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6.5-m MMT Mirror Support Load Spreader Gluing:

Summary of Problems, Investigations and Solutions

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1 Requirements and Specifications

The MMT and Magellan 6.5-m honeycomb mirrors are supported in their polishing and telescope cells on a set of metal "load spreader" frames which provide the attachment points for the support actuators and distribute the support forces in an optimum way to the mirror's honeycomb structure. These load spreader frames carry the "puck" support pads which are glued to the glass surface of the mirror backplate. The full complement of load spreaders for these mirrors consists of 68 three-puck and 24 two-puck devices. In addition there are 12 actuators with single on-axis pucks. The latter are distributed primarily near the top and bottom of the outer edge of the mirror backplate.

The glue layer performs two main functions:

1. It firmly adheres the puck to the glass under the combined axial and lateral support loads during operation, handling and transport.
2. It acts as a cushioning layer under the metal load spreader frames and pucks to absorb and isolate unwanted extraneous strains and moments from the glass structure resulting from thermal mismatch, load spreader deflections, and off-center support loads.

In operation the maximum loading on the glue layer occurs as a combined shear and small axial pull when the mirror is horizon-pointing. In this position it is supported by bolts in the load spreader corners engaged in the rubber static supports. The glue layer is required to have an adhesive (surface interface) and a cohesive (bulk material) strength that exceeds these operational stresses by an adequate margin of safety. The design maximum shear force per puck is 187 lbs ($2500/3 = 833$ N). This load is applied ~ 75 mm above the glass surface. The resultant moment can thus generate a small axial tension on the glue joint of 37 lbs ($3"/15" \times 833 = 167$ N).

For the glue to behave as an acceptable cushioning layer, it must have a relatively soft axial compliance (to absorb deflections and moments due to the metal frames before they enter the glass), but at the same time have a stiff shear compliance (to minimize the relative motions of load spreader supports and glass structure). The axial compliance must be in the range of 78 to 160 kN/mm. This is derived from detailed FEA modelling of the load spreader deflection behavior using a limit of 0.7MPa as the maximum allowable glass tensile stress. An extensive series of reports on the FEA modelling work done on the MMT mirror and load spreaders is given in BCV Reports 144-150 (ref 1) and BCV Reports 152-154 (ref 2). The allowable shear compliance is derived from a maximum sideways displacement of 0.5 mm under the operational lateral load (2500 N) which is equivalent to a shear stiffness of between 2 and 7 kN/mm. A discussion of the required glue specifications is given by Hill 10/13/94 (ref 20).

2 Preliminary Investigations of Dow Corning (DC) 93-076 Silicone Adhesive

During 1993, in parallel with the design and FEA modelling of the load spreader frames, experiments were carried out on silicone adhesives and different glue layer geometries. Direct experimental measurements of compliance were necessary since the behavior of silicone as a rubbery material makes numerical calculations unreliable. The majority of these tests were carried out on DC 93-076 silicone adhesive. A summary of these tests can be found in Gray 10/14/93 (ref 34).

Generally, silicone adhesives were thought to have the most suitable characteristics of predictable compliance and long term stability. DC 93-076 silicone was selected because it had been used extensively in similar applications, both at the Mirror Lab (ML) with, for example, the AF 3.5m mirror and elsewhere (several satellite mirror supports). The experience of the ML opticians at that time was that it was a reliable, reasonably strong adhesive which did, however, require extreme care in application (cleaning, priming, and mixing). This was confirmed with sales representatives from Dow Corning who indicated that DC 93-076 had the optimum properties for our application of relatively high strength, operational temperature extremes, long term stability, and low outgassing. A comparable GE silicone adhesive, GE RTV566, was also studied.

The studies consisted primarily of compliance measurements of different layer thicknesses, though a smaller parallel effort was undertaken to examine the efficacy of composite layers to achieve the required axial and shear compliance characteristics. Based on this work, a glue layer of 2 mm was selected and the experimental values for axial compliance (78 kN/mm) and shear (1.9 kN/mm) were used in the subsequent detailed FEA analysis and optimization of load spreader design.

The compliance measurement samples consisted of ~ 2" thick x 100 mm diameter mild steel (type A36) disks. The surfaces to be glued were machined 1-2 days prior to gluing, then given the recommended cleaning with trichloroethylene and acetone. The primer coat was applied using a cotton swab, which gave a medium-thick layer of variable consistency. The primer was allowed to dry for periods of between 1-2 hours. All compliance samples were pulled apart after testing. Every one of these samples was well adhered to the steel surfaces and gave typical failure strengths of 2000 lbs shear load and 5,000 lbs axial load.

The tests with the GE RTV566 silicone gave acceptable compliances and adequate strengths. However, the uncured silicone was found to be hard to work with because of its low viscosity, and cured silicone had a brittle texture when compared to the resilient DC 93-076. It was therefore rejected as a candidate adhesive.

2.1 First Gluing and Proof Testing

The first load spreader frames were ready to glue 7/11/94. The load spreader pucks were made from 4340 steel which had a "light zinc phosphate" coating. Just prior to gluing, the puck bases were cleaned with a trichloroethylene solvent tissue wipe followed by an acetone wipe. It was noticed that a brownish red corrosion-like layer had formed on many of the pucks, residual amounts of which colored the solvent wipes even after 2-3 wipes.

A small disk of soft plastic foam (3.2 mm thick polyethylene tape) was inserted across the center flex pivot hole to prevent silicone adhesive from jamming the pivot. This disk was made from double sided tape that had a rubber cement coating. During cleaning and priming, the foam insert was avoided, but, on occasion, solvents may have dissolved the rubber cement and trace amounts may have, on occasion, been wiped across the puck base.

The primer was applied with a natural bristle brush in a moderate coat with a drying time of 1 hour. The two part DC 93-076 silicone was weighed out in batches of 200 grams to the 10:1 mix ratio. An electronic balance was used to weigh the added catalyst to ± 0.1 gm. It was then mixed for ~ 15 minutes with a power mixer and degassed for 15 minutes before application. The mixed silicone was dispensed in a fixed 50cc quantity onto the puck surface, buttered down, leaving a center lump, then squished out onto the glass when the load spreader was pressed into position. Plastic (nylon) shim blocks located the load spreader pucks and set the 2mm glue layer thickness.

Proof testing was started after a ~ 1 week cure. All load spreaders were tested. Pairs of three-puck load spreaders were pulled in shear against one another with a lateral force of 450 lbs at a distance of ~ 38 mm above the back plate. The load was applied for a total of 30 minutes and cycled twice. The load was measured to 10% using spring deflection.

Two-puck load spreaders were proof tested with a 450 lb axial tension which was applied for two cycles of 30 minutes each. One failed during this test. Inspection of the puck adhesion showed the failed puck to have $\leq 5\%$ adhesion area. The surviving puck had 100% adhesion.

Two three-puck load spreaders then failed by puck de-adhesion after ~ 30 minutes of testing. Inspection of pucks on a failed load spreader revealed \sim half with poor ($\leq 50\%$ area) steel-glue adhesion and the remainder with good ($\geq 75\%$ area) adhesion.

The proof testing was repeated starting 8/18/94 on all remaining load spreaders with a larger 650 lb lateral loading and pulling in both directions. Load spreaders at the edge which could not be pulled against other load spreaders were tightened against the generating machine's steel frame. All load spreaders, apart from one, survived this test. Cutting off and inspecting the remaining glue pads of the failed spreader showed a mixture of poor adhesion (on a surviving puck) and good adhesion. A more detailed summary of the work at this stage can be found in reports Gray 8/17/94 (ref 31) and Martin 8/16/94 (ref 32).

Further axial pull tests were started 8/23/94 using a 950 lb load. Of the first six tested, two

failed, one after only 2 hours of loading. The surviving pucks from these failed load spreaders had adhesions ranging from 10% to 100% adhesion area. A description of the adhesion characteristics of these failed load spreaders is given in Gray 8/24/94 (ref 27).

On the basis of the poor results from this last proof test and the wide range of adhesions observed under removed pucks (both failures and non failures), it was decided with some reluctance to cut off all load spreaders. A strategy then adopted was to follow a "fast track repair"—regluing the load spreaders as quickly as possible with the same adhesive using an improved procedure which would be based on a quick, intensive lab investigation of the likely causes of the adhesive failures. This is discussed in more detail in email Hill 8/24/94 (ref 28).

On 8/25/94, all load spreaders were cut from the back of the mirror, using a combination of paint scraper and wire garrotte. The wire produced some fine scratches on the polished mirror backplate. Each puck was inspected for adhesion, and other characteristics such as corrosion, surface treatment color, and distribution of adhesion were recorded. The main results were that over 50% of pucks had $\geq 75\%$ area adhesion whilst 25% had less than 10% area adhesion. This bi-modal distribution suggested that there was an uncontrolled factor which was causing the lack of adhesion. The data were examined to determine whether a correlation existed between adhesion and any of the recorded characteristics such as corrosion, coating color, gluing date and glue batch number, but no positive links were found.

2.2 Lab Investigations of First Gluing

To obtain some expert outside advice on the DC 93-076 adhesion problem, Dow Corning was contacted. After some initial fruitless discussions with their technical hot line, contact was made with Dave Salverson (ph. 510-490-9302), one of Dow's polymer chemists who specializes in silicone adhesives. Several extended discussions with Salverson resulted in the conclusion that the main areas of concern were: the phosphate coating and its possible contaminants; the rubber adhesive on the foam insert; and the need for tight control of humidity and primer thickness. Overall the conclusion was that the 93-076 has excellent adhesive and cohesive properties but requires careful surface preparation and primer application. These discussions with Salverson are summarized in Gray 8/16/94 (ref 33). An email from Hinman 8/31/95 (ref 26) summarizes information obtained from Kodak on silicone adhesives *they* have used.

A program of lab testing of DC93-076 was started by Gray and Olbert, concentrating on the above areas. Shear samples were prepared with a 38 mm square x 2mm thick layer which could be fitted to the ML Instron test machine. The samples were made from machined A36 mild steel with a Pyrex glass insert on one side. An outline of this test plan is given by Olbert 8/18/94 (ref 30). The major results from these tests were:

1. The thickness of the primer had a major effect on the adhesion reliability. A moderate to heavy application seemed to work best, whilst a very light or very heavy coat gave poor results. (Note that this was at variance to Salverson's advice on a very light coating being optimum).
2. The rubber cement on the foam insert was highly soluble in the primer solvent, and trace amounts caused a lack of adhesion of the RTV to the steel.