***Practical Design and Performance of the Stressed Lap Polishing Tool***

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**Synopsis by Jerrod Young**

**Introduction**

The *stressed-lap* technique was developed at the Steward Observatory Mirror Lab as a solution to the fundamental problem of shape misfit for large polishing tools on highly aspheric optical surfaces. This is a deformable large tool which is built on the concept of the large stiff tool actively changing its shape over the surface of the optic being polished. Shape changes are induced in a large circular plate through the application of bending and twisting moments. This technique allows the use of large stiff tools which are desirable due to its ability to produce high glass removal rates as well as the provided natural smoothing ability over a wide range of spatial frequencies.

**Basic Description**

The stressed lap deformation is computer controlled and has a relatively complex control system for the purpose of allowing the optician to regard highly aspheric surfaces as if he/she were polishing a sphere. Encoders allow the computer to continuously read the lap’s position and orientation along the mirror, making the lap shape independently control by the computer. Experimental data has shown that by attaching the lap to a machine, convergence rates were increase by the ability to vary the axial position in proportion to local surface error as well as allowing the ability to control unwanted pressure gradients across the lap face.

*Mechanical:* The stressed lap consists of a solid circular aluminum plate with steel tubes around the perimeter. Each tube contains an actuator that creates a bending and twisting moment to the tubes by way of tension in the steel bands that connect series of the actuators together in a triangular pattern that can be view in the schematic to the right. The tension in each band is measured with a load cell at the termination point of a steel band, and this tension serves as the servo feedback signal to control the motor torque. A preload tension is applied to the bands causing the bands to be in a constant state of tension over the surface of the mirror in order to eliminate back lash from the mechanical force system at the transition between compression and tension. Only 80% of the lap is used for polishing to compensate for the scalloping of the plates near the actuators caused by the discrete bending moments.

Figure : **Top view of the 60cm stressed lap. 12 actuators are attached to the periphery of the plate.**

The first lap had a force feedback system based on sensing the deflection of a steel beam with a LVDT (linearly variable differential transformer). It provided an adequate finish to the 1.8m f/1.0 primary mirror of the Vatican Advanced Technology Telescope, however, the hysteresis of this feedback system led to unacceptable shape error. This tool has since been retired in favor of a model that incorporated load cells to measure the tension of the steel band harboring a seven-fold improvement.



Figure 2 side view of the actuators placed on the post around the perimeter of the stressed lap.

*Electrical:* Change in the shape of the lap is controlled by changing the force distribution of the tension bands connected to the actuators. The electrical components of the controlling system contain a DC torque motor driven by a pulsed wave modulated servo amplifier, an analog proportional integral stage, and a feedback load cell force signal. A force command is sent to an actuator by placing the force value and the actuator number onto a bus that is connected to all the actuators.

*Shape Calibration:*  The relationship between the shape of the lap and the forces exerted by the actuators are determined with a set of LVDT sensors. The correct plate shape is determined by an iterative least squares method that takes feedback on the geometry of the optical surface, and position and orientation of the lap through a sensor matrix in contact with the lower surface of the lap plate via a three point kinematic attachment.

*Empirical Performance Data:* The next figure are for the purpose of illustrating the typical shape accuracy of the 1.2m stressed lap on the Air Force 3.5m f/1.5 primary mirrors along with the errors seen from the reproduction of the shapes. Figure 3 shows the corresponding decomposition of the banding moments into coma, defocus, and astigmatism. The following figure illustrates the bending hysteresis resulting from all possible sources. The hysteresis and shape repeatability were obtained by placing the lap on a calibration fixture simulating the movement.



**Figure 4 Highly exaggerated stressed lap hysteresis plots derived from the data set used to produce Figure 5.**

**Figure 3 The upper plot shows the shape accuracy of the 1.2m stressed lap produced by calibration for the 3.5-m f/1.5 Air Force mirror). The lower plot shows the corresponding moment amplitudes introduced by the actuators for defocus, coma, and astigmatism.**

**Attachment to the Polishing Machine**

The internal stresses on the lap plate applied by the actuators are not the only stresses on the lap. Stresses on the lap are also caused by external force consisting of lateral forcers to translate and rotate the lap, overturning moments from edge overhang, and the pitch blocks dragging along the surface causing unwanted pressure gradients. These external forces must all be account for in order to successfully polish the surface of a mirror. The VATT 1.8m f/1.0 mirror was polished using a stress lap that had a ball joint connection at the center that compensated for the overturning moment, but not the unwanted pressure gradient. In reverse fashion, the 3.5m f/1.5 and f/1.75 mirrors were all polished with a mechanical link that eliminated the pressure gradient that didn’t fully compensate for overturning moment.

The lap and the polishing machine are connected by 3 4-bar linkages that have their instantaneous rotation centers near the glass-to-lap interface to eliminate drag induced surface gradients. The projected intersection of the two arms of each linkage is the instantaneous rotation center will provide no unwanted motion eliminating plate deformation as long as the point are coincident with the actual dragging surface. Torque is transmitted to the plate by attaching the three linkages tangent to the polishing machine spindle. In the future the three axial forces projected through the 4-bar linkages will be controlled independently allowing the elimination of unwanted pressure gradient and the application of desired pressure gradients as well in order to adjust the glass removal profile.



**Figure 3: shows the details of a single 4-bar linkage.**

**Figure 5: depicts the layout of the 3 4-bar linkages and shows how torque is transmitted to the lap plate.**

**Conclusion**

The ability to construct a polishing tool with off axis optical shapes has been demonstrated with a straight forward design. The lap described in this paper is capable of routinely producing surface finishes as smooth as 20nm rms on large aspheric mirrors with speeds ranging from f/1.75 and f/1.0. The shape repeatability errors for a tool 1/3 the diameter of an optic is below 4μm rms. The stressed lap as stated earlier has enjoyed great success and has successfully polished several borosilicate honeycomb primary mirror.

**Refernces**

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