S.P. Schneider, Purdue University, School of AAE, 765-494-3343, 24 November 1999
Measurements by Murthy Haradanahalli, Purdue University, School of AAE.

Note: This document is best accessed as a Word file, since the images are in color, and the original electronic version allows magnified views of the images.

Zygo Optical Profilometer Measurements of Test Mandrel, Following Regrinding and Repolishing

1. Introduction

The mandrel and electroformed throat are critical sections of the Purdue Mach-6 quiet-flow Ludwieg tube. The largest flaw in the mirror finish of the throat controls performance. Peaks are of particular concern, since they are most likely to trip the laminar boundary layer; pits are of lesser concern. NASA Langley fabricated many quiet-flow nozzles during 1972-1994, many of which suffered from problems with waviness and roughness in the throat. These problems were often large enough to make the nozzles useless. Eventually the technique of electroforming nickel onto a polished mandrel was developed. This was used successfully for the LaRC Mach-6 quiet-flow nozzle ca. 1990. The electroform is supposed to reproduce the finish of the mandrel, and it is much easier to polish on the outside of the mandrel.

A number of tests of a test mandrel were earlier carried out as part of this project, to check the mandrel and electroform processes and properties. A drawing of the test mandrel is shown as Figure 1. The mandrel was fabricated at Purdue by Lester Cox, and heat treated at Circle-City heat treat. Measurements of the test mandrel and electroform were reported in earlier memos. Unfortunately, the first real mandrel, made of the same Optimax stainless steel, suffered from unexplained pitting when first polished at Optical Technologies. In an attempt to determine the cause of this problem, the test mandrel was reground at DMC in Dearborn, Michigan, and then polished at Optical Technologies. The goal was to determine if the problem would repeat. Optical Technologies reported achieving a good finish, so the problem did not repeat. However, the mandrel was shipped back to Purdue, for Zygo measurements, to check the visual inspection.

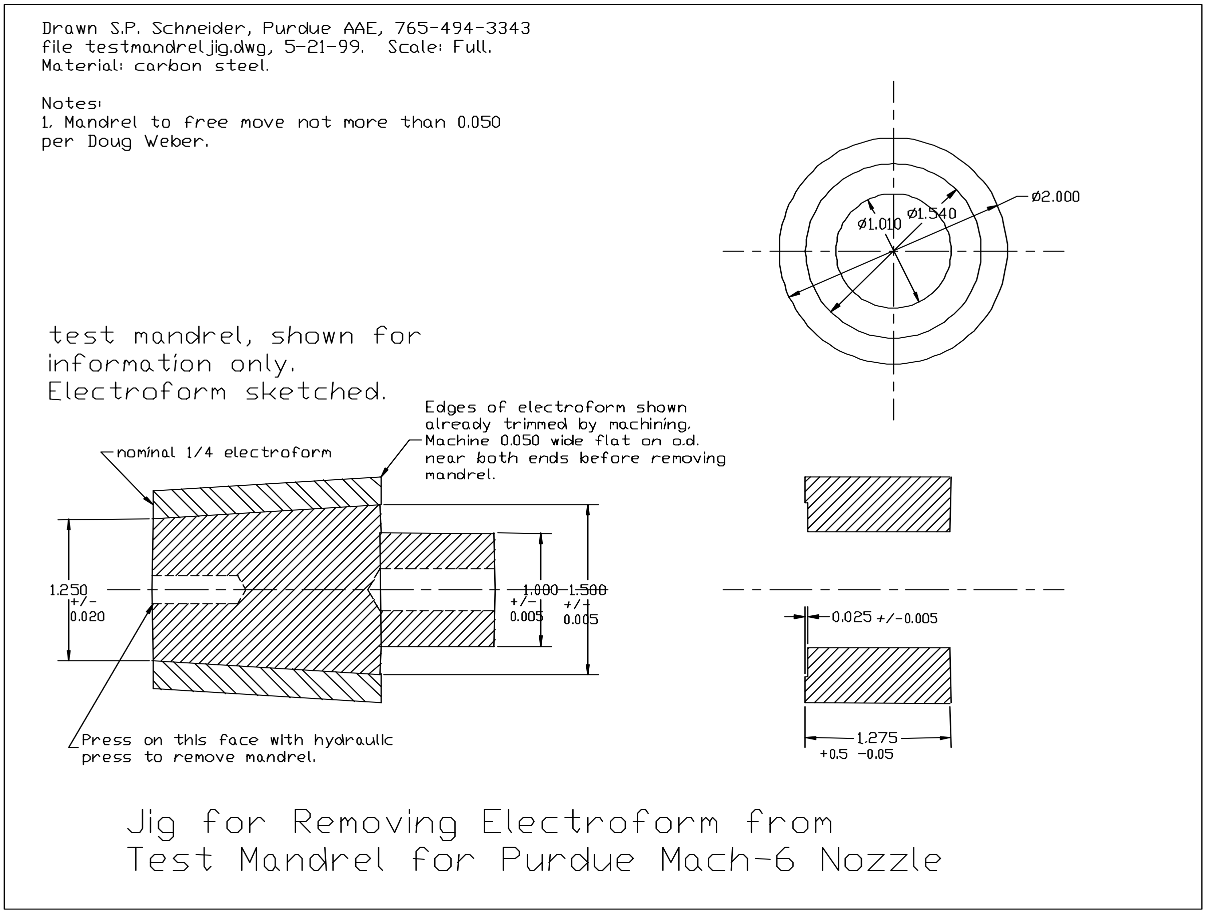

Figure 1: Drawing of Test Mandrel Electroform with Removal Jig

2. Optical Profilometer Measurements

Murthy Haradanahalli carried out measurements on the specimen using the Zygo optical profilometer at Purdue, and provided a set of .bmp files, along with an emailed summary (appended). This section presents his results. Murthy is a graduate student in tribology who works under the direction of Prof. Tom Farris. The student who had earlier performed similar measurements, Chris Tieche, has graduated and left the University.

Figure 2 shows the top view of the first sample area, with Fig. 3 showing the selected profile. Murthy noted *`3 small holes towards the right and half way from the top. One small hole at the bottom half way from the left.'* Ra is 9.1 nm or 0.36 microinches, well within spec. The peak-valley variation is 0.43 microns, or 17 microinches, a substantial value that is apparently caused by the pits.

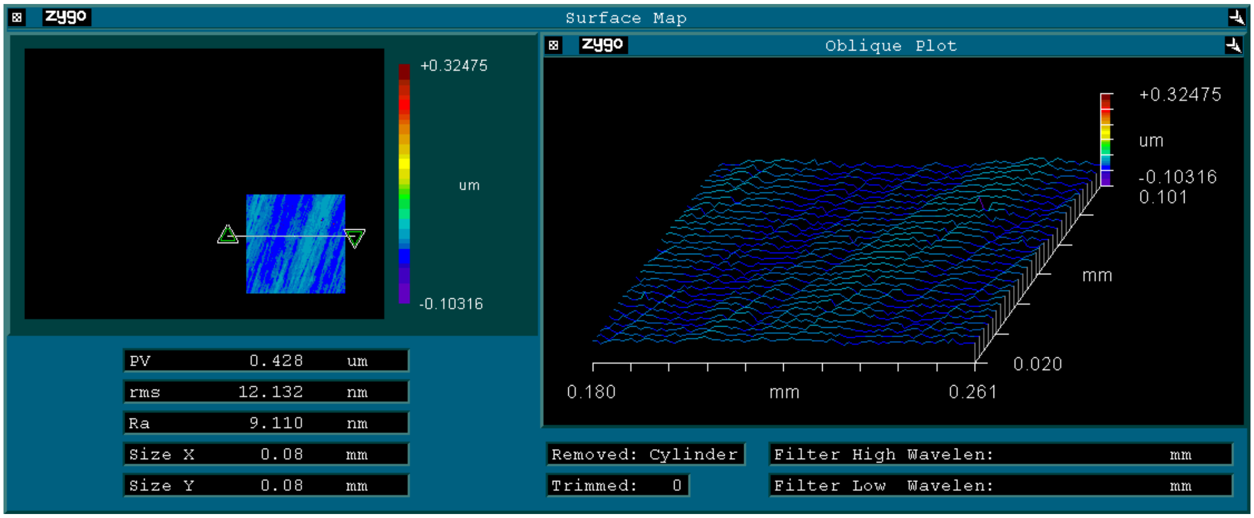

Figure 2: Top View, Sample Area 1

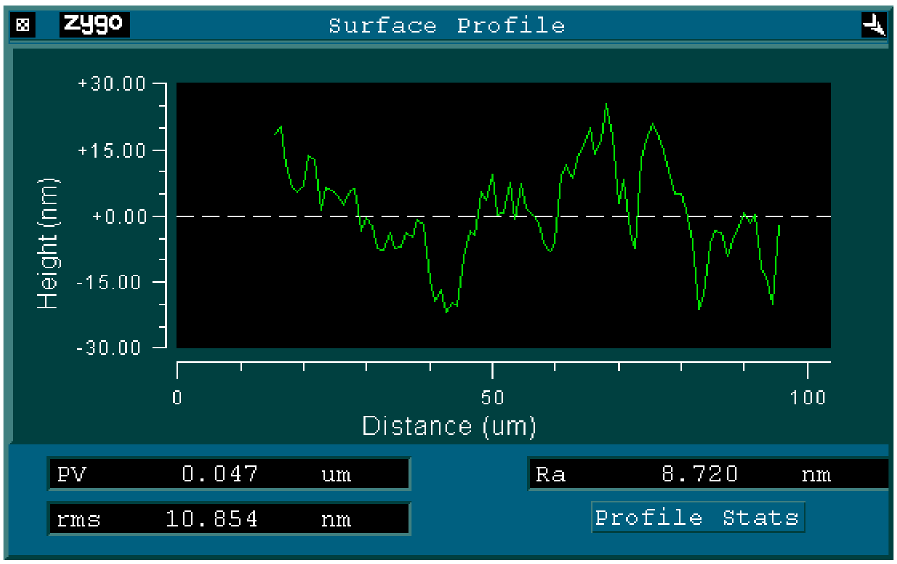

Figure 3: Selected Profile, Area 1

Figures 4 and 5 show area 2, which Murthy notes has a *`small hole at the bottom (midway from the left).'* The image is similar.

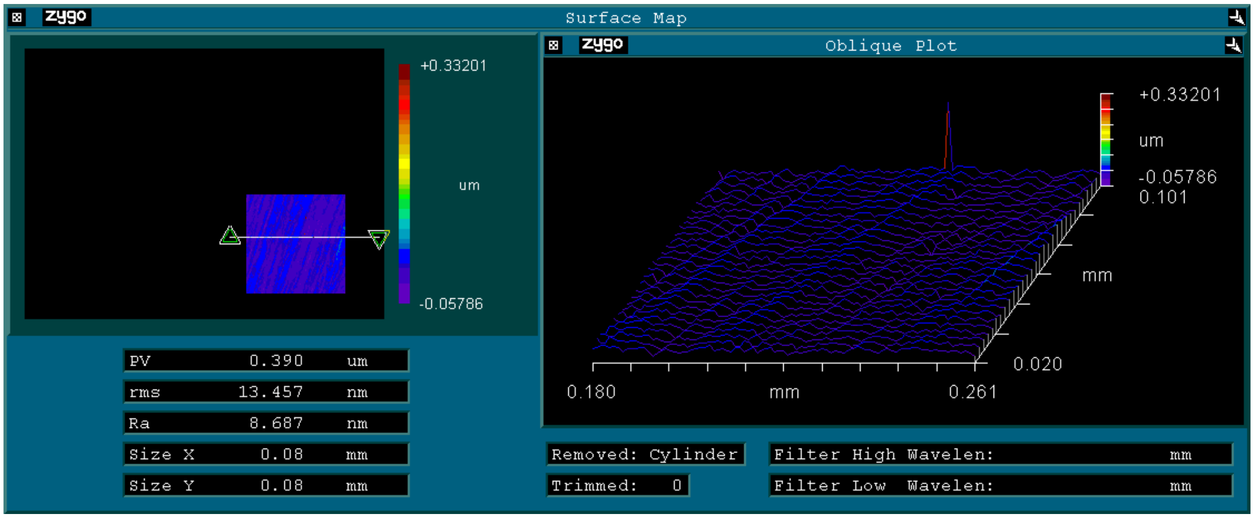

Figure 4: Top View, Area 2

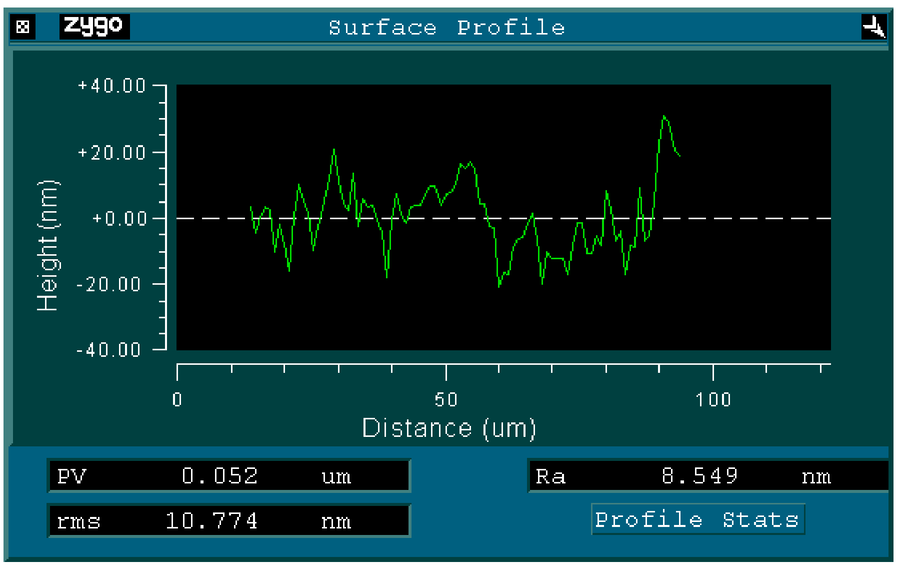

Figure 5: Selected Profile, Area 2

Figures 6 and 7 show area 3, which Murthy notes has *`one hole at top right corner, one small hole near bottom right corner.'* The image is again similar. There is a spike in the top view, it's not clear whether this is a dust speck or a real spike in the surface. The profile does not show the depth of the holes, but PV is again similar.

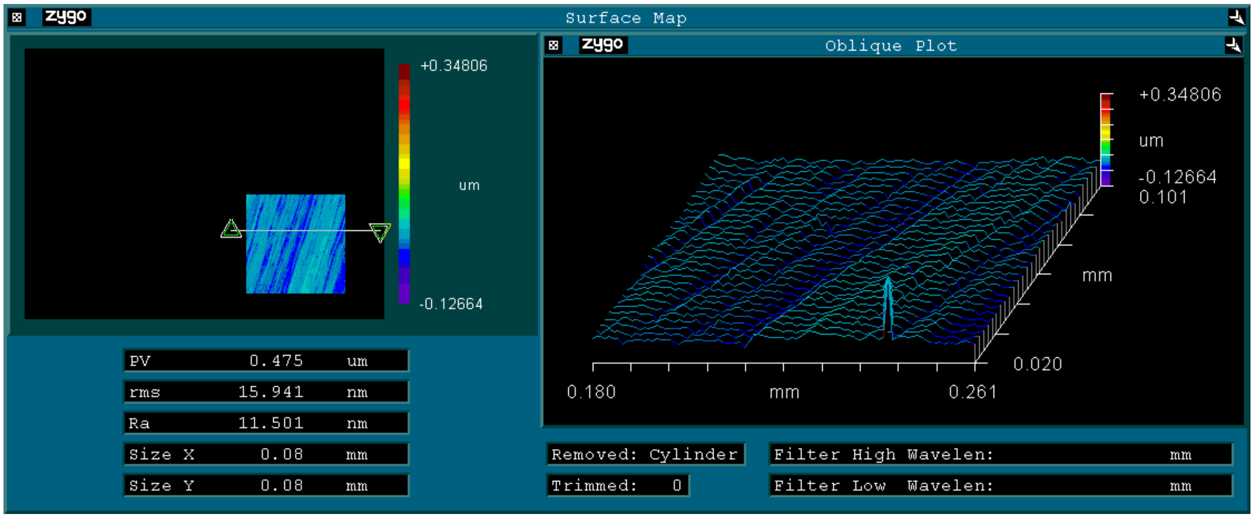

Figure 6: Top View, Area 3

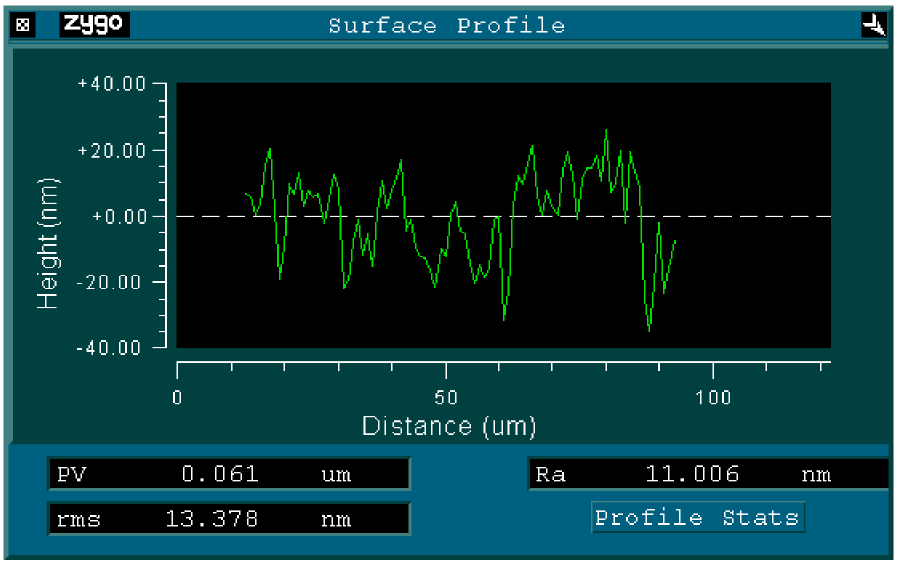

Figure 7: Selected Profile, Area 3

Figures 8 and 9 show area 4, which Murthy notes have a *`couple of dips - one at the top (about midway from left), another towards left.'* The results are again similar.

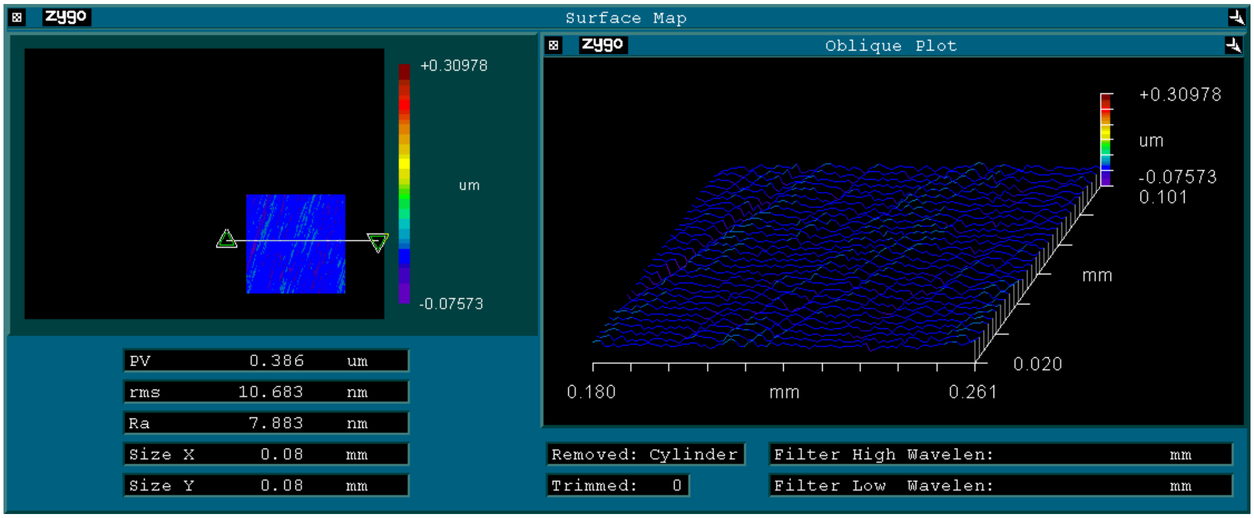

Figure 8: Top View, Area 4

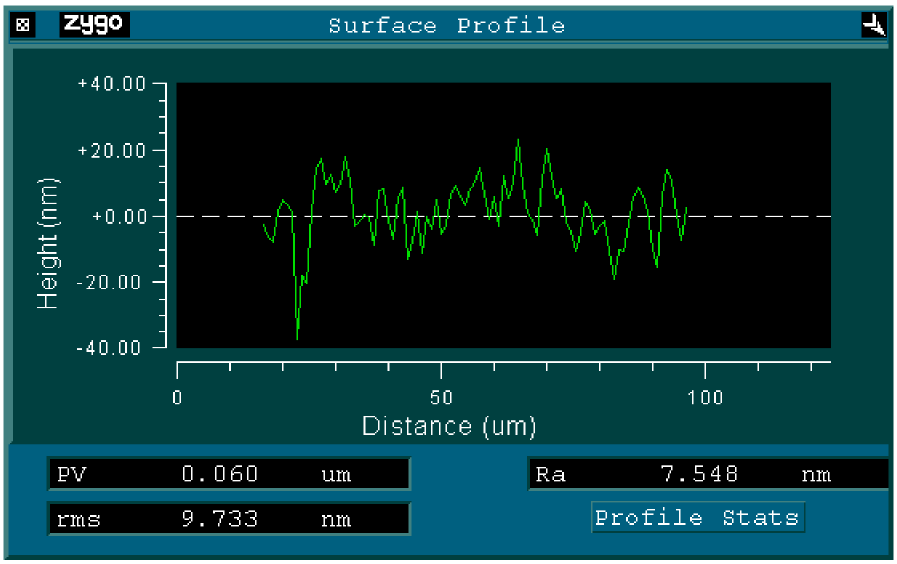

Figure 9: Area 4, Selected Profile

Figures 10 and 11 show area 5, which Murthy notes has *`2 holes , one at each end of the line along which surface profile is taken (about bottom-center and right-midway from top)'*. However, the profile line does not capture the 384 nm peak-valley deviation, which may be noted in the spike in the center of the image, which may again be dust. Otherwise, the results look similar.

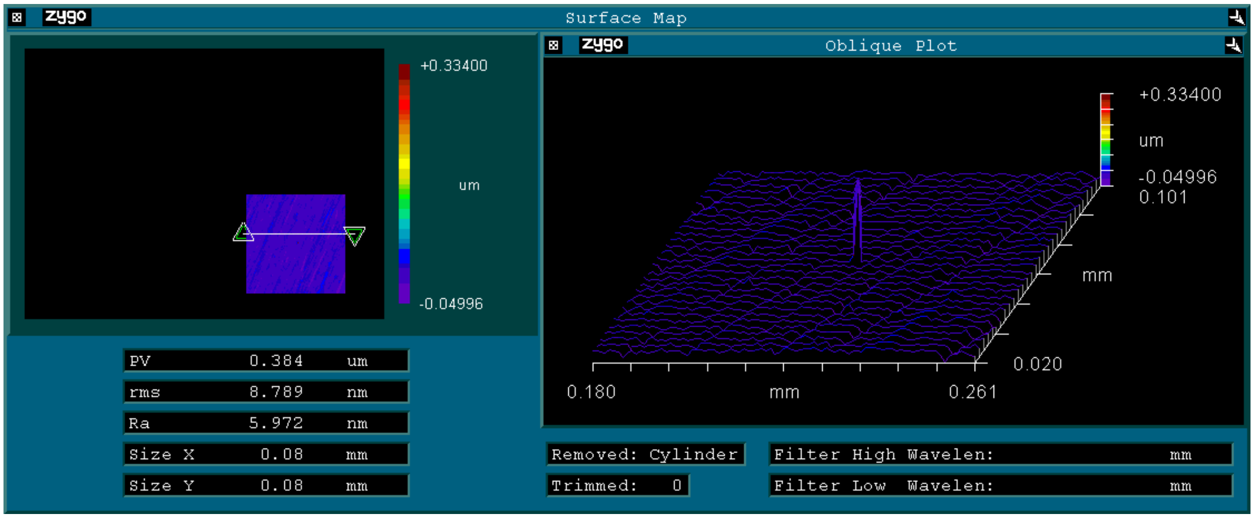

Figure 10: Area 5, Top View

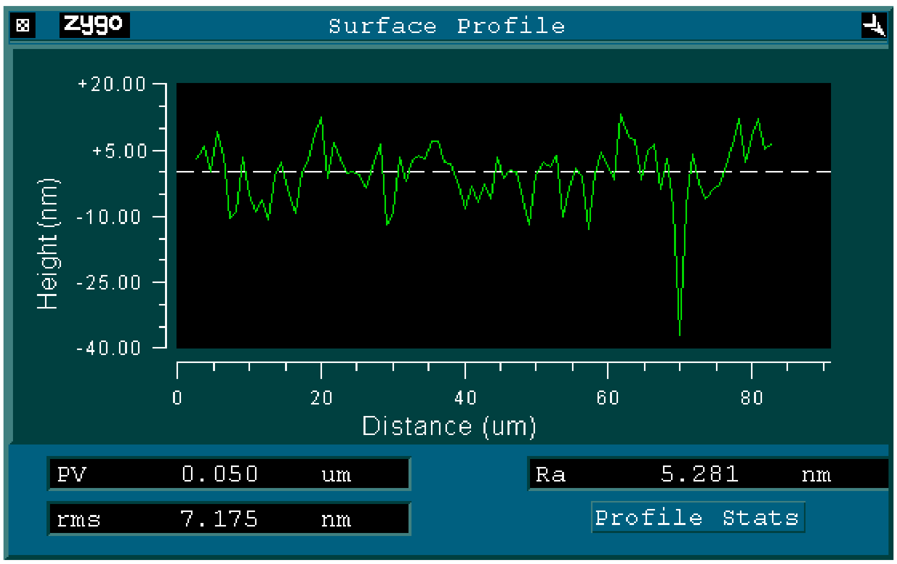

Figure 11: Area 5, Selected Profile

Figures 12 and 13 show area 6, in which Murthy notes there `*seems to be some scratch all along the length slightly towards right.'* Again there is a spike visible at the lower edge, it's not clear whether this is dust. The Ra and PV values are again similar. The depth of the scratch is perhaps 40 nm or 1.6 microinches, a small value.

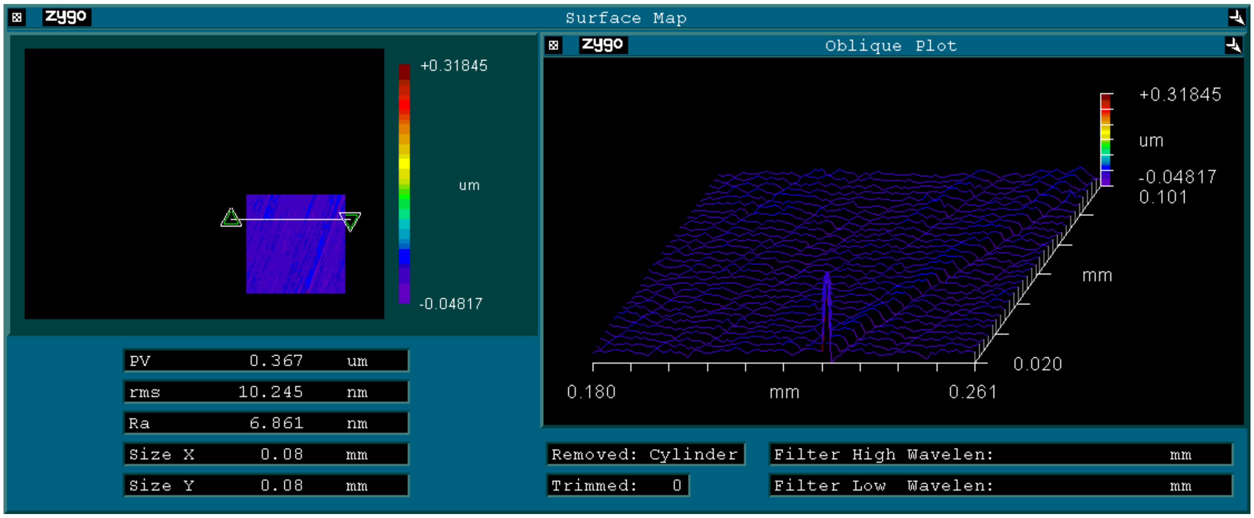

Figure 12: Area 6, Top View

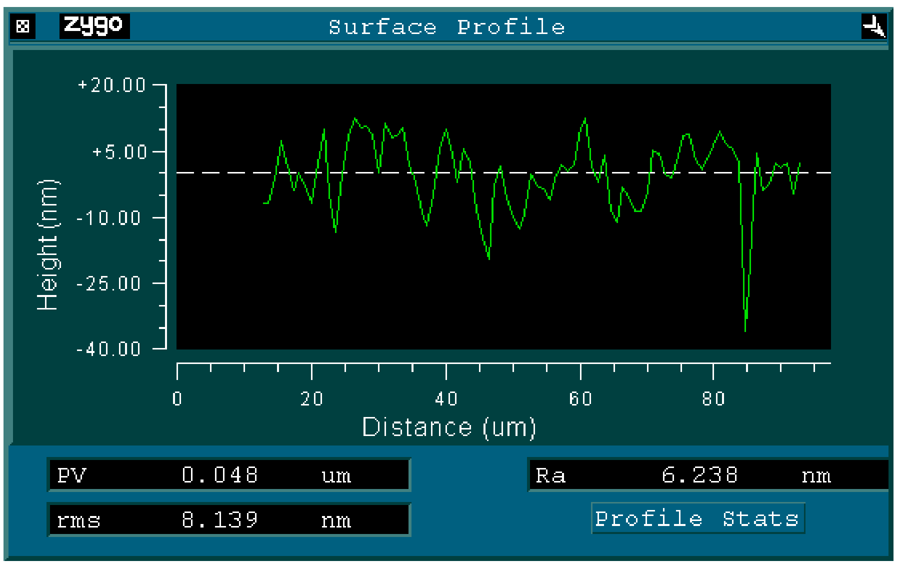

Figure 13: Selected Profile, Area 6

Figures 14-17 show areas 7 and 8, in which Murthy notes `*no major defects'*. However, area 7 appears to have several spikes, which again may or may not be dust specks. The Ra and PV values are again similar, but the spikes are a much bigger concern than the pits. Area 8 shows a large pit on the selected profile, of about 600 nm or 24 microinches. There is also a nearby spike of a size which is not clear. PV is about twice as large as usual, in area 8.

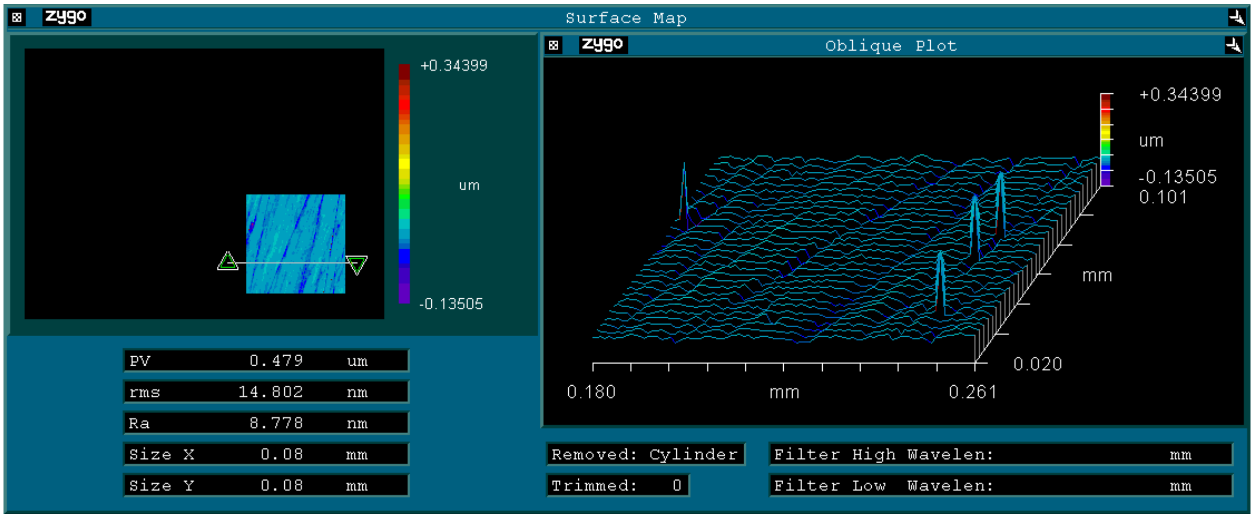

Figure 14: Area 7, Top View

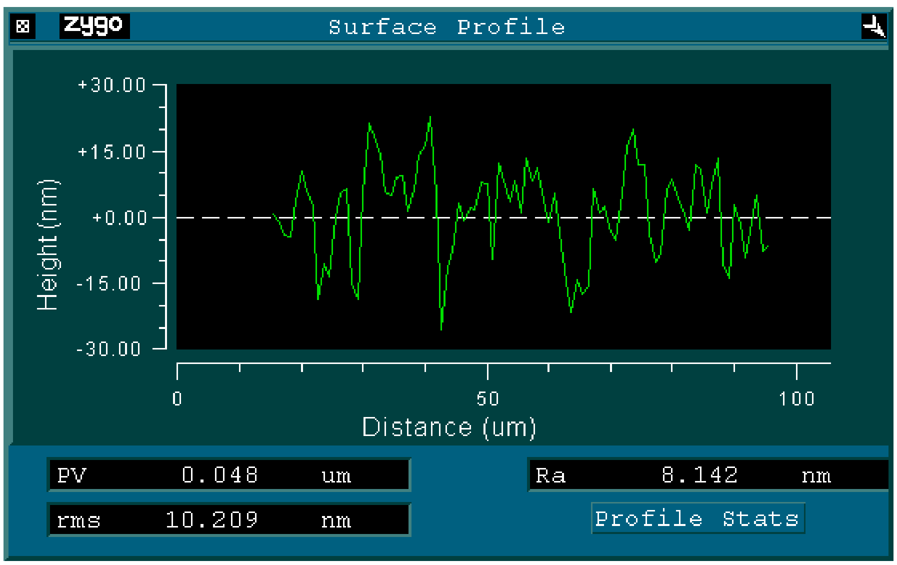

Figure 15: Selected Profile, Area 7

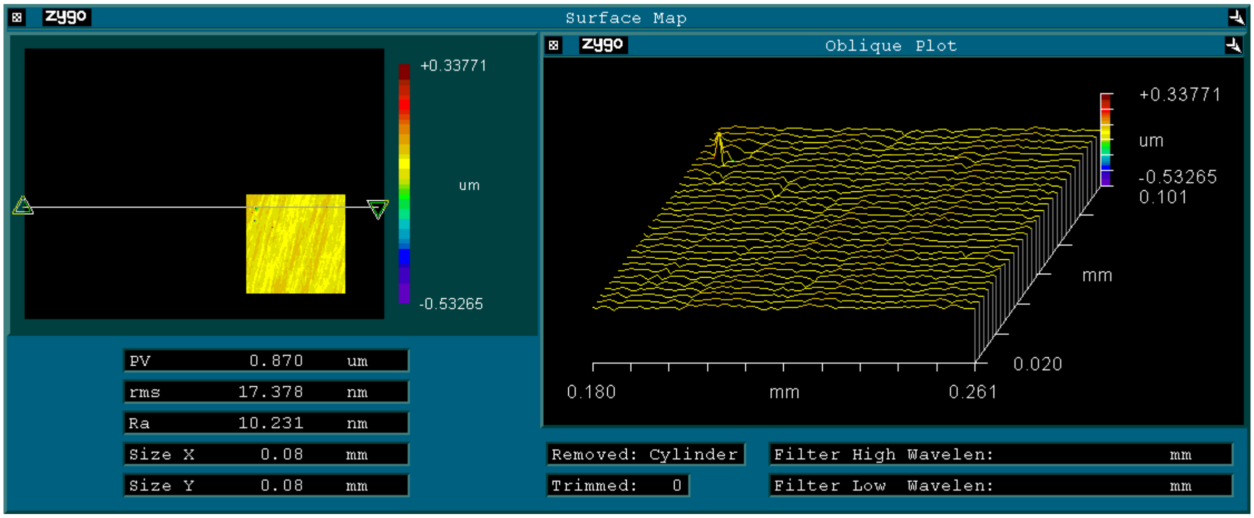

Figure 16: Area 8, Top View

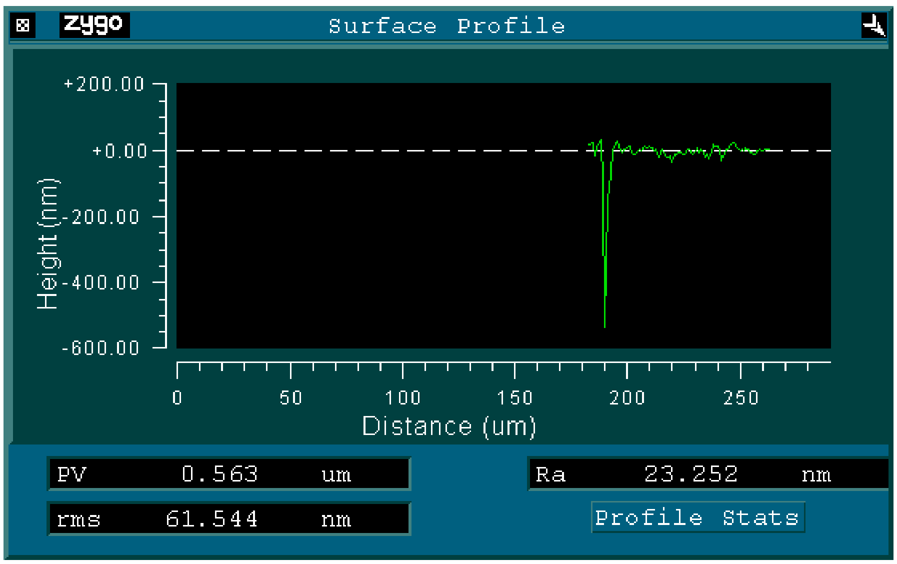

Figure 17: Selected Profile, Area 8

Figures 18-21 show area 9 and 10. In area 9, PV is again larger, with a number of spikes that appear to be about 0.2 microns or 8 microinches, a significant but not catastrophic size. The number of spikes suggest that these are not dust particles. Area 10 is similar, but with fewer spikes, and a smaller PV that is more like the others.

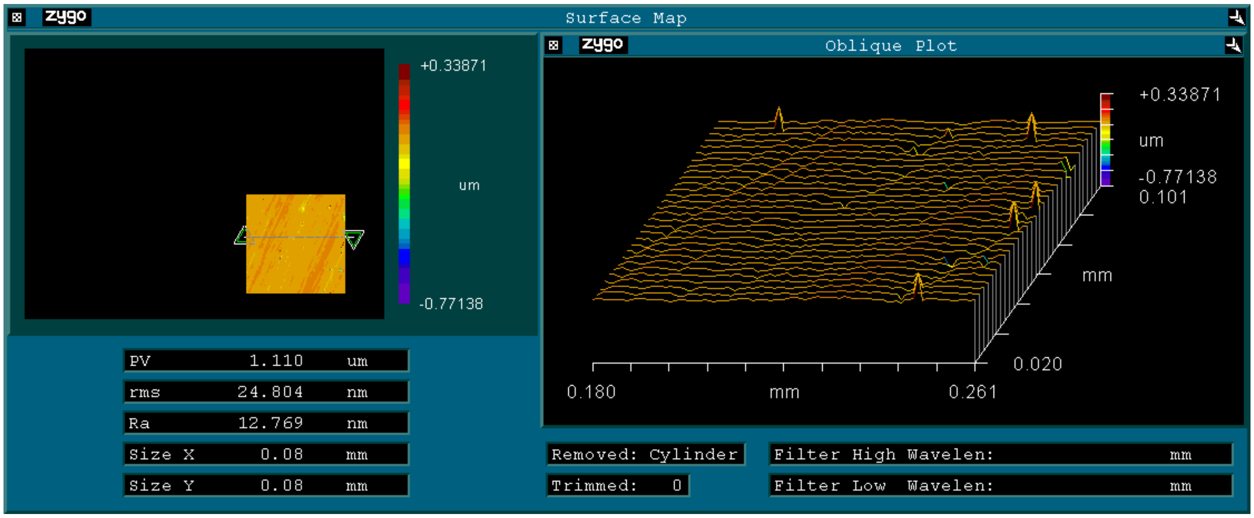

Figure 18: Area 9, Top View

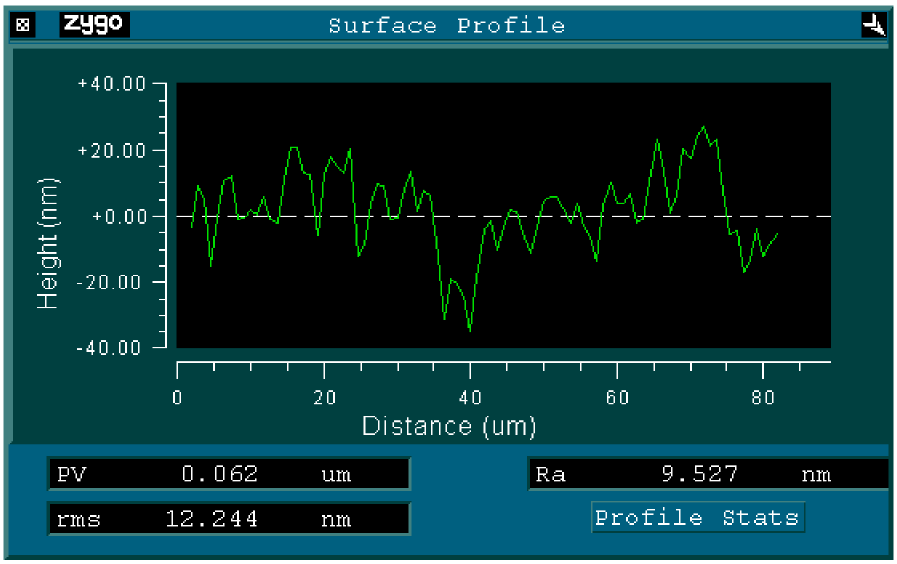

Figure 19: Area 9, Selected Profile

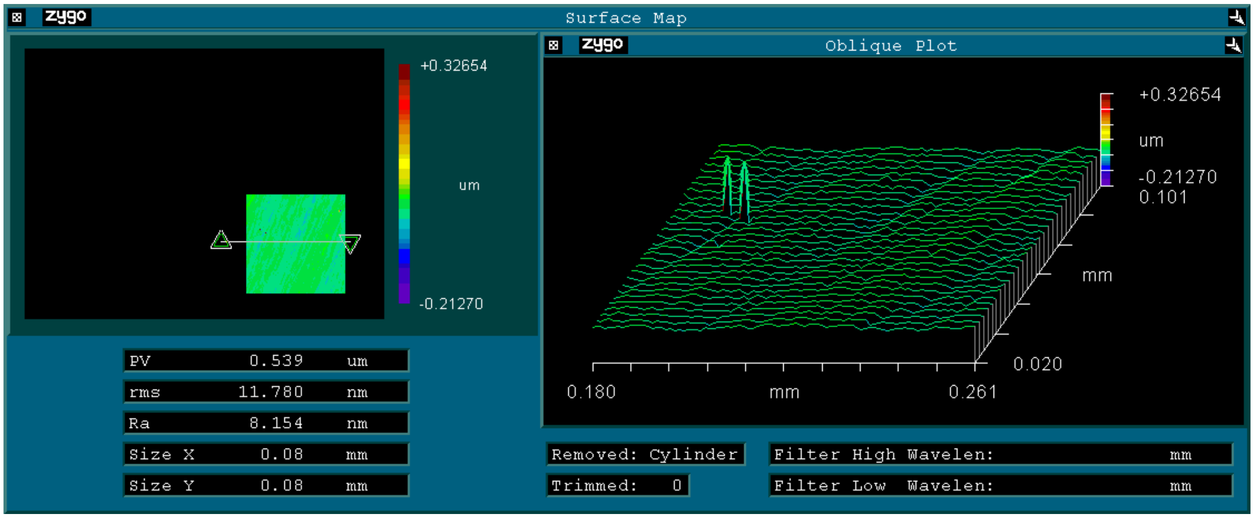

Figure 20: Area 10, Top View

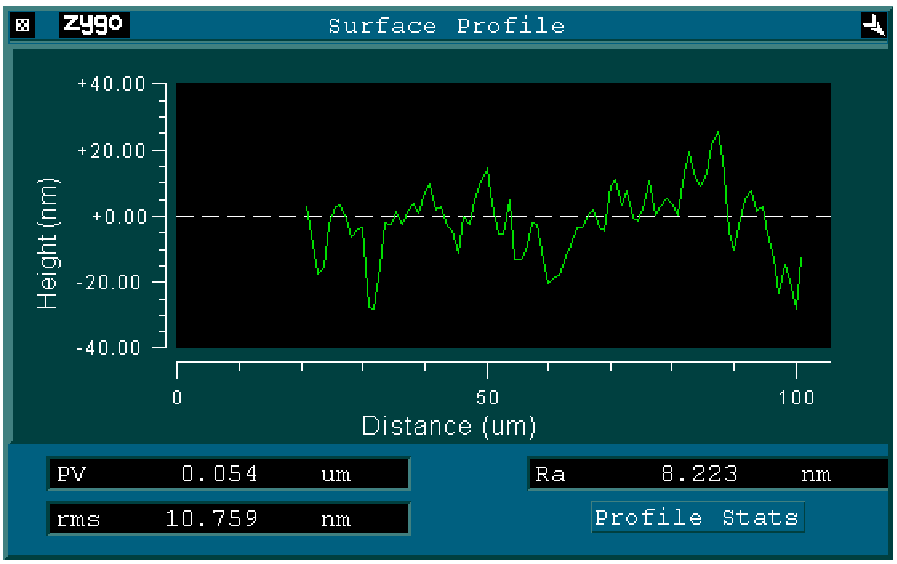

Figure 21: Area 10, Selected Profile

3. Conclusions

The reworked mandrel has an rms roughness of Ra=6-12 nm or 0.24-0.48 microinches. The peak-valley deviations are 0.4-1 micron or 16-40 microinches. A number of isolated pits and spikes are present. It remains to be determined whether any or all of the spikes are dust particles or not.