VIBE™ finishing to remove mid-spatial frequency ripple

J. DeGroote Nelson*, B. Light, D. Savage, B. Wiederhold and M. Mandina

Optimax Systems Inc., 6367 Dean Parkway, Ontario NY 14519
*jnelson@optimaxsi.com

Abstract: The VIBE™ process is a full-aperture, conformal polishing process incorporating high frequency and random motion designed to rapidly remove sub-surface damage in a VIBE pre-polish step and eliminate mid-spatial frequency (MSF) errors in a VIBE finishing step.
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1. Introduction to the VIBE process

The Optimax VIBE process is a full-aperture, conformal polishing process incorporating high frequency and random motion designed to rapidly remove grinding damage in a VIBE pre-polish step and eliminate mid-spatial frequency errors created during deterministic figure correction with a VIBE finishing step.

To better understand the significance of the VIBE process, we will first briefly describe traditional optical pitch polishing. In traditional optical polishing, a pitch lap must take on the exact shape of the desired optic (see Figure 1a). If it does not match, the exact shape (see Figure 2a) the high points on the optic will be polished away causing the optic to become the shape of the polishing lap. The long polishing strokes (indicated by black arrows) associated with traditional pitch polishing exaggerate this phenomenon and make it extremely difficult to polish aspheres or non-spherical surfaces using traditional pitch polishing.
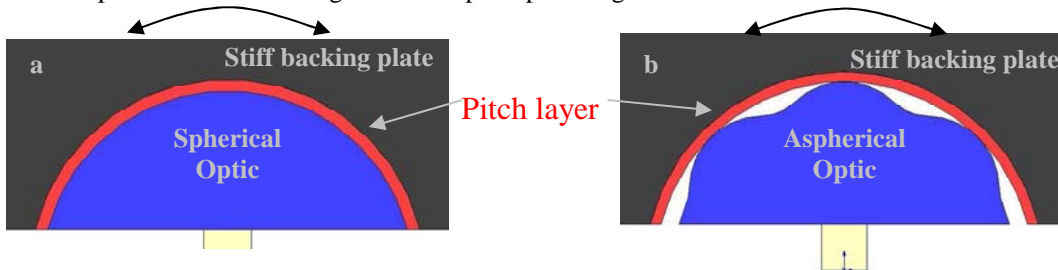

Figure 1 – Schematic diagram depicting traditional pitch polishing of a) a sphere and b) an asphere (exaggerated shape). The black arrows indicate the long strokes (>3cm) made during polishing as the pitch lap is rubbed against the optic.

The VIBE process implements a uniform compliant lap layer that allows for polishing of non-spherical optics, as shown in Figure 2. The compliant layer allows polishing of non-uniform local sloped parts, such as aspheres. VIBE also introduces short stroke, high-frequency vibratory motion. Given the compliance in the lap and the short stroke length, the aspheric shape can be maintained without inducing other errors. By altering the level of compliance, the localized slope can be selectively maintained or removed.
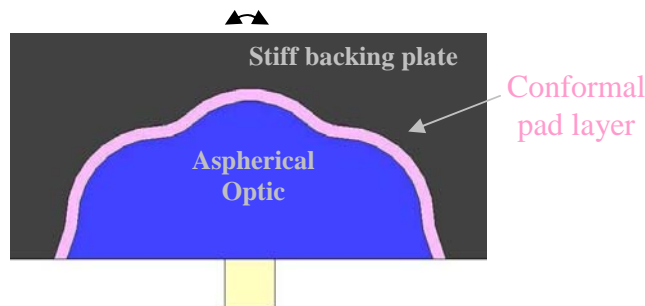

Figure 2 – Schematic diagram depicting the VIBE compliant polishing process. The black arrow indicates the short strokes (1-2mm) made during polishing as the conformal VIBE polishing lap is rubbed against the optic.

2. Introduction of VIBE into today's optics manufacturing process

Figure 3 contains three process flow diagrams that depict the optics creation process using a) traditional optics manufacturing processes, b) CNC optics manufacturing technology and c) VIBE and CNC optics manufacturing technology.

In traditional optics manufacturing, opticians create lenses or optics by grinding in the correct radius with specialized tooling with the desired radius, followed by pitch polishing again using specialized tooling, artisan skill and a time intensive and iterative process. Figure 3a indicates the traditional optics manufacturing approach.

The creation of an optic became more deterministic with the introduction of CNC optics manufacturing technology[1] represented in Figure 3b. The CNC generation process replaced the need for specialized grinding tools by the ability to create the desired radius on the optic using diamond ring tools and computer programming. Deterministic sub-aperture polishing methods gave optics manufacturers the ability to correct known errors. Their proprietary software along with a user defined desired surface, interferometrically measured surface with errors, and measured removal function create a dwell map where the sub-aperture tool would remove more material from the high points than the low points resulting in the desired surface form. The pre-polish step, still outlined in red in Figure 3b, is required after the CNC generation step to remove the damage induced during generation and to create a specular surface that can be measured interferometrically. This pre-polish step still requires conventional polishing techniques that can be iterative, time consuming and extremely difficult for non-spherical surfaces.
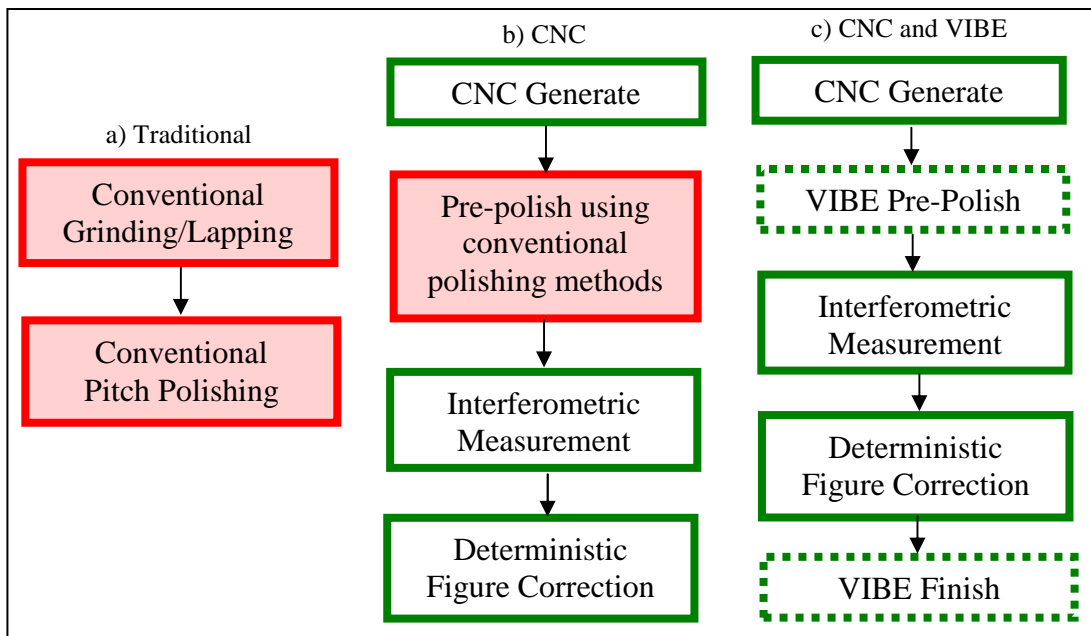

Figure 3 – Three process flow diagrams that depict the optics creation process using a) traditional optics manufacturing processes, b) CNC optics manufacturing technology and c) VIBE (greed dotted line boxes) and CNC optics manufacturing technology. Red (shaded) boxes indicate iterative, artisan-based solutions.

The VIBE process has potential to be introduced in two areas of today's CNC manufacturing process as indicated in Figure 3c. The first instance is replacing the conventional pre-polishing step with the rapid VIBE pre-polish step. Increasing the frequency of the VIBE motion has been shown to increase material removal rates by 10 – 30x over conventional polishing. High removal rates combined with the compliant lap results in damage-free surfaces that have the same form that was generated by the CNC generation process for spherical and non-spherical surfaces.

The second potential area to incorporate VIBE into today's CNC manufacturing process is as a finishing step after deterministic sub-aperture polishing. By selectively altering the compliant properties of the VIBE pad, and adjusting the frequency of the VIBE motion, VIBE finishing can remove the mid-spatial frequencies caused from sub-aperture polishing processes while maintaining the desired corrected surface form.

3. Definition and causes of mid-spatial frequency errors

Novel surface shapes, such as aspheres, acylinders and free-form optics require CNC deterministic sub-aperture polishing techniques. These sub-aperture polishing techniques revolutionized the optics industry with the ability to correct surface low spatial frequency form error to a very high accuracy level in a pre-determined amount of time. This technology has allowed many designers to include non-spherical or higher accuracy spherical surfaces into their optical systems.

Two of the most common patterns used by deterministic polishing techniques are rotational and raster patterns. These periodic sub-aperture tools leave a residual pattern on the surface of the final optic. Many optical fabrication shops and lens designers often refer to this pattern residual from the sub-aperture tool shape as mid-spatial frequency (MSF) errors or "ripple". The size and periodicity of these tooling marks, dependent on the machine platform by which they were polished, can range from 1 – 50mm periods.

Figure 4 illustrates a power spectral density plot (PSD) drawn by Harvey and Kotha[2] where low, mid and high spatial frequency regions are indicated and correlated to the point spread function (PSF). Low spatial frequency errors are associated with conventional aberrations and blurred features. High spatial frequency errors (also referred to as surface roughness) cause wide-angle scatter that reduces the power throughput to the image. Mid-spatial frequency errors contribute to flare or small-angle scattering that reduces the contrast between nearby features.
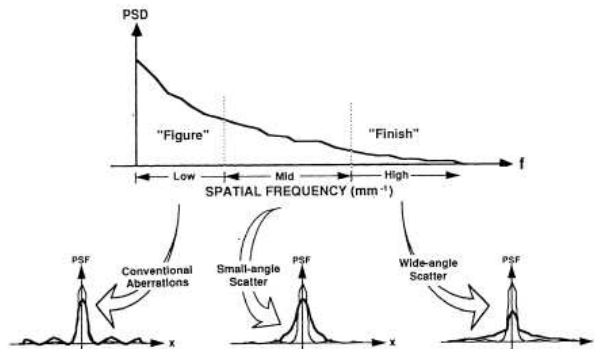

Figure 4 – A generic power spectral density function correlated by spatial frequency region to the point spread functions.[2]

Data will be presented that compares power spectral density plots, localized slope error and residual rms error after a high-order Zernike removal of surfaces polished with deterministic polishing processes and then finished with a VIBE finishing step.

References

[1] H. Pollicove, and D. Golini, *Computer Numerically Controlled Fabrication* (SPIE, 2002).
[2] J. E. Harvey, and A. Kotha, "Scattering Effects from Residual Optical Fabrication Errors," (SPIE), pp. 155-174.