BASELINE SUPPRESSION PROBLEMS FOR HIGH PRECISION MEASUREMENTS USING OPTICAL BEAM PROFILE MONITORS.*

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Abstract

The use of fluorescent screens (e.g. YAG screens) and Optical Transition Radiation (OTR) screens for beam profile monitors provides a simple and widely used way to obtain detailed two dimensional intensity maps. What makes this possible is the availability of relatively inexpensive CCD cameras. For high precision measurements many possible error contributions need to be considered that have to do with properties of the fluorescent screens and of the CCDs. Saturation effects, reflections within and outside the screen, non-linearities, radiation damage, etc are often mentioned. Here we concentrate on an error source less commonly described, namely erroneous baseline subtraction, which is particularly important when fitting projected images. We show computer simulations as well as measurement results having remarkable sensitivity of the fitted profile widths to even partial suppression of the profile baseline data, which often arises from large pixel-to-pixel variations at low intensity levels. Such inadvertent baseline data suppression is very easy to miss as it is usually not obvious when inspecting projected profiles. In this report we illustrate this effect and discuss possible algorithms to automate the detection of this problem as well as some possible corrective measures.

INTRODUCTION

There is a number of precautions required when extracting quantitative information from fluorescent or OTR screen images of beam profiles obtained with CCD cameras [1, 2]. Well known concerns have to do with response non-linearity, saturation and “blooming”.

Here we address a different problem that is often present, and rarely recognized. It has to do with the background levels in CCD images of beam spots. Such backgrounds can be due to low level diffuse light (e.g. from vacuum gauge filaments), CCD dark current, stray radiation, beam halos, etc. Usually, the brightness and contrast controls of the camera are used to largely suppress such backgrounds so as to retain the full dynamic range for the measurement of the beam profiles. This is often done while observing the summed or projected profiles, i.e. the intensity vs. channel number plots obtained by summing the pixel values in all the rows or all the columns of the CCD cells.

We will show how, for “noisy” backgrounds, this procedure can introduce fairly large systematic errors. Pixel-to pixel background fluctuations (noise) originates from a combination of photoelectron statistics, screen non-uniformities, CCD cell area variations, etc. When adjusting the zero level with the brightness and contrast controls, a fraction of these fluctuations is suppressed since the minimum value read out for each CCD cell is zero and not negative. This introduces a bias in the background level used when fitting the distributions e.g. with Gaussian functions to evaluate their widths and areas. What makes this problem so insidious is the fact that it is usually not detected when inspecting the summed profiles. While the values from a large fraction of the background pixels may have been suppressed (zero readouts), there is a sufficient number of positive values remaining to show an apparently safe (non-zero) background in the summed profiles.

In the following sections we analyze computer-generated profiles to illustrate the problem as well as actual data, and we suggest precautions and procedures to avoid this source of systematic errors.

COMPUTER MODEL SIMULATIONS

Data for a beam spot from a 500 ×500 pixel CCD camera were simulated with several different offsets that would normally be controlled by the brightness control of the camera. The peak amplitude was s 95% of the available range, and the standard deviation of each pixel intensity was set at 10% of that peak amplitude. A background level of 15% of the peak intensity was selected. Several offsets between 0% to 30% of full scale were studied. The results shown in Figs. 1 and 2 correspond to these two extremes. The plots closest to the beam spot picture are the summed profiles, and the ones further away are single rows or column of pixel values corresponding the peak of the two-dimensional intensity distribution. The indicated rms width values σx and σy were obtained by least square fitting with Gaussian functions.

While the summed profiles look acceptable in both cases, we see how the corresponding single pixel line profiles are being cut off at their base in Fig. 2. One would naturally tend to reduce the base level when seeing the high value in the summed profiles of Fig.1. By doing so using the brightness control one would bias the results as can be seen by the reduced width value in Fig. 2. The areas of the peaks, measuring total intensity are also affected. The width errors, as well as measured peak areas errors are plotted in Fig. 3 as function of zero offset values.

A better approach for reducing the background level in summed profiles is to limit the sums to regions of interest as indicated in Fig. 4. No bias is introduced in measured beam spot widths, and the areas are not affected as long

* Work supported by Brookhaven Science Associates, LLC under contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.
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as sufficiently wide regions are chosen. We see also that the summed spectrum points have smaller random errors since the information outside the region of interest is irrelevant, but contributes to the statistical fluctuations.

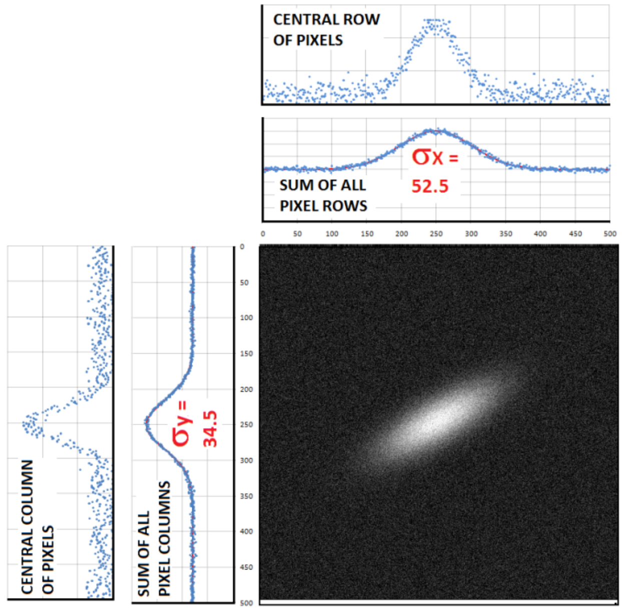

Figure 1: Simulated beam spot without background suppression. The indicated widths of the summed spectra were obtained by least squares Gaussian fits. The individual pixel rows and column intensity distributions show mostly non-zero values.

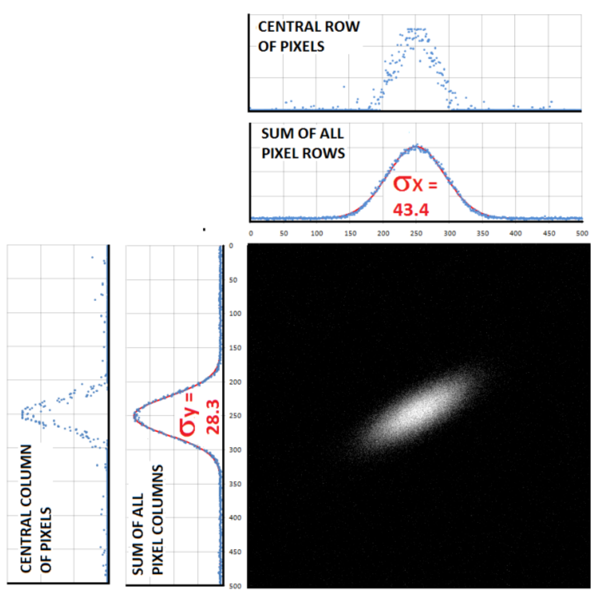

Figure 2: Simulated beam spot with strong background suppression. The indicated widths of the summed spectra were obtained by least squares Gaussian fits. The individual pixel rows and column intensity distributions show a large fraction of zero values indicating that the fitted baseline value will be severely biased. Note that the summed profiles look quite normal.

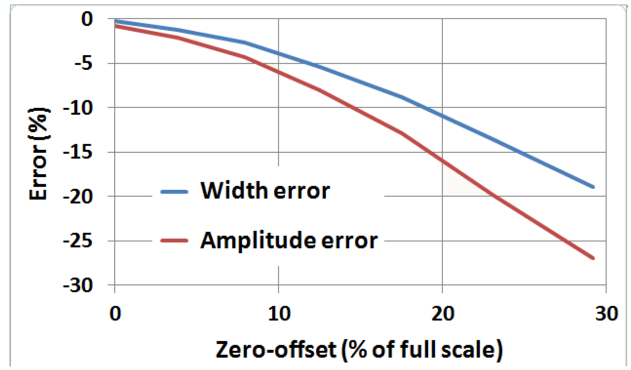

Figure 3: Summary of width and amplitude errors when fitting beam spot intensity distributions obtained with increasing zero-offset values. The same beam spot simulated in the previous figures was used.

The errors shown in Fig. 3 are of course only valid for the example studied here. Such errors will in general vary widely according to background levels and pixel value fluctuations. The point we wish to make here is that they can be substantial.

Both approaches; the use of regions of interest and background suppression through zero-level adjustment are often used together.

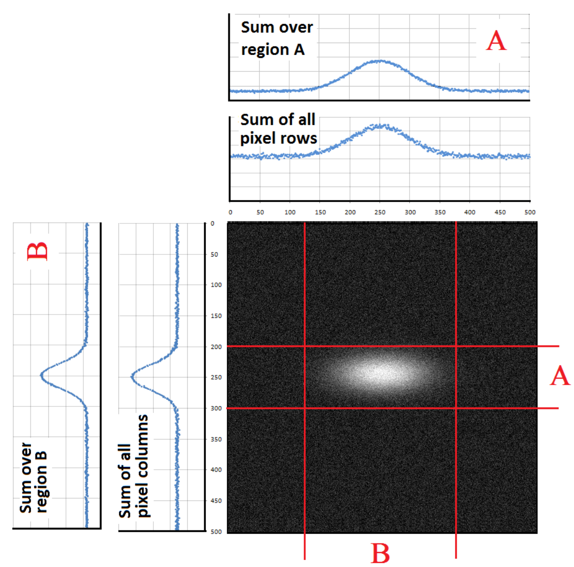

Figure 4: Simulated example of the use of regions of interest to obtain baseline and error reduction of the summed profiles

PROFILES OF A BEAM MEASURED WITH A RANGE OF ZERO OFFSETS

Figures 5, 6 and 7 show horizontal profiles [3] of the same beam obtained with progressively higher baselines. In the case of Fig. 5, the baseline suppression is clearly excessive. But that is not obvious in the case of Fig. 6

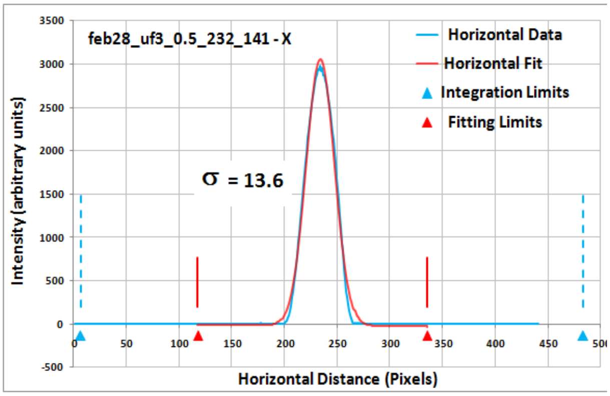

Figure 5: Horizontal beam profile obtained with a 10 GeV proton beam in the transport line from the AGS to RHIC [3]. In this case the zero suppression is clearly excessive.

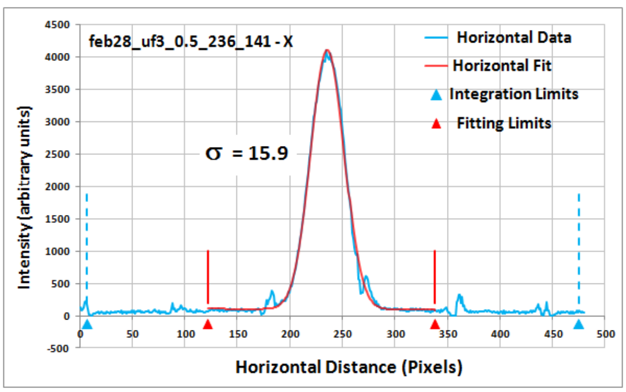

Figure 6: Horizontal profile of the same beam as in Fig. 5, but with less zero suppression. The zero suppression is still excessive but that is not obvious from this profile since all baseline values are above zero.

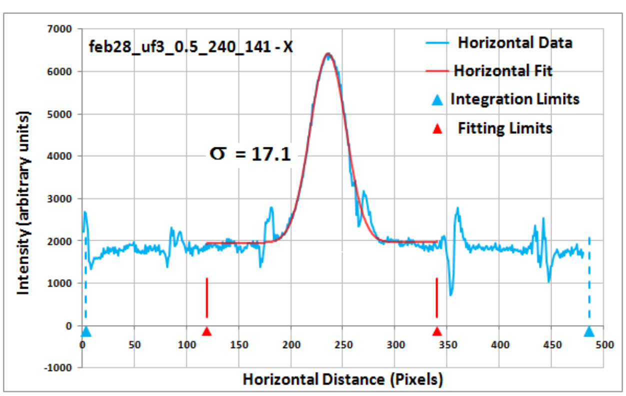

Figure 7: Horizontal profile of the same beam as in Figs. 5 and 6 but with yet less zero suppression. The irregularities in the baseline, due to a defective CCD, have little effect on the Gaussian fit. As can be seen from Fig. 8 (third point), this baseline elevation is in this case close to the minimum necessary to avoid significant width measurement errors.

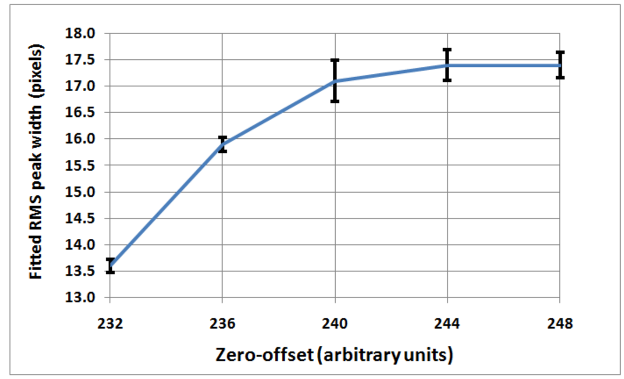

Figure 8: RMS beam spot widths obtained from Gaussian least-squares fits to data obtained with five different zero-offset settings.

since all the baseline values are above zero. Yet the fitted Gaussian widths keep increasing as seen in Fig. 8 where the first three points correspond to these three cases. In this example the beam width deduced from the data in Fig. 6 would be in error by about 8%.

CONCLUSIONS

We have shown how using the brightness and contrast controls of CCD cameras can lead to erroneous results when suppressing noisy backgrounds and how this situation is often not apparent when only monitoring the summed profiles. The problem is made worse by the fact that for many CCD cameras, it is not clear which settings correspond to no zero-level offsets.

Possible solutions could involve monitoring individual rows or columns of pixel values in addition to the sums, or using software to warn when too many pixel values are zero. Further data taking automation would be desirable to establish the regions of interest by detecting the peak location, and the approximate widths in both dimensions. The software could then check the background at some pre established range of distances away from the peak and automatically readjust the zero level if necessary. Finally, a two dimensional fit to the data will provide more information than fitting just the projections or sums along each axis. Many or all of these features are probably being used in various systems. Here we wanted to call special attention to the need to avoid excessive background suppression.

REFERENCES

[1] M.G. Minty and F. Zimmermann, Measurement and Control of Charged Particle Beams, Springer, 2003.

[2] P. Strehl, Beam Instrumentation and Diagnostics, Springer 2006.

[3] T. J. Shea, et. al. PAC97 Proceedings, pp. 2215