Developing Enabling Optics Finishing Technologies for the National Ignition Facility

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Developing enabling optics finishing technologies for the National Ignition Facility

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Summary
Lawrence Livermore National Laboratory is in the process of constructing the National Ignition Facility, a half million square foot facility which will house a 192 beam laser system capable of generating the 2 million joules of ultraviolet light energy necessary to achieve fusion ignition with inertial targets by 2004. More than 7,000 meter class optics will need to be manufactured by LLNL’s industrial partners to construct the laser system. The components will be manufactured starting in 1998 and will be finished by 2003.

In 1994 it became clear through a series of funded cost studies that, in order to fabricate such an unprecedented number of large precision optics in so short a time for the lowest possible cost, new technologies would need to be developed and new factories constructed based on those technologies. At that time, LLNL embarked on an ambitious optics finishing technology development program costing more than $6M over 3 years to develop these technologies, working with three suppliers of large precision optics. While each development program centered upon the specialties and often proprietary technologies already existing in the suppliers facility, many of the technologies required for manufacturing large precision optics at the lowest cost possible are common to two and in some cases all three efforts. Since many of the developments achieved during this program stemmed from intellectual property and trade secrets at the vendors, the program cannot be described completely in a public forum. Nevertheless, many non-proprietary advances were made during this program which the vendors are willing to share with the greater community. This presentation will describe the manufacturing process in a general sense which is used by all three of the companies under contract; Zygo Corporation, Tinsley Laboratories, and Eastman Kodak. In each of the principle process steps of shaping, grinding, polishing, figuring, and metrology, development highlights will be discussed.

The NIF optics finishing development plan
The development effort in the area of optics fabrication technology consisted of three parts; an internal LLNL finishing science, wavefront analysis, and specifications activity, three flats fabrication development subcontracts, and an aspheric lens fabrication development subcontract. All four of the vendor subcontracts were initiated through competitive solicitation, and the three selected companies (Tinsley Laboratories was awarded 2 contracts) then worked closely with LLNL in advancing the technologies most critical to their manufacturing processes. In most cases, successful subscale experiments were followed by full scale experiments on production equipment. A list of the funded activities is shown in Table 1.

Not every technology development effort was successful. All three vendors and LLNL each had one or more development paths which gave disappointing results; however, such is the nature of true development. Overall, the program was highly successful, in some cases resulting in unexpected gains and new technologies not originally identified for development. All three vendors were able, through their development programs, to demonstrate a process which would satisfy all (or nearly all) the NIF performance requirements at a fraction of today’s costs. The factories based on these technologies currently under construction at the vendors have large precision optics capacities 3-5x higher than facilities based on earlier technology.
Table 1 Funded development activities

<table>
<thead>
<tr>
<th>Technology</th>
<th>LLNL</th>
<th>Vendors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Abrasive Grinding</td>
<td>none</td>
<td>hybrid tool grinding, ELID dressing</td>
</tr>
<tr>
<td>Table lapping/loose abrasive grinding</td>
<td>double sided lapping</td>
<td>high speed pellet lap grinding</td>
</tr>
<tr>
<td>Polish out</td>
<td>high pressure polishing, thermal figure control</td>
<td>high speed polishing, variable pressure polishing, synthetic lap polishing</td>
</tr>
<tr>
<td>Deterministic figuring</td>
<td>none</td>
<td>reduced ripple small tool polishing, deterministic planetary polishing, ion beam figuring, variable pressure polishing</td>
</tr>
<tr>
<td>Metrology</td>
<td>PSD based wavefront specs</td>
<td>various</td>
</tr>
<tr>
<td>Other tools/Processes</td>
<td>cladding and cleaning specifications, automated cleaning</td>
<td>optic handling, improved tooling, cladding technology</td>
</tr>
</tbody>
</table>

**Shaping, Grinding and Polishing**

It is well understood that, although substantially more than half of the total cost of fabricating a precision optic is accrued in the final figuring and metrology steps of the process, often the easiest way to reduce those costs are by improving the surface quality, roughness, figure, and sub-surface damage of the part prior to polishing. It is no surprise therefore, that about half of the development projects were in the areas of shaping, surface grinding, and the process of removing the gray from grind, or polish out.

In the area of Fixed Abrasive Grinding, Kevin Grobisky and Doug Johnson of Zygo successfully developed Electrolytic In-situ Dressing (ELID) on a small Yashikawa grinder, fabricating 6” samples of FS, BK-7 and Phosphate with substantial increases in mesh numbers over conventional shaping work. They work on modeling the ELID process greatly enhanced our understanding of the process. They then performed full-size experiments which were also successful. The fixed abrasive process to be used for NIF will be largely based on Kevin’s work, extended to a 61” Toshiba vertical rotary grinder.

Jim Kennon, Ben Catching and others at Tinsley laboratories developed a full-scale pellet grinder capable of running as fast as 400 rpm. Their one meter lapping system was used successfully to fabricate Tinsley’s first clad amplifier slab for AMPLAB in ’97, with grinding times of a few hours. Jim and Ben also developed a synthetic pad polisher capable of polishing out flat and spherical surfaces up to a meter in as little as 2 hours. These high speed grinding and polishing tools will be transferred to the NIF facility in late 1998.

Other efforts in shaping, grinding and polishing include: successfully polishing 6” and larger pieces using lap and slurry temperature control to correct figure under high-removal rate conditions on synthetic laps by Flemming Tinker at Zygo and Mike Nichols at LLNL; combined coarse and fine edge grinding using hybrid grinding tools by Kennon and Bajuk at Tinsley, and experiments into alternatives to conventional fabrication technologies such as waterjet cutting, double sided lapping, and full scale variable pressure laps for fast correction polishing. While none of the latter developments have matured to NIF qualified processes, the groundwork has been done for each technology to be pursued when a more suitable final application of the technology presents itself.

**Deterministic figuring and precision polishing**

Figure control using advanced, highly deterministic processes and modern optical metrology tools and control systems were pursued by all three vendors. Figure control for large optics is generally accomplished one of two ways; precision planetary polishing, or computer controlled small tool polishing.
Many of the results are revolutionary, but the details are unfortunately highly proprietary, and so cannot be discussed here. Instead, a summary of the technologies is given.

LLNL has shown, through the mathematical formalism of Fourier decompositions of PMI interferometry measurements and power spectrum density plots documented elsewhere\(^1\), \(^2\), that the greatest impediment to the small tool polishing for high energy lasers is the very low amplitude (< 10 nm) ripple which is inherent to these processes. Both Ben Catching, Jim Kennon and Bob Kestner at Tinsley, and Lisa Rich and Mark Baumler at Eastman Kodak, were able to reduce or eliminate the ripple in their computer controlled small tool processes using Fourier analysis, and a rigorous study of the frequency spectra of potential noise sources. The results have been an impressive 10-25x reduction in mid-spatial frequency ripple for both vendors technologies.

In the past, the only impediments to planetary polishing of precision plano optics are the high capitalization costs for large planetaries, and the frequently encountered lack of determinism for the technology. Both Zygo and Kodak were very successful in lending determinism to their planetary polishing processes, increasing projected throughputs (and hence lowering costs) for their planetary polishers by 3 to 6 times, through a combination of advancements in machine improvements, new diagnostics, and metrology.

**Conclusion**

LLNL has led a highly successful development effort to reduce the costs of manufacturing the optics for the National Ignition Facility. In a remarkable collaborative effort, the four parties, working separately and together, have been able to achieve accomplishments in every area of large optics fabrication, from specification to metrology, from shaping to polishing, and from grinding to final figuring of optical surfaces.

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**References**


