CAVITY SURFACE TOPOGRAPHY FROM OPTICAL INSPECTION

E. Toropov, D. A. Sergatskov, FNAL, Batavia, IL 60510, U.S.A.

Abstract

Characteristics of the cavity surface geometry such as roughness affect cavity performance. The optical cavity inspection system at Fermilab allows us to obtain pictures of cavity surface at different lightning conditions. By analyzing the images of some fixed location inside a cavity taken while the light source moves progressively along the axis we can deduce some topographical information of that surface. In the large-grain cavities after BCP, grains are oriented at distinct angles to the surface and, therefore, reflect light in different directions. We developed a simple algorithm to calculate the angle distribution of the grains and thus to estimate the roughness. We discuss this method and the results of the analysis of the actual cavity surface.

INTRODUCTION

Rough niobium surface can cause field emission during cavity testing. Several studies were conducted on niobium coupons to explore surface geometry and to learn how different cavity treatments (EP, BCP) change the geometry. [1], [2], [3]. However, it is not possible to explore surface inside a cavity.

Angles between grains in large-grain cavity surface give some information about geometry at large scales. An optical inspection system, such as described in [4] can be used to study these angles if they are distinguishable on optical inspection images. The system allows us to illuminate the surface from different angles and we can see that different grains reflect more light at certain angles. This information leads us to calculating angles between grains and to consequently make an estimate of surface roughness.

The method can be a quick supplement to optical inspection procedure. However, it can be used only on large-grain cavities, new or after BCP. The limitations are discussed at the end of the paper.

SURFACE MODEL

We use a simple model for cavity surface. We assume that the surface is made up from grains oriented at different angles to the surface plane. The grains are considered flat. You can see the 1D model of such a surface in Fig. 1. The surface roughness is determined by angles between grains and grain sizes. No special assumptions about angle and grain size distribution are made at this point.

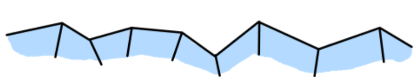

Figure 1: Surface model.

EXPERIMENTAL SETUP

The new TB9ACC015 cavity was installed onto the inspection system and moved to an equator region. The mirror tilt was adjusted so that the inspected area was aligned with the camera focus plane. We used a camera with 20 um resolution. That put a limit on the size of grains that could be distinguished and analyzed. In our case this minimum grain size is ~100 um.

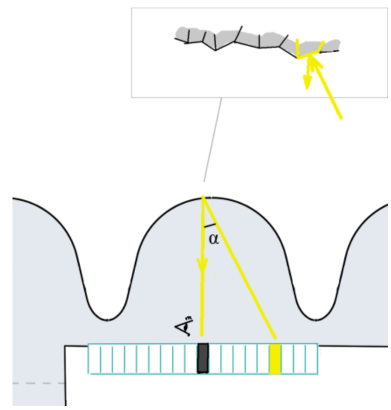

Figure 2: Experimental setup.

The system has 20 LED lights located at both sides of the camera aperture. We sequentially turned each of them on and off. The angle α ranged from -40 to 40 degrees (see Fig. 2.) Accordingly, angles of grains relative to the surface plane range approximately from -20 to 20 degrees. You can see grains at different angles in Fig. 3.

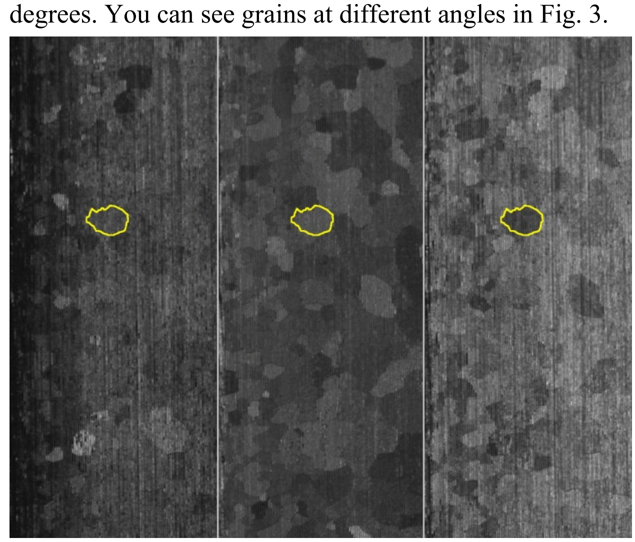

Figure 3: Snapshots for three different LEDs turned on. Grains have a peak in reflection at some angle (one grain is highlighted.) Vertical stripes are mechanical polishing artefacts.

IMAGE PROCESSING

A set of 20 images was acquired. The information that should be extracted from the images is the set of grain sizes and angles.

At first, we have to do image preprocessing. Brightness is aligned among images. The brightness differs due to different distances to the surface from a LED and reduced LEDs luminosity for large α angles. Next, it was necessary to remove the artefacts of mechanical polishing of the niobium sheet, which you can see in Fig. 3 as vertical stripes.

Grain Recognition

The second step is to separate grains in the image set. At this point it was performed manually by drawing borders around grains and labelling them. The grain mask is shown in Fig. 4a.

A much more sophisticated way to separate grains would be to automate grain recognition. Software would have to use information from the whole image set. A prototype method has been developed. It combines neighbour points into clusters that perform similarly (reflect light at the same angle). These "similarity" functions can be different. An example is the function defined as:

$$f(point1, point2) = \sum_k \left| i_k(point1) - i_k(point2) \right|$$

where i is intensity, k is the image number.

The prototype of the algorithm appeared to be very sensitive to noise, mostly to traces of vertical stripes discussed above. An example of the image mask it was able to generate is shown in Fig. 4b.

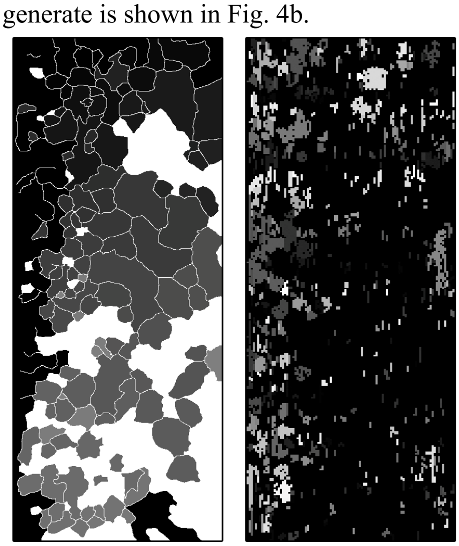

Figure 4: Grain mask. Each colour corresponds to a grain. (a) manually drawn mask; (b) automatically created mask.

Information Extraction

Once the grain mask is created it is possible to calculate the angle of every grain. Below is a plot of grain brightness vs. LED number for three different grains. Curves for some grains have a pronounced peak but others do not. For those curves that do have a peak we can calculate the peak position and, therefore, figure out the angle of the grain relative to the surface.

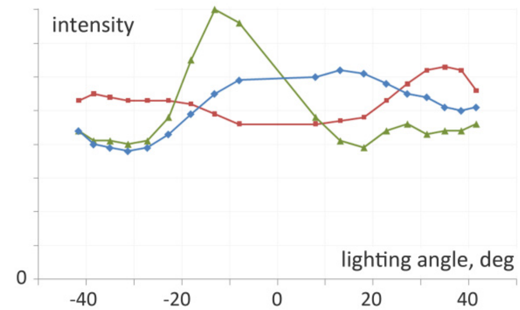

Figure 5: Typical intensity vs. angle plot.

Roughness Estimate

The model suggests that angles between grains account for surface roughness. However, the model could be a good surface approximation only for the scales of order of magnitude of grain size, which is in this case 100-1000 um. Roughness at scales of 1-100 microns would be more valuable information.

It could be possible to estimate roughness at that scales by using power spectral density approach (PSD). It was shown that PSD plot in double logarithm scale can be fitted by a line with the slope k different for BCP and EP processed surfaces [1]. If we could estimate PSD at scales of 100-500 um using the grain model, we would be able to calculate PSD at scales of 1-100 um.

RESULTS AND DISCUSSION

For one of the explored regions a grain mask was manually created as described above and 126 grains were labelled at this mask. Out of them, only 45 grains had one sharp peak. The angles relative to the surface plane and the diameters, which were defined as square root of grain area, were calculated for only these 45 grains (Fig. 6).

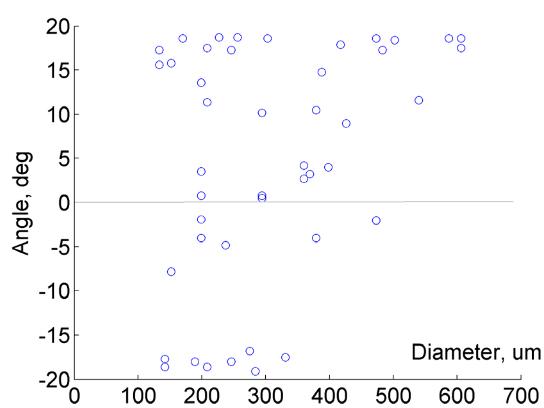

Figure 6: Diameter and angle distribution.

This plot is for one-dimensional surface profile. If we take into account that there is surface height gradient in the perpendicular direction, angles values become higher.

The points are not normally distributed across angles, as predicted for fine-grain surface [2]. Instead there are two clusters of points close to minimum and maximum angles. That suggests that there are grain angles higher than ±20 degrees and a wider range of illumination directions would be necessary to explore the surface.

Another concern is secondary reflection from cavity far surfaces. Light may reflect from the sides of a cell and produce wide peak at the intensity vs. angle plot (see Fig.5 for an example). Though it is often possible to distinguish direct and indirect reflections on curves, eliminating side reflections would increase the number of grains used in the analysis (here 45 out of 126) and produce more accurate results. Using polarisers or covering sides of cells with non-reflective material could be a solution to the problem.

The method is limited by camera resolution and can be applied only to large-grain surface. Therefore, angles can be estimated only for scales of 100-500 um. At the same time, grains with high angle variance can usually be met in BCPed cavities or in new cavities that did not undergo any material removal. In this analysis a newly-manufactured cavity was used.

To sum up, the method is a simple way to acquire information about grain angles distribution but is limited to estimating angles at 100-500 um scale for new and BCPed cavities.

REFERENCES

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