Manufacturing plastic lenses on a Fanuc Robonano ultraprecision lathe

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ABSTRACT:

Ultraprecision lathes are commonly used for manufacturing optical elements. For visible spectrum lenses, plastic elements are the most common material. For infrared spectrum lenses, crystalline materials are most common. While the most commonly used commercial ultraprecision lathe used for lens manufacture is sold by Moore Nanotechnology Systems in the U.S., we show results of manufacturing a deep meniscus lens on an ultraprecision lathe sold in Japan, the Fanuc Robonano α-OiB. Because the Fanuc system is less specialized towards manufacturing lenses, users must take additional steps to during preparation. However, the results show that excellent surface quality is not difficult to achieve. We describe our approach and show initial results from our measurements of the surface profile and roughness.

Keywords: Diamond turning, lens manufacturing, ultraprecision lathe

1. Introduction

Unlike a Moore Nanotech lathe, the Fanuc Robonano is not specialized for cutting lenses. In particular, it does not have a vacuum spindle, and so that one must either make a fixture that allows adjustments for centering the lens, or (the approach we show below) one can mount the lens material directly onto the spindle using screws rather than a vacuum seal. With this approach, one starts with a cylinder of material (the lens blank), cuts out slots from the center of the blank to allow room for mounting screws, and then cut the concave side of the lens. The lens blank is then removed from the spindle, flipped over, and the initial mounting flange is cut away during the process of generating the convex surface. This sequence of steps is illustrated in Fig. 1. (The images show the result after rough-cutting the surfaces, and before diamond-turning.)

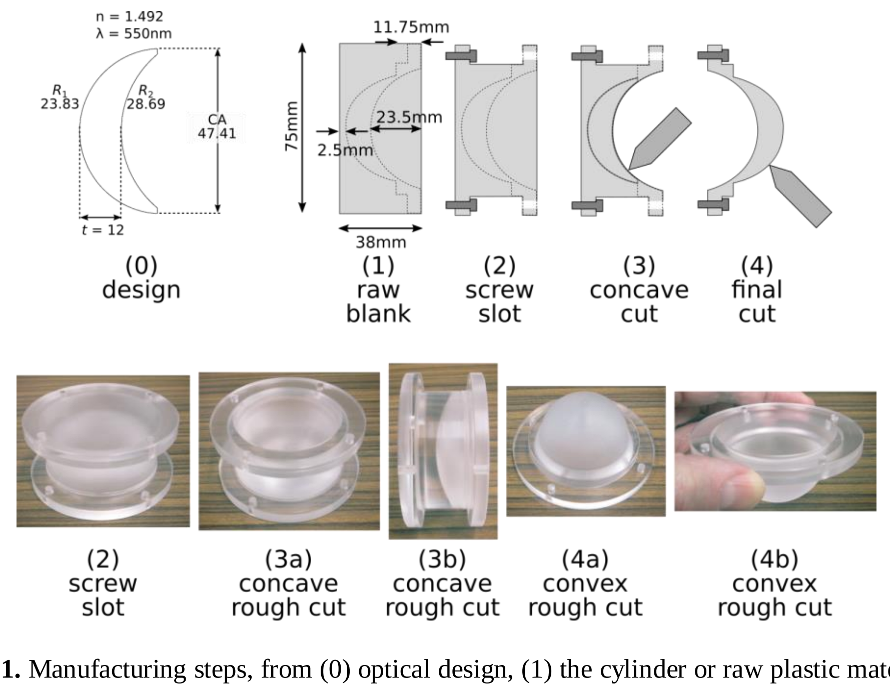


Figure 1. Manufacturing steps, from (0) optical design, (1) the cylinder or raw plastic material, (2) cutting out slots for the mounting screws, (3) cutting the concave surface, and (4) cutting the convex surface.

The optical design parameters for the meniscus lens are shown in Table 1 (the values are given in units of millimeters). The lens is designed to operate over a wide field of view of 170°, but with a long focal length of $f = 158$mm, and a narrow pupil (0.7mm diameter).

Table 1: Design parameters of the meniscus lens.

Surface	Radius of curvature	Distance	Clear aperture diameter	Material
Lens front	23.8309	12.0	23.7	PMMA
Lens back	28.6920	19.2	22.0	
Aperture Stop		466		
Image			850	

Cutting and measuring such a deep meniscus lens encounters several difficulties: (1) cutting a deep concave surface requires a tool with an unusually long shank; (2) the tool cutting tip must have a wide “included angle” of nearly 45° in order to cut at both the center of the lens and the farthest edge; and (3) because the surface to be measured lies deep inside a cavity shape, Michelson-type interferometric objective lenses (used in white light interferometers) are too wide to fit into the concavity.

The diamond tool used for cutting the lens had a 0.5mm radius, a 55° included angle, and a waviness spec of 59nm. The cutting recipe involve rough cuts of 20um depth, followed at the end by fine cuts of 2um depth. The spindle speed was 2000 rpm and feed rate set to 5mm/min (equivalent to 2.5um per rotation).

2. Results

Completing the rough and fine cuts to the concave side, followed by the rough and fine cuts to the convex side, produced the lens is shown in Fig. 2

Figure 2. Photographs showing two views of the manufactured meniscus lens. The lens surface exhibits a low degree of scattering, but has periodic features that look much like a Fresnel lens imposed on the spherical surface shape, as is evident in subfigure (b). Surface profile measurements later confirmed that these errors are present only on the concave side of the lens, and are ~1µm in amplitude, with a period of about 450µm.

We measured the surface profile and roughness of the manufactured lens using a Zygo NewView 7300 white light interferometer. Figure 3 shows the roughness measurement (using a 50× Mirau objective lens) at one location on the convex side of the lens. The results give an estimated RMS surface roughness (after the lens surface spherical shape is removed) of 11 nm, primarily due to mid-spatial frequency deviations rather than microroughness.

Next, we measured the surface profile using a 10× Mirau objective lens on a white light interferometer (Fig. 4a) and a 1× objective lens on a laser microscope. Both instruments show a profile error with a period of about 450µm, while the interferometer measurement estimates the profile error amplitude to be about 1µm high. While not large, this surface shape error is large enough to cause imaging problems, and we are currently searching for the cause of the error.

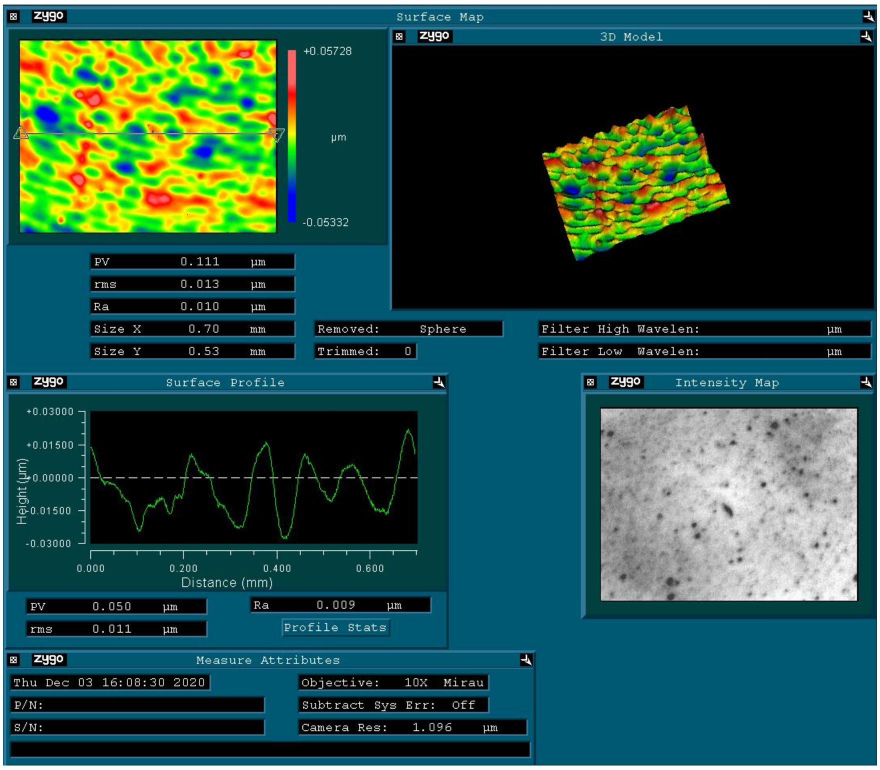
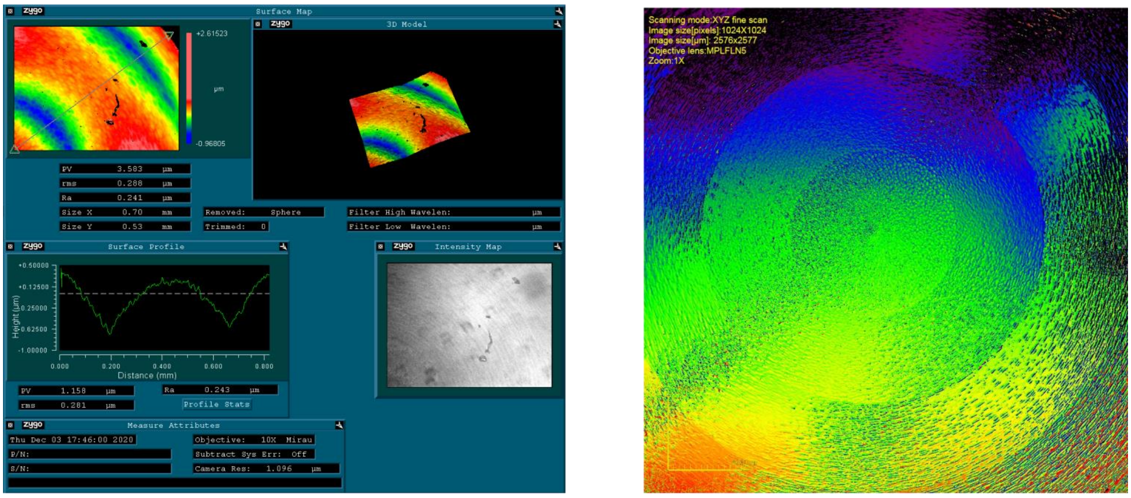


Figure 3. Measurement of the convex surface roughness using a Zygo NewView 7300 white light interferometer (with a 50x Mirau objective lens).



(a) (b)

Figure 4. Measurement of the concave surface profile using (a) a Zygo NewView 7300 white light interferometer (with a 50x Mirau objective lens); (b) an Olympus OLS4000-SAT laser microscope.

We also attempted to measure the radius of curvature of the manufactured lens, but the profile information delivered by the metrology tools gave data that was either too noisy or provided to small a section of the overall profile for a reliable fit. However, we were able to make a rough measurement of the lens focal length, giving approximately 150mm. This is in agreement with the design value of f = 158mm.