COMPUTER-AIDED RECONSTRUCTION OF THE CATHODE IMAGE IN HIGH CURRENT VACUUM ARC FROM THE RESULTS OF HIGH SPEED PHOTOGRAPHY

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Abstract- The images of the cathode, obtained by the method of high speed photography, are of ellipsoidal form as they are taken at the small (about 10 degrees) angle to the cathode surface. For this reason it is very difficult, if possible at all, to make conclusions about the spatial distribution of cathode spots and current density over the cathode surface. One can perform inverse parallel projection, but previously it is necessary to clean the image from the noise occurring from the plasma radiation and from other noise sources. In this paper we propose the method of image filtering, based on contours of equal intensity evaluation and subsequent estimation of the current density on the cathode.

1. INTRODUCTION

High speed photography (HSP) is a very powerful tool for investigation of time-history behavior of high current vacuum arcs. Unfortunately, the discharge geometry forces to take photos at small angles to the cathode surface, and the image of the cathode surface with spots is of ellipsoidal form with semiaxis ratio about 0.1. In simple cases with regular spots distribution (ring for example) it was possible to compute the parameters of the spots distribution [1]. If this distribution is more complicated it seems that one should make inverse parallel projection before doing any valuable conclusion about parameters of the spots distribution. Inverse parallel projection is possible if the center of projection and the angle of observation are known. These parameters are obtained from the image itself. In order to obtain them it is necessary to extract the cathode spots images from interelectrode plasma radiation. There are many evaluation-ready digital filters available for image filtering (MATLAB tools, for example), but the plasma radiation is inhomogeneous and the scale of this inhomogeneity is in the same range as the spots dimension. In other words, the spatial spectra of the signal (cathode spots image) and noise are overlapped. For this reason our attempts to use standard filters did not lead to valuable and reproducible results. So we were forced to devise the original technique of image filtering. In addition, it was necessary to develop the method of current density estimation from the cathode spots distribution. A lot of work was done for verification purposes with various scanner resolutions and filtering parameters in order to achieve repeatable results.

2. CATHODE SURFACE IMAGE FILTERING.

An example of the high speed photography cathode surface image is presented in Fig.1.The original photo was scanned with effective resolution about 800 dpi. One can see the cathode surface with spots at the bottom of the image. The anode surface (invisible) is at the top of the image and the interelectrode gap is 6 mm. One also can see the inhomogeneous plasma radiation, strongly masking the spots image. The goal is to remove plasma radiation, to estimate the position of the cathode center, semiaxis ratio and the angle between ellipsoid axis and x-axis of the image (which occurs in HSP and scanning processes) and to make the inverse parallel projection.

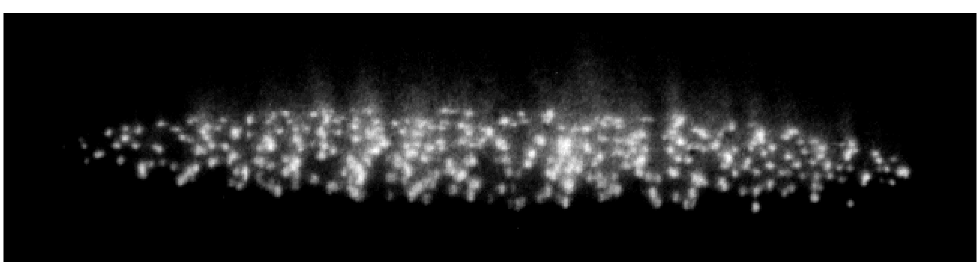

Fig.1. Cathode surface HSP shot.

As the first step we build the equal intensity contours of the image. Due to the high level of inhomogenuity of the image, the number of contours to be constructed is very big – about 20000. The filtering method is based on rejection or acceptance of the every individual contour in accordance with its length, intensity and relative positions of adjacent contours. The low spatial frequency part of plasma radiation produces the long opened contours, which we reject. The middle and high spatial frequency parts of plasma radiation produced, as a rule, the contours, which have few other contours within them and we also reject such a contour. Contours of very small length are produced mainly by graininess of photographic paper and film so they must be rejected too. Therefore we accept only systems of enclosed contours. The image of cathode surface can be conceived of the map of a mountainous country with contour lines. The procedure is that we only deal with areas of rather big local heights difference independent of their absolute height and reject to peaked mountains. The contours obtained from the image presented in Fig.1 are shown in Figs. 2,3 and 4,5 before and after contour filtering respectively.

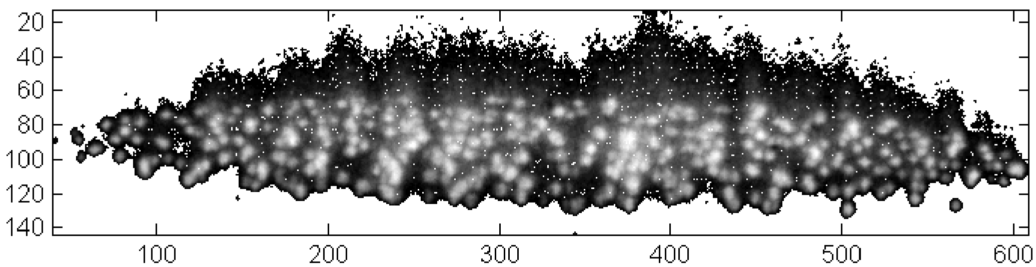

Fig.2. Equal intensity contours (~14500) of the image from Fig.1.
In this scale individual contours are invisible (see detail in Fig.3)

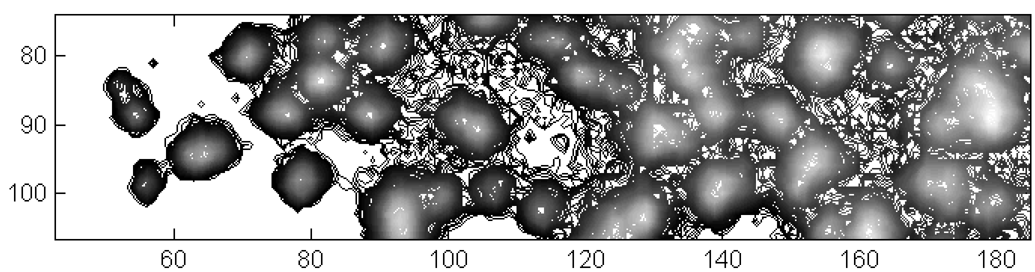

Fig.3 The detail of Fig.2 (left edge). Individual contours can be seen.

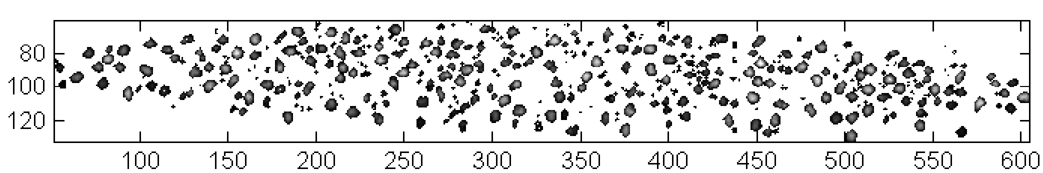

Fig.4. Accepted contours from Fig.2.

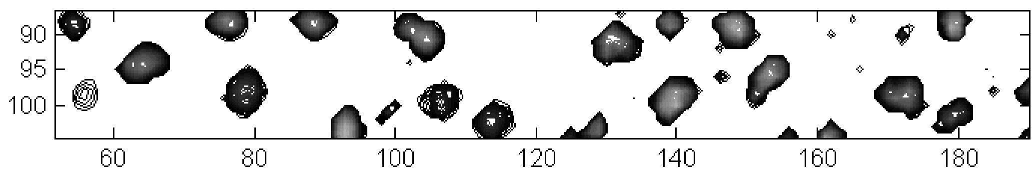

Fig.5. Accepted contours from Fig.3 (detail)

Every system of enclosed contours we associate with one cathode spot. The center of the smallest contour in the system is associated with the spot position. On the next step of image evaluation we build the convex hull of the spots centers and calculate the parameters of equivalent ellipsoid (which has the same moments as the convex hull). Then we rotate the image to adjust the major axis with x-direction, put the ellipsoid center into the origin and change the y-coordinates of spots centers in accordance with major to minor ellipsoids axis ratio. At the last step of inverse parallel projection we translate the system of contours, associated with spots to the new positions of their centers. Such a procedure means that we consider the spot radiation being of rather hemisphere than planar shape, so during inverse parallel projection we translate only the centers of spots radiation regions and leave the intensity contours unchanged. The result of inverse parallel projection of image shown in Fig.4 is presented in Fig.6.

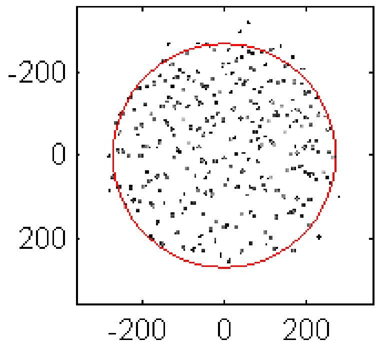

Fig.6. Reconstructed image of the cathode surface.

3. CURRENT DENSITY ESTIMATION

The current density may be estimated, for example, by counting the spots number in regions with the equal areas. But this procedure gives a very rough estimate. So we have proposed to use the procedure based on Delaunay triangulation and Voronoy diagram. The Voronoy diagram divides the plane into polygons each of which contains one of given points and consists of points for which the given point is the nearest neighbor.

After building the Voronoy diagram for cathode surface we can estimate the current density by dividing the spot intensity by the area of respective polygon. Such a procedure means that we consider the near-cathode plasma as consisting of columns with constant current density which shorts on respective cathode spot. When current density distribution is obtained for every shot, we make a movie of the discharge. In order to increase the spatial resolution we build the Voronoy diagram for spots from several subsequent shots and make a movie frame from it. The next frame is made from the same assembly of shots except the first shot is excluded and the new last shot is added (moving average ideology). The example of resulting cathode image is shown in Fig.6, where the image is averaged over 50 movie frames (1.25 ms).

4. VERIFICATION OF THE METHOD

We have delivered a series of test evaluations of images in order to make sure that the method resolves the image processing task adequately. The optimal values for some parameters in contour processing program were found. Also the optimal scanner resolution and film processing regimes were found. As a result we consider now that we can obtain the number of spots with the accuracy of approximately 5-10%. On the other hand the results have shown that it is desirable to obtain the ellipsoid parameters of the original image from the independent experiments because otherwise spatial resolution considerably decreases due to the drawbacks in these parameters, which lead to jitter of subsequent frames.

5. CONCLUSION

We consider that the proposed method of image filtering and processing allows us to estimate the cathode spots distribution and current density near cathode much more precisely than direct estimation from HSP shots. This method may be useful in other experiments where the two-dimension signal is masked with the noise which has the spatial spectrum overlapping with signal spectrum. The method of current density reconstruction in the cases when few regions with high current are nonuniformly distributed over cathode may be useful for other tasks as well.

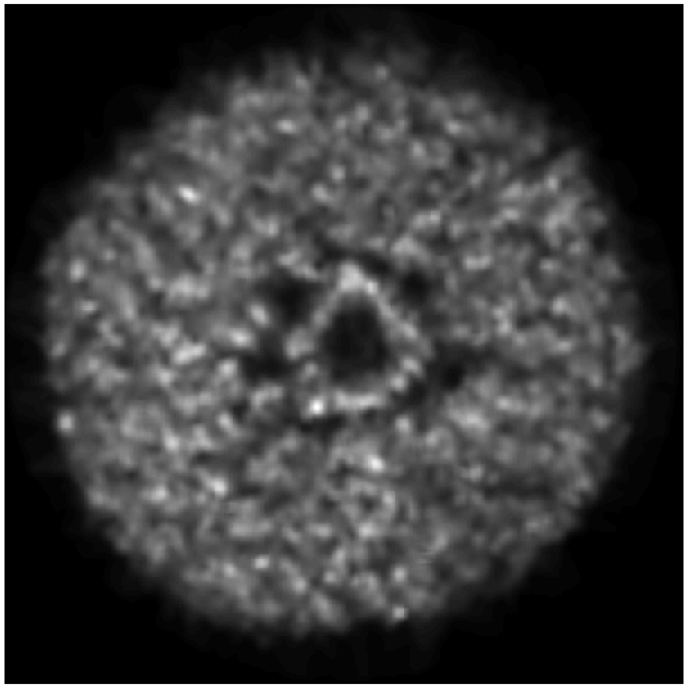

Fig.7. Near-cathode current density reconstruction, averaged over 50 movie frames (~1.25 ms). The hole in the center is a result of the technological hole in the center of the cathode.

REFERENCES

[1] J.C. Sherman, R. Webster, J.E. Jenkins and R. Holmes, “Cathode spot motion in high-current vacuum Arc on copper”, J.Phys.D: Appl.Phys., Vol.8, May 1975, p.p. 696-702.