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Summary of Synthetic Lap Polishing Experiments at LLNL, FY'95

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INTRODUCTION

The purpose of this research was to support the optics finishing development work for the NIF, the National Ignition Facility. One of the major expenses for the construction of NIF is the cost of finishing of the large aperture optics. One way to significantly reduce the cost of the project is to develop processes to reduce the amount of time necessary to polish the more than 3,000 amplifier slabs. These slabs are rectangular with an aspect ratio of more than twenty to one and are made of a very temperature sensitive glass, Nd doped phosphate laser glass.

As a result of this effort, we could potentially reduce the time necessary to polish each surface of an amplifier from 20-30 hours of run time to under an hour to achieve the same removal and still maintain a flatness of between one to three waves concave figure. We also feel confident that we can polish rectangular thermally sensitive glass flat by use of temperature control of the polishing platen, pad curvature, slurry concentration with temperature control, pad rotation, and pressure; although further, larger scale experiments are necessary to gain sufficient confidence that such a procedure could be successfully fielded.

DESCRIPTION OF EXPERIMENTS AND EQUIPMENT

The goal of this series of experiments was to use a synthetic pad to polish a scaled down replica of a rectangular phosphate amplifier slab made of LG-750 to a flatness of three waves or better, concave, and remove the amount of material necessary to be below the depth of sub-surface damage for the process. The parts dimensions were 8.650" by 4.720". The thicknesses used were .500", .700", and 1.680". This pre-polish process would be followed by final figuring on a pitch lap. Our goal was to reduce the total time required to remove a specific amount of material to insure that we were below the depth of damage. The amount of removal required for phosphate laser glass is 20-25 microns, after a nine micron grind. This would require more than 30 hours of run time on the continuous polish pitch lap. In an effort to increase the removal and decrease the amount of machine time we experimented with synthetic laps, which are capable of polishing at extreme pressures and speeds, and can achieve the same amount of removal.

The machine we chose to use for the experiments was a Spitfire, Gryo Matic, thirty-six inch diameter machine with pneumatic pressure loading capability. It has a speed range on the main platen of zero to fifty revolutions per minute (rpm). The pressure range is from zero to three hundred fifty pound load, which when applied to our test samples, allows a maximum finishing pressure of 8.57 pounds per square inch (psi). The type of synthetic pad used was a thirty six-inch diameter, fifty-thousands thick Greyrock 25 pad by Rhodes. The Greyrock is a polyurethane pad, with pressure sensitive adhesive backing. To accommodate the lap shaping an 8-inch center hole was cut out. The polishing slurry used was Hastelite P.O., a cerium oxide based compound with particle size of 1.3 micron. It was diluted ten-to-one by volume with de-ionized water.

The platen of the Spitfire is cast iron with water channels cut in a spiral pattern in it, mated with a thermal grease to avoid bi-metallic expansion, to a one-inch thick stainless steel plate. This plate was previously ground and polished to observe any figure distortion caused by heating and cooling the platen and to measure the flatness. The figure of the platen was about one half wave convex, with a small amount of cylinder. This figure did not change more than one-quarter wave throughout the forty degree temperature range that we applied to the platen. We changed the temperature of the platen by pumping water through the channels and back through a neslab heater-chiller.

We built a temperature control system for the slurry delivery to monitor and control the slurry temperature. It consisted of a pump, dedicated to moving the slurry from the main tank through a young heat exchanger, then into a YSI controlled heater. The controller is capable of controlling the temperature to one-tenth of one degree C. The temperature was monitored in the slurry tank before the final delivery to the pad.

We ran several tests at different speeds and loads to determine an optimal starting point. We selected ten rpm for the platen and a load of one hundred fifty pounds. The run time used for most tests was either twenty minutes or forty minutes. The starting temperature for the platen was 72.5 degrees F.

EXPERIMENTAL RESULTS

Before we shaped the pad, made any adjustments in the temperature of the platen, or anything else to influence the figure, a run resulted in a part with a flatness of eight waves convex after twenty minutes. This was defined to be a baseline.

The first experimental deviation from baseline was to put a curvature in the pad using a diamond ring tool we designed and built. It is made of stainless steel with thirty-four quarter-inch diamond pellets around the circumference of the seventeen-inch diameter stainless steel ring. We were able to influence the curvature by letting the ring tool rotate on the pad with the machine running. We were able to measure the curvature of the pad by using a set of four identical small glass etalons as a base for the bar spherometer’s ball feet and a LVDT probe. The curvature we used was measured to be 7.5-10 microns convex over the 317.5 mm long bar spherometer. These measurements were taken at nineteen different locations on the surface of the pad. We determined that when the curvature of the pad would start to change to a non-uniform curvature that redressing with diamond ring tool would bring the shape uniform after five minutes of running or less. The pad held a curvature that worked to achieve the flatness required without reconditioning for more than fifty consecutive runs.

With a ten rpm table rotation, and a one hundred fifty pound load, the removal on the LG-750 phosphate laser glass was 10 microns per twenty minutes of run time. We were able to hold flatness to one-to-three waves concave of uniform power very easily. We ran a three-hour run on a part to show the process to be stable at an extended run time and achieved a five-eighths of a wave concave surface at the end of that run.

We were able to control the temperature of the slurry. We made adjustments in the temperature of the slurry of up to 40 degrees F. from ambient. The change in temperature had an effect on the parts.

While we were able to make corrections in the curvature of the parts by adjusting the platen temperature, there did not seem to be a single platen temperature setting that was repeatable day after day to get the desired flatness. One explanation for this is that the pad was retraining a memory of the last part run, ie, if a part finished concave the next part would be more concave and vice versa for convex. This was verified by taking a two-inch round disk and running it centered in the septum with a load of three hundred fifty pounds. When we ran the rectangles, the interferometer showed that instead of the normal uniform figure, we had a two-wave bump in the center of the rectangle that was about two inches in diameter. This result repeated for the next twelve runs. This indicated that it should be possible to imprint the lap with almost any shape and have its inverse duplicated on a part. Further tests are necessary to confirm this opinion, but this demonstration seems to correlate the theory that the pad was being deformed during finishing resulting in a need to change the temperature for every run.

We then did a test to determine the thermal characterization of the polishing table. We used the Bales Scientific Inc. dual-band infrared (DBIR) camera and TIP200 twelve bit digital image processing system. The system was mounted on brackets, five feet above and facing the polishing table. We recorded and stored temperature images at three to five microns and at eight to twelve microns. The recording time per frame was 0.080 seconds. The delay was 0.260 seconds between images. The table rotated counter clockwise at ten rpm". Every fourth frame had a rotation of about sixty degrees, which allowed us to show the complete table top with six images. By placing metal washers and a razor at the zero degree and one hundred eighty degree positions, we characterized hot and cold spots on the table relative to the fiducial marker at zero degrees. The tests showed that the table-top was not of a uniform temperature and at sixteen degrees C. but had a thermal variation across the table of 2.7 degrees C. We monitored the temperature to heat or cool the platen at the heater chiller unit and at the input and output of the polishing table. Measurements indicated the temperature had stabilized at these three points in thirty to ninety minutes, the temperature on the pad takes three to eight hours to stabilize. We plan further tests to show that this is probably the major factor for the lack of being able to find a specific temperature for a specific flatness. We believe this is even more of the control than the deforming of the lap.

To prove that we were controlling the flatness by adjusting the temperature of the platen we made up a fused silica blank of the same size and thickness of the phosphate ones used in the above test and ran it simultaneously with the phosphate blanks. We observed that the manipulation of the temperature of the platen continued to change the curvature of the phosphate blanks but had no discernible effect on the fused silica blank. The phosphate moved between three waves convex and three waves concave. The fused silica running at the same time stabilized at four and one quarter waves convex and did not change with the temperature inputs. This shows that we were controlling the flatness on the phosphate parts by using the coefficient of expansion lever, which implies that this approach should work for other temperature sensitive glass, such as BK-7. (See table 1)

We believe that the curvature of the synthetic pad is the key to being able to control the flatness of temperature insensitive glass.

In polishing the ratio of removal is well known to be linear with lap velocity, that is when you double the speed you double the removal. This is also true for load. (Prestons equation: $dh/dt \propto PV$; where dh/dt is the removal rate, P = Pressure, V = Velocity. Therefore we know that we should be able to reduce the time for this process from forty minutes to twenty by increasing the speed to twenty rpm. At forty rpm it should have the same amount of removal in ten minutes. It is our plan to try these variables and verify the results.

Table 1

Material	Expansion Coefficient
Phosphate (LHG-8)	12.7×10^{-6}
Phosphate (LG-750)	11.4×10^{-6}
BK-7	7.1×10^{-6}
Fused Silica	$.52 \times 10^{-6}$

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