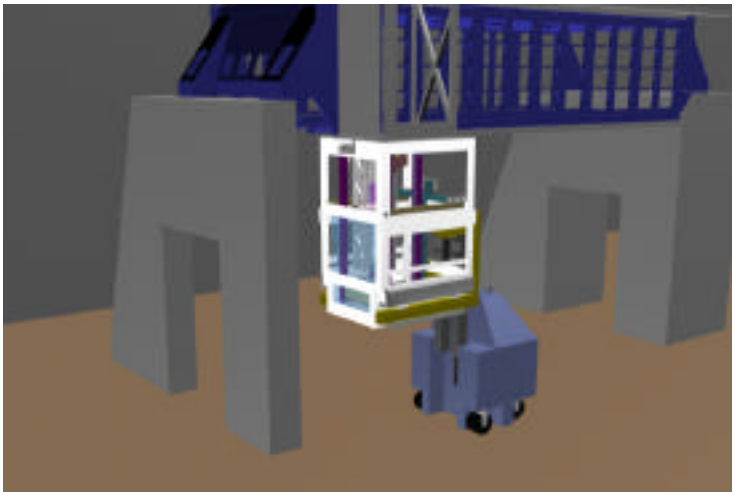

Figure 2. Bottom Loading Delivery System docking to the SF4 support structure.

Application of tolerance allocations

The success of automatically inserting and removing a SF4 optical assembly is directly dependent on the ability to place the SF4 inside the structure kinematic coupling capture zone. The SF4 capture zone is +/- 10mm and has been divided into tolerance allocations between the four design teams. The tolerance allocations are shown in Table 1. If all teams design, build, and install their systems to the agreed-to tolerances, the SF4 can be automatically installed and removed. For these tolerance allocations, the agreed-to tolerances placed on fabrication and installation are as stringent as that of aligning the laser optics themselves.

Table 1. Top-down tolerance allocation as determined by needs of the SF4 Optic

Capture zone of structure-mounted SF4 kinematic couplings:	+/- 10.0 mm
Survey (SF4, kinematic couplings for docking)	- +/- 1.0 mm
SF4 optical assembly (fab, assembly, and alignment)	- +/- 1.0 mm
SF4 structure (fab, assembly, and alignment)	- +/- 3.0 mm
SF4 structure (setting in the building)	- +/- 1.0 mm
Net tolerance left for the delivery system (fab, assembly, alignment, repeatability in operation)	+/- *4.0 mm*

The capture zone for the structure mounted kinematic couplings for SF4 is +/- 10 mm. Starting with +/- 10 mm, and adjusting for tolerances in fabrication and assembly, setting, and survey error for both the SF4 and the structure, the net capture zone left for the delivery system canister is +/- 4 mm.

Interrelationships between the elements

Each team was using their own local datums to measure and locate the respective features. The tolerance stackup between the local datums was more than the tolerance allocation. To eliminate this additional tolerance stackup, a local global coordinate system based upon the local optical location was defined and tied to the global coordinate system. This local coordinate system was identified as an Assembly Coordinate System Origin (ACSO). Figure 3 illustrates how the ACSO provides a single point reference for each design team.

Now the features provided by each design team are located relative to the ACSO, and the survey team measures the location of all features relative to the ACSO and relates the measurements to the global coordinate system.

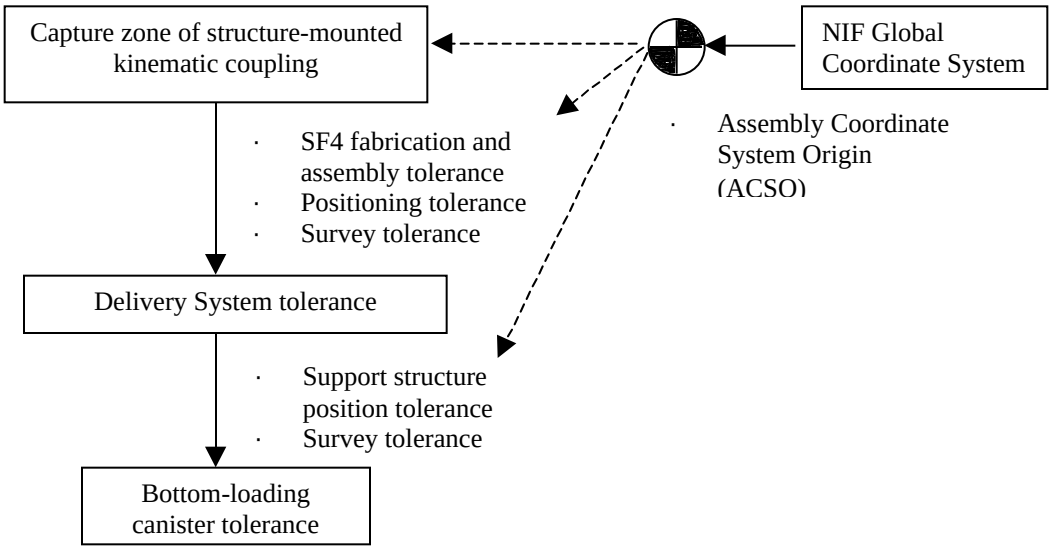

Figure 3. Flow-down requirements for tolerance for inserting an SF4

Details of the kinematic couplings and the structure tolerance allocation

The SF4 optical assembly package is the size of a refrigerator and houses the optics inside a support frame. Two sets of kinematic couplings are designed into the support frame. They position the SF4 to the support structure and the SF4 on the Delivery System.

The kinematic couplings to the support structure are two tapered pins in two slots. The lower pin constrains the SF4 laterally, while the upper pin fixes the vertical position. Four bolts at the corners of the SF4 hold it to the support structure, completing the 6-degree-of-freedom constraint.

The kinematic couplings at the interface between the delivery system and the SF4 are a form of the traditional tetrahedron-vee-flat, with the pins on the SF4 and the tetrahetron-vee-flat on the Delivery system. Other optical assemblies have different designs of kinematic couplings.

The bottom loading delivery system team must consider two tolerances: the accuracy and repeatability of the canister insertion mechanisms used to insert SF4, and the accuracy and repeatability of the docking structure where the delivery system docks. The docking accuracy and repeatability involves the amount, the accuracy, and the repeatability that the structure fabrication and placement can be controlled.

The delivery system docks to a three-point ball-vee kinematic coupling. Three counter bores are milled into the structure, into which machined cones are placed. In the structure, the positional tolerance specified for the three locations of each pattern is +/- 1.5 mm in the lateral directions, a vertical tolerance of +/- 5 mm, and a co-planarity tolerance between the bases of the three pockets of +/- 1 mm (Figure 4). Given that the distance between pockets is 750 mm, the co-planarity tolerance of +/- 1 mm results in a tilt of 2.67 mrad. When the cones are inserted into the support structure, they will be surveyed and shimmed to a co-planarity not to exceed +/- 0.22 mm. This results in a much smaller tilt angle of 0.59 mrad. For a 2500 mm tall SF4, a tilt of 0.59 mrad at the support structure will transmit throughout the delivery system to a net lateral misalignment at the top of the LRU of +/- 1.47 mm. The total lateral tolerance allotment for the support structure is then 1.5 + 1.47 = +/- 2.97 mm. The fabrication tolerance for the structure need to be tighter than the positional tolerances. Given that the structure is 30 feet long with 6 patterns of features to control, the fabrication tolerance of +/- 1.5 mm on position and +/- 1 mm on co-planarity provides a challenging fabrication. (See Figure 4).

Figure 5 illustrates the tolerance allocations for SF4. The figure also depicts the vertical and horizontal motions over which the tolerances must be held.

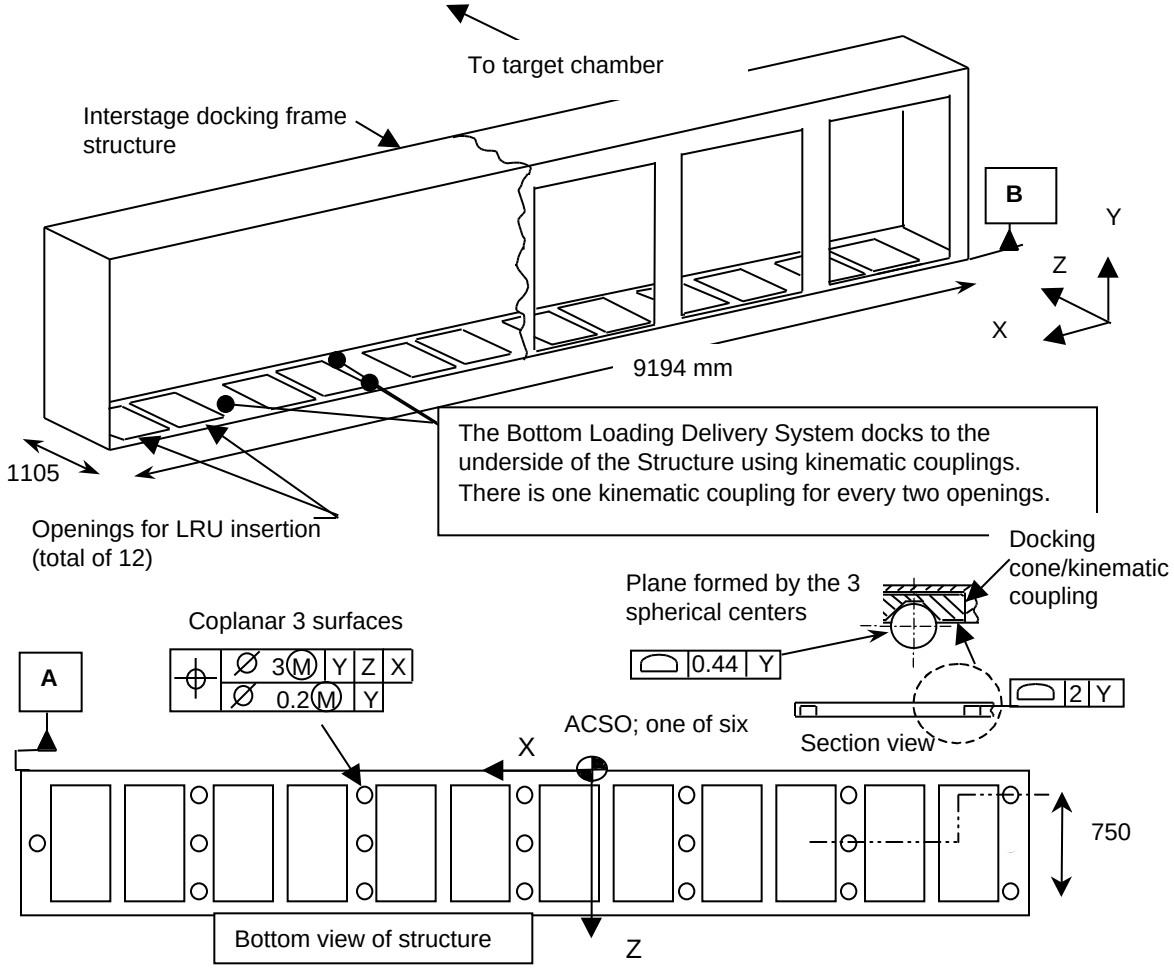

Figure 4. Positional tolerance imposed on the Interstage Docking Structure. To meet the positional tolerance allocation, the fabrication tolerance must be tighter still.

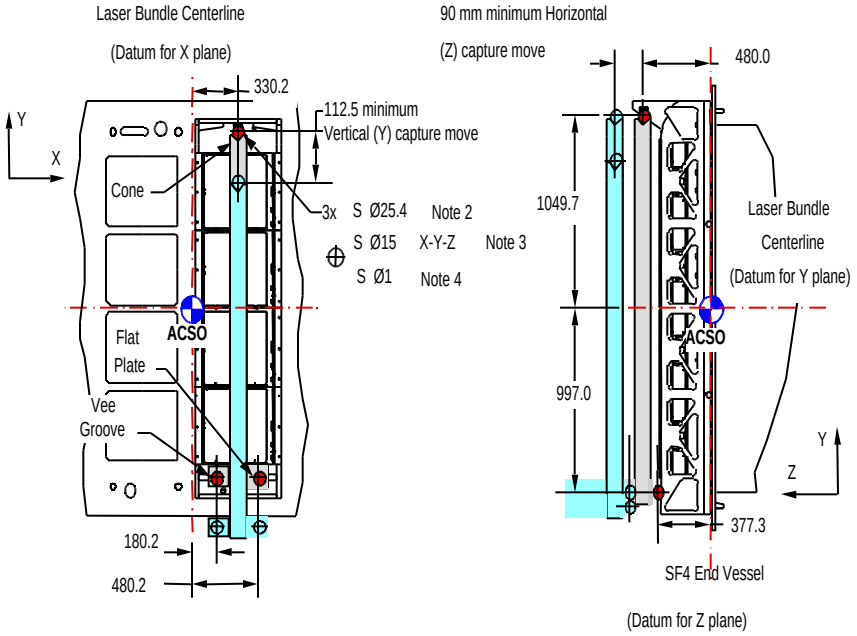

Figure 5. Interface Control Drawing showing location of kinematic couplings to the ACSO for the SF4.