Design and Implementation of Coating Hardware for the Hobby-Eberly Telescope Wide-Field Corrector

John Good[†], Hanshin Lee, Gary J.Hill, Brian Vattiat, David Perry, Herman Kriel, Richard Savage

McDonald Observatory, University of Texas at Austin, 1 University Station C1402, Austin, TX, USA 78712-0259

ABSTRACT

A major upgrade of the HET is in progress that will substantially increase the pupil size to 10 meters and the field of view to 22 arc-minutes by replacing the spherical aberration corrector. The new Wide Field Corrector is a 4-element assembly weighing 750kg and measuring 1.34 meters diameter by 2.1 meter in length. Special fixtures were required in order to support the mirrors of the Wide-Field Corrector and adapt them to the coaters chamber, during the vacuum coating process. For the 1 meter-class mirrors, the only suitable support interface was located on a 80mm wide cylindrical surface on the periphery of each mirror. The vacuum compatible system had to support the mirrors with the surface facing downward, and accommodate thermal ranges from ambient to 100C without inducing stresses in the substrate. The fixture also had to accommodate washing, as well as support of witness samples during testing and production runs, and provide masking for alignment fixtures in the center apertures of each mirror. Design principles, materials, implementation details, as well as lessons learned are covered[*].

Keywords: Hobby-Eberly Telescope, HET, HETDEX, VIRUS, Wide Field Upgrade, WFU, Wide Field Corrector, WFC, vacuum coating hardware

1. INTRODUCTION

Optical components typically comprise the major portion of the capital budget for a telescope or instrument. In addition to the monetary cost, the cost in time often paces the development of the entire project and defines the majority of its total duration. It is, therefore, not surprising that considerable angst and energy is devoted to planning, in order to assure that each stage in the manufacturing process is successful. The persons responsible for creating the figured mirror can be disconnected entirely from those selected to apply the coating. While much attention is understandably focused on the development of the figure on the glass substrate, it is essential that early and equal consideration be given to the design considerations and tasks for the successful application of the coating. The design of hardware for coating glass substrates is as much about enabling the coating process outside the vacuum chamber, as it is in safety supporting the mirror while in the chamber. It is therefore as important, on day one of the creation of a new mirror, to factor in the requirements of the coating, along with those devoted to achieving its figure. Note, that care has been taken to disclose design principals and features in terms that do not violate confidentiality agreements with the coater selected for the Wide Field Corrector. The spirit of the information contained herein, is to facilitate successful coatings, and interaction with coating vendors in general, without disclosing trade secrets earned by those in the business of providing top quality coatings.

2. DESIGN CONSIDERATIONS

Early, frequent and clear communication with the coating vendor is the most important facilitator of successful coatings. The following are general guidelines found to be useful in the development of hardware for coating mirror substrates:

Substrate compatibility with coating hardware

The glass substrate should incorporate features in its geometry that enable secure attachment to coating hardware and enable handling throughout the coating process. Ideally, these are features created in the glass when it is machined to

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[†] R.S.: E-mail: good@astro.as.utexas.edu

[‡] http://hetdex.org/

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shape, prior to figuring and polishing. However, mechanical features can be bonded to the substrate to accomplish the same purpose. These features should consider loading for all orientations in the flow of work; from shipping, washing, pre and post inspection, as well as coating in the vacuum chamber. These features should be designed to prevent movement, or creeping of the glass during the coating process, since masks and witnesses are often located quite close to the glass, and could cause damage if contact occurs. It should also include stops, or fail-safe mechanisms, if movement or creeping inadvertently occurs, or there is a failure of the primary support system.

Cleanroom compatibility

The coating hardware design should facilitate cleaning to the cleanroom standards of the coater. Surfaces should be milled and finished smooth. Vents and holes for fasteners should be large enough to be easily cleaned and inspected. While the coater will clean all parts, they should arrive at the coating facility, solvent cleaned, and free of all milling and cutting fluids and debris. Parts should be compatible with ultrasonic cleaning and be able to withstand temperatures in excess of that to be used while applying the production coating.

Vacuum compatibility

The coating hardware design should eliminate virtual leaks and be composed of materials that are low out-gassing and otherwise vacuum compatible. Fasteners, as well as any other metal-to-metal contact surfaces that rub together, should be of dissimilar materials in order to prevent vacuum welding and galling, to facilitate assembly and dis-assembly. Fasteners and other parts should not be used near the coating surface once the surface to be coated has received a final cleaning prior to coating. Vacuum compatibility can also depend upon the materials proximity to the surface to be coated, or its line-of-sight to the surface. While plastics and elastomers may be rated for vacuum service, they may still emit particles or gasses, and contaminate the surface to be coated if they are close to it, or have a line-of-site to the surface.

Witness samples, test-run, and production-witness compatibility

The coating hardware should incorporate mounting for witness samples for both test and production runs. For the test-run phase, the distribution of witness samples should closely approximate the location of coating surface. For the production phase, the distribution of witness samples should be as close as possible to the substrate surface so that the coating applied is representative of that on the substrate. Careful consideration should be taken to make sure that the act of assembling the hardware and the installation of witness samples does not contaminate the surface, or pose risk of damage to it.

Substrate washing compatibility

There should be close collaboration with the coater in order to understand their cleaning procedures and assure that the coating hardware allows use of cleaning procedures they are practiced in using. This can include the use of large amounts of water as well as solvents and acids. In addition, the coater will need to manipulate the entire assembly in order to closely inspect the surface to verify that it is clean enough to proceed with coating. This can involve rotating the entire assembly 360 degrees and in all degrees of freedom in order to allow washing, drying, and inspection. The coating hardware must accommodate these procedures and safely support the substrate.

Contamination control and cleanliness

Final assembly of the coating hardware, including masks, and witness samples should not result in contamination, or risk of damage, to the surface. Tightening of fasteners, or movement of metal to metal parts can produce a spray of particles that contaminate the mirror surface. Care should be taken, to either not locate these feature near the surface, or prevent their movement after final cleaning of the surface. Ideally all coating parts should be ultrasonically cleaned. In particular, plastics and elastomers should be ultrasonically cleaned.

Material selection

There should be close collaboration with the coater on materials selection for coating hardware. In general, even vacuum-rated plastics and elastomers can be a contamination source, if located near the surface to be coated. If plastics and elastomers are used, they should be shadowed from line-of sight of the surface to be coated, if possible. Metals in moving contact with each other should be dissimilar (example: Stainless Steel screw with Brass nut). Metals in moving contact with each other should remain static, if near the surface to be coated, since particles are generated and broadcast when they move against each other. Glass to metal interfaces requiring cushioning with plastics or elastomers (example: Viton), should not be located near the surface to be coated and should be shadowed from direct line of sight from the surface to be coated. In order for Viton to provide adequate friction it should be ultrasonically cleaned if it is used to provide a cushion and gripping surface between the support hardware and substrate.

Substrate safety during assembly and disassembly

Coating hardware parts being assembled around the substrate need to be designed so they are easy to handle securely in cleanroom apparel. Cleanroom garments tend to reduce the dexterity, steadiness, and control of technicians performing the assembly. To help in this process, guides and guards should be designed that reduce potential for errors, technician stress and the risk of contact with the substrate during assembly. Larger fasteners, and fewer fastener types and sizes, should be used in order to reduce the tooling required and the complexity of the assembly process, while wearing cleanroom garments. Tools coming close to the substrate should be padded with tape, rubber, or similar cleanroom compatible materials.

Thermal expansion issues

Hardware designs that endeavor to incorporate thermal compensation over the design temperature range can be expensive to design and build. The design of coating hardware can completely avoid thermal expansion considerations by not over-constraining the substrate as different materials in the assembly expand and contract. A demonstration of one possible design incorporating this feature is included in this paper.

Substrate handling

The coating design must include means for substrate handing for moving the glass substrate from its shipping/storage container, to the coating hardware, and back to the shipping crate after storage. This must be compatible with the coating hardware and the coating vendors equipment.

Coating hardware handling

There should be close collaboration with the coater to assure they are able to handle and manipulate the coating hardware assembly, including glass, in and out of their chamber. Since many coating processes require that the surface to be coated is facing downward, the handling design will likely require the ability to flip the entire assembly 180 degrees from the assembly orientation. Also, for inspection purposes, the coater may also need to orient the substrate

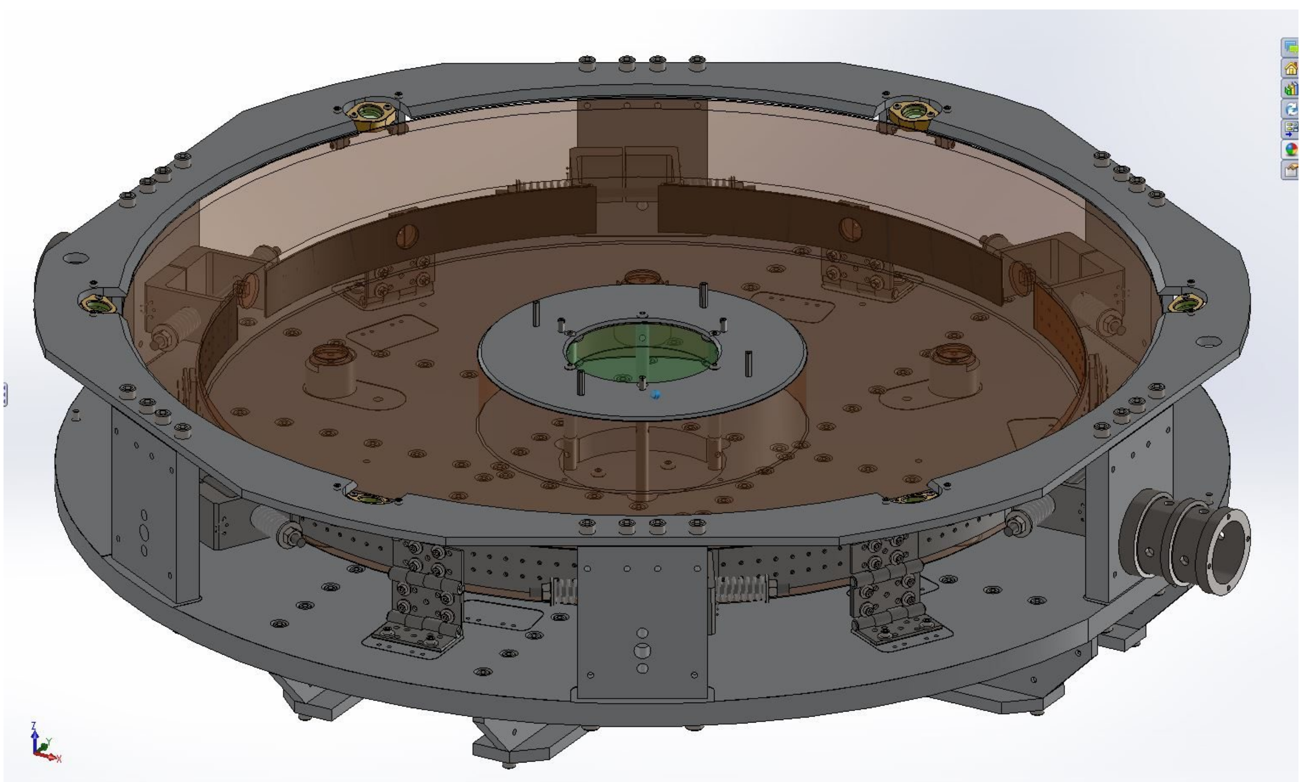

Figure 1. M2, M3, & M5 production coat hardware configuration with center and peripheral witnesses.

vertically for sustained periods of time. Thus, provisions for flipping and locking the assembly in various orientations, while outside of the chamber may be required.

Vacuum Chamber interfaces

There should be close collaboration with the coater to design the mounting interface between the coating hardware and their coating chamber. In addition to dimensional and thermal issues, the load allowed on this mount may drive the entire design. Often, the substrate will be rotated during the coating process, requiring consideration of balance and resonances in the total assembly.

Hardware Storage After Coating

By the time the coating job is accomplished and the mirror is packed away in its shipping crate, a lot of effort has been expended to get the coating hardware to a vacuum compatible state. Storage of the coating hardware for the next use should include packing to prevent contamination of the hardware while it is stored. Sources of contamination can include outgassing of resins from wood and paper used in the storage container. Therefore, the entire hardware assembly should be sealed in gas-tight packaging that is durable in the storage conditions and over the interval between re-coatings.

3. M2, M3, AND M5 HARDWARE FOR COATING

The geometries of M2, M3, and M5 were similar enough in diameter and shape to enable design of a single support structure which was configurable using common elements. The mirrors are nominally 0.75 meters to 1 meter in diameter and ranged in mass from 110 kg to 174 kg. The primary hardware feature used to hold onto the substrates, was a spring-loaded stainless steel band that was divided up into six segments, in order to more evenly distribute loading around the substrate. Each of the six bands were manufactured from a solid piece of 304 stainless steel, by means of a wire electro-discharge machine (WEDM) process. This technique was chosen because it allowed mounting features to easily be incorporated into the bands, and it also allowed the inclusion of features to engage spring-loaded clamps. The resulting design reduced part-count and manufacturing time, and provided secure support as well as even loading on the mirrors. For each of the three mirrors, the bands engaged the cylindrical feature on the outer diameter of the substrate behind the mirror surface. In order to avoid thermal expansion problems between the mirror and the support plate, temporary shims, of 3mm thickness, where placed between the mirror and structural back-plane, prior to placing and tightening the bands. Once the bands were tightened, the shims were slipped out, and the mirror was free-floating, except for the constraint offered by the mounting on the bands.

To lower the mass and cost of fabrication, the material selected for the structural back-plane was 6061 aluminum alloy plate. The bands were anchored into this structure with a circular arrangement of stainless steel hinges, which were assembled in pairs to allow differential thermal expansion without over-constraint, but otherwise completely supported the substrate. In general, stainless steel fasteners were used throughout the assembly, with a few exceptions where high strength, or dissimilar materials were required. The configuration for M2 is shown in Figure 1. Note that CAD models are used for the illustrations due to restrictions on photography in the coaters facility. A thin layer of Viton was used as a cushion between the bands and substrate which provided sufficient friction to support the loads encountered during the coating process. Experimentation with dummy mirrors indicated that the Viton layer did not have sufficient grip on either the bands or glass unless the Viton was ultrasonically cleaned. Once ultrasonically cleaned there where no issues with loss of friction or creeping due to vibration or thermal cycling during the entire coating process. For our particular case, the decision was made to bond safety pucks to the substrate in order to engaged the bands mechanically, thereby adding a safety feature in the event the substrate slipped in the bands. These features were considered important as a safety due to the small clearance between the mirror surface and the hardware for masking, which would have damaged the figured surface if creeping had occurred. The Invar pucks were bonded using Master Bond EP42HT-2LO, chosen primarily for its bonding strength at the coating temperature of about 100C. A separate fixture was designed and built by the University of Arizona Mirror Lab, for moving the substrates in and out of the shipping crates and onto the coating hardware.

The coating hardware was designed to accommodate three distinct phases of the coating process; testing, washing, and production (coating). The first phase required the coating hardware to accommodate witness samples in place of the substrate in order to test the coating design. A flexible and low-cost technique was used to place 25mm and 50mm diameter witnesses at the precise position of the substrate surface. Plates were milled to mimic the mirror profile and attached to the back plane of the support structure. An off the shelf mount by Newport Corporation was adapted to support the samples and these were held onto the plate using a simple clamping mechanism.

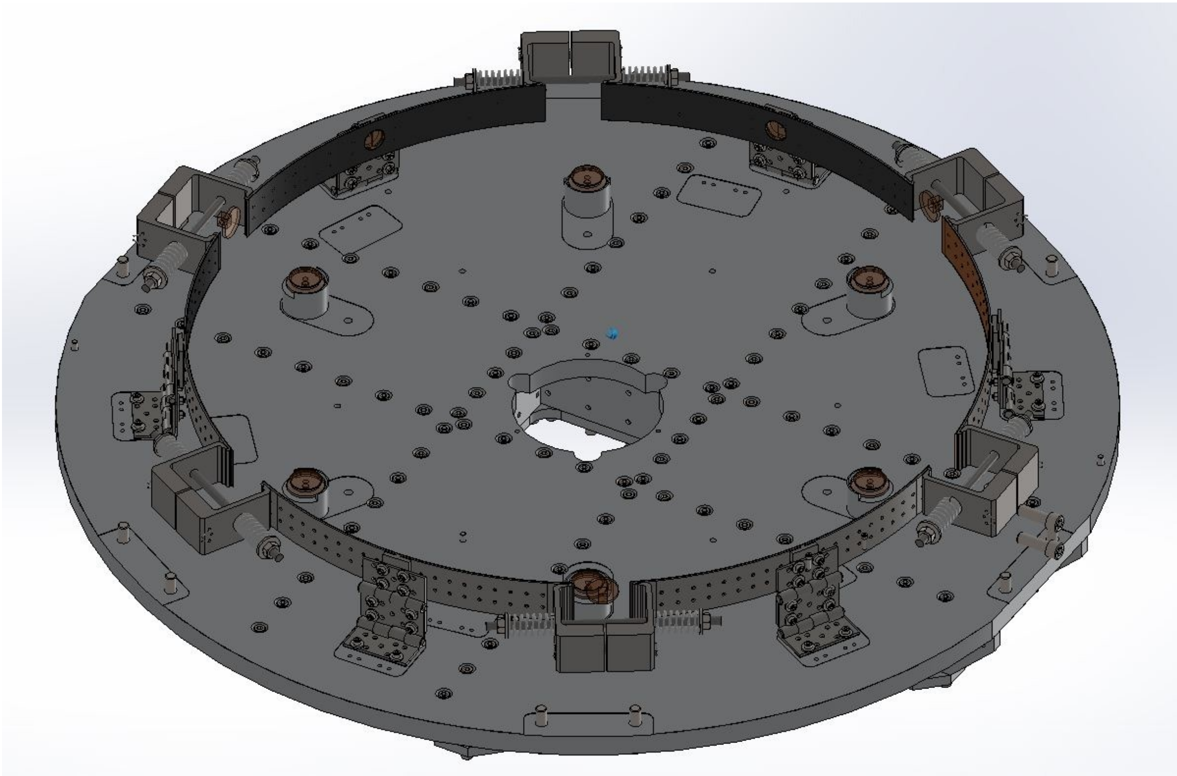

Figure 2. The mirror substrate is supported by an assembly of six spring-loaded bands. Each band is lined with a thin layer of Viton to provide cushion and improve frictional engagement of the bands with the substrate.

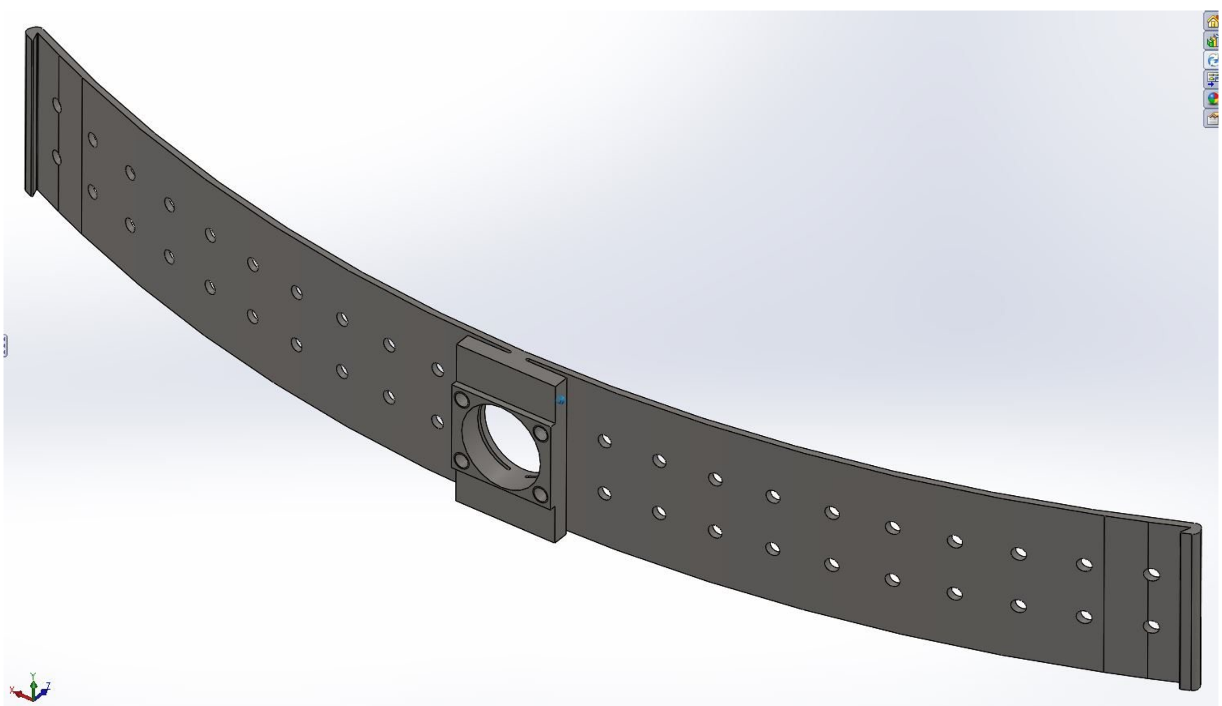

Figure 3. Each support-band segment was Wire ED machined from 304 Stainless Steel. While the part cost is higher than metal strapping, it incorporated support mounts and terminations for clamps, and resulted in cost savings when assembly and total part count was taken into consideration.

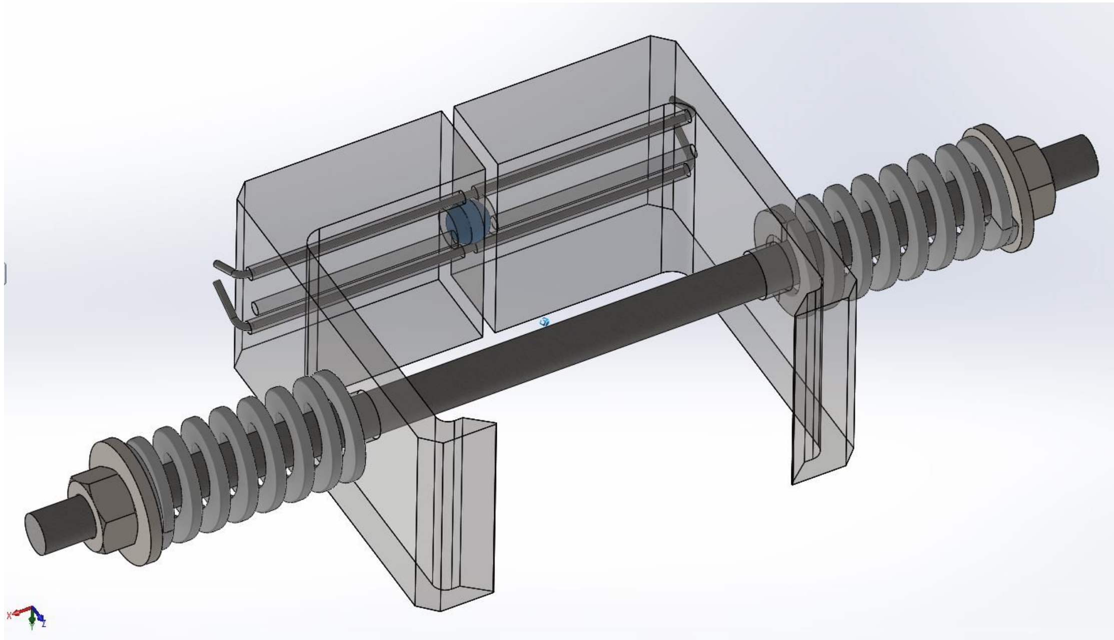

Figure 4. The clamps incorporate die-springs for loading. Brass nuts, where used on a stainless steel threaded rod in order to prevent galling and vacuum welding. A ball-bearing is used for a hinge to allow the clamping jaws to apply even loading across the width of the band.

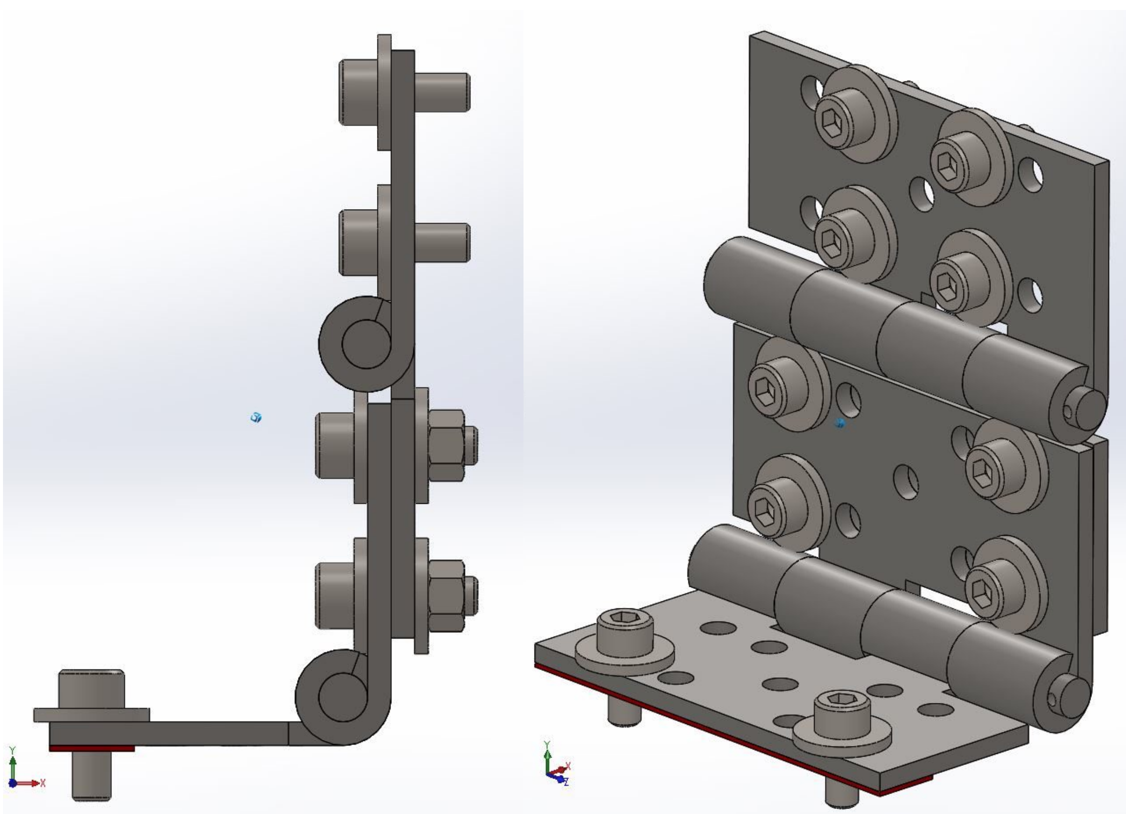

Figure 5. A key design feature to avoid thermal expansion issues between the substrate and the support frame was an assembly of off-the-shelf hinges used to attach the bands. A shim is used at the attachment to the support frame which allows flexure in the axial direction as the entire assembly is being heated in the coating chamber.

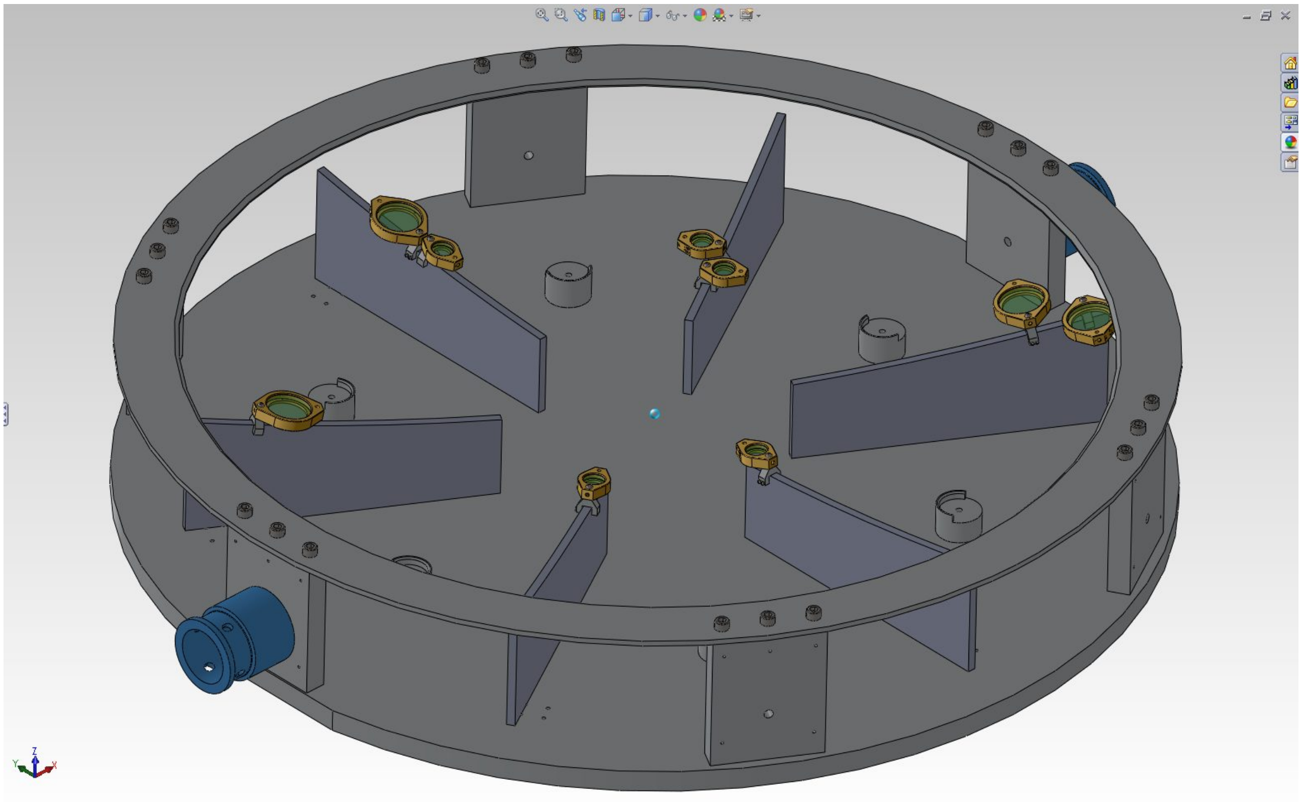

Figure 6. The coating hardware accommodated test runs by using plates cut to the profile of the mirror substrate and attached to the back plane of the support structure. This configuration allowed the coater to position witnesses to assure uniformity of the coating prior to the production run.

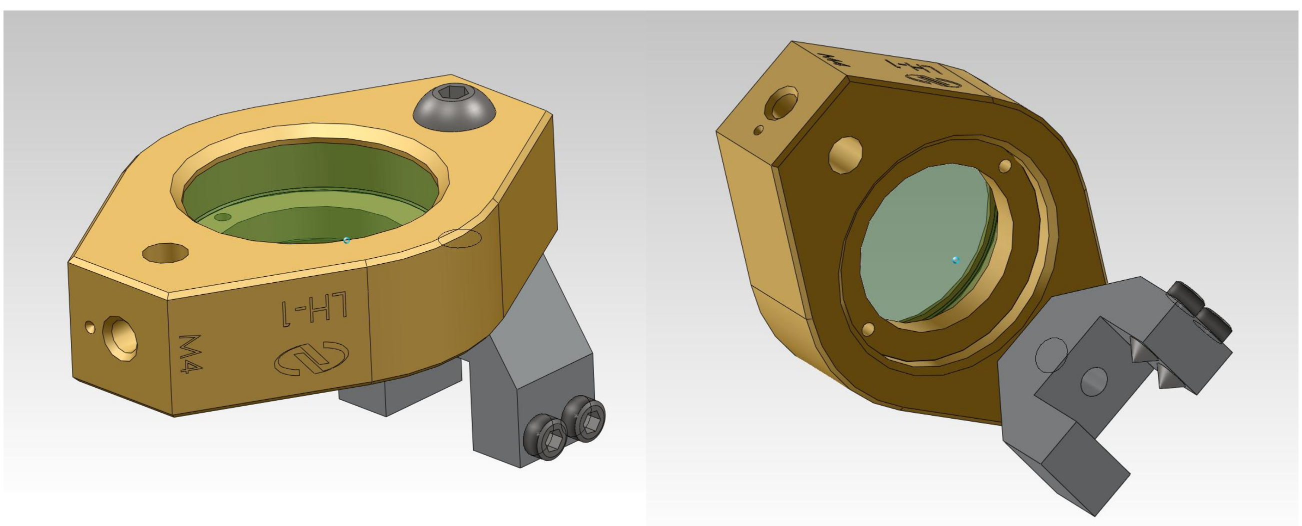

Figure 7. Off-the-shelf hardware, in this case by Newport Corporation, was incorporated for witness mounting by means of a simple clamping mechanism to the mirror profile plate. The anodized coating had to be removed to make it vacuum compatible.

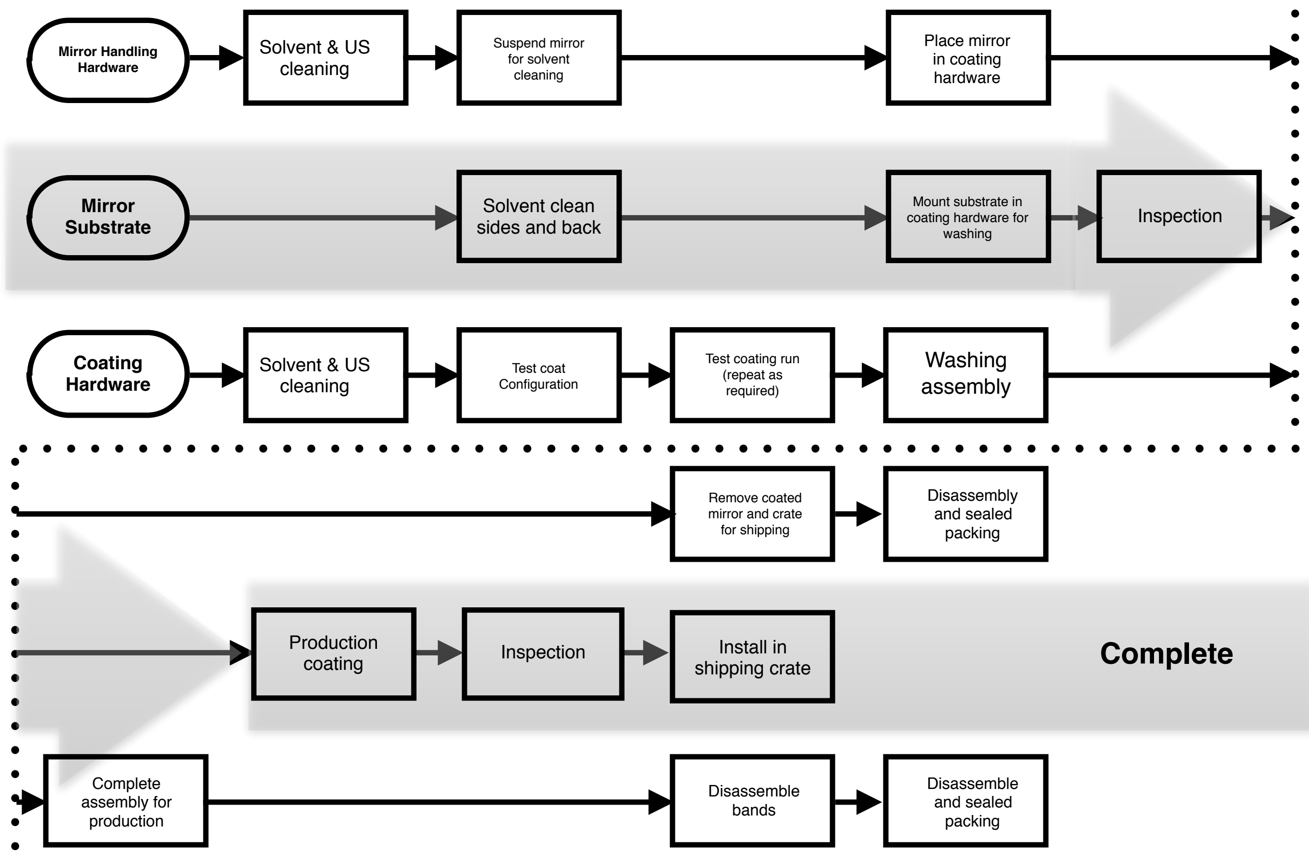

Figure 8. Example of essential sub-systems and work flow at coater facility.

For washing, the witness mounts and mirror profile plates were removed from the back plane, and the substrate was placed upright on the back-plane of the support structure. The coater created a sealed funnel and drain for washing fluids through the center hole of the mirror and back-plane. Another sealed barrier was created around the perimeter of the mirror to prevent fluids from spilling over the outer edge of the mirror. Once the surface was washed, rinsed, cleaned, and dry, the coating assembly was completed to include the front-mask and witness-mounts, and was lifted by trunions, provided by the coater. Following careful inspection in multiple orientations, the entire assembly was mounted inside the coating chamber and pumped-down. For the production phase, witnesses were incorporated into the outer and inner masks and supported by the same Newport hardware about the outer and inner perimeter of the substrate.

One feature of the band-clamps was that no form of lubrication could be used between the stainless steel screw and nut, which resulted in severe galling and lock-up after the parts were cleaned to vacuum compatible status. At first a compromise solution was attempted by wrapping the screw with Teflon tape. The forces were great enough, however, to quickly penetrate the Teflon film on the treads and allow the system to lock-up. A solution was found by making the nut out of brass. Due to the relative softness of the brass, a vacuum cleaner had to be used as the nut was turned, in order to remove brass particles that were shed as the nut was tightened against the clamping springs, since these could have been a source of contamination on the coating surface. The brass nuts were discarded after one use, due to loss of material on the threads, while loading and unloading the clamping springs.

SUMMARY

Mirror coatings can require highly specialized hardware in order to provide the means for the coater to safely handle the substrate, and provide a quality coating. It can fall upon the end-user of the mirror, to work between the substrate manufacturer, the figuring lab, and coater, and to establish an early relationship with the coater in order to assure the mirror substrate is suitable for coating, and to understand the needs for hardware that can adapt to the vacuum chamber and facilitate the coaters work flow and procedures. Understanding of the process, requirements, and design priorities will greatly reduce the overall program risk as well as cost of mirror coatings.

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