SINGLE PASS COLLIDER MEMO CN-366

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TITLE: LIMITS TO THE RESOLUTION OF BEAM SIZE
MEASUREMENT FROM FLUORESCENT SCREENS DUE
TO THE THICKNESS OF THE PHOSPHOR**

1. INTRODUCTION

The advent of fast TV image digitisation and analysis has created renewed interest in the use of fluorescent screens as an alternative to secondary-emitting wire arrays for the measurement of beam profiles of non-circulating particle beams. Their use at CERN for the antiproton source (AAC) and at SLAC for the SLC are just two examples ^{1,2}. In the late 1960's the screen material was usually activated zinc sulphide fixed to a metallic substrate with an inorganic binder. These screens suffered from radiation damage and their outgassing rates were incompatible with all but the crudest of vacuum systems. Various other materials, ranging from quartz to sapphire and ruby, have been used to overcome these defects³, but the two most common materials remaining in use are: chrome-activated alumina, produced electrochemically (LBL and SLAC) or as a ceramic (CERN), and activated Gadolinium Oxide (SLAC) as used by TV tube manufacturers.

At CERN the screens are in the form of thin (1 to 2 mm) ceramic plates, often up to 400 cm² in area, but more generally around 100 cm². A thick-film resistive ink, developed for hybrid circuit manufacture, is used to print graticules and identification marks onto the screens.

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This ink is glass based and, after firing at a few hundred degrees centigrade, is UHV compatible and highly resistant to radiation.

The fluorescence has the characteristic ruby emission spectrum with a peak at 690 nm. The widths of the spectral lines have not been measured. The ceramic fabrication and firing techniques have been selectively developed to give a fine-grain structure which exhibits little thermal quenching of the fluorescence below 400° C. In addition this material has particularly good thermal shock resistance and at CERN screens have withstood months of use, with no loss of performance, in proton fluxes of up to $1 \times 10^{12} \text{ pmm}^{-2} \text{ s}^{-1}$ and have withstood for shorter periods beams five times more intense.

2. TILTED SCREENS

This phosphor is one of most sensitive of present-day screen materials and for some low-flux applications advantage has been taken of it's semi-transparent nature (extinction coefficient below 1 mm^{-1}) to extend the overall sensitivity by using thicker screens. However, this causes some loss of spatial resolution due to the increased depth of field and, more important, broadening of the image on screens that are not mounted and viewed orthogonal to the beam axis (e.g. by using a mirror with a hole through which the beam passes). Image broadening is particularly important at the SLC where the beam sizes are of the same magnitude as the screen thickness and where the screens are tilted at up to 60 deg. from normal incidence in order to enhance the spot size. The SLC geometry is illustrated in Figure 1a. This is more favorable than the CERN/AAC geometry, Figure 1b.

Fig. 1a

Fig. 1b

The beam spot broadening has been calculated by numerically integrating the image through the depth of the phosphor along the major axis of a Gaussian beam. For the SLC geometry this amounts to integrating the expression:

$$I(x) = \int_0^t e^{-\left[\frac{(x \cos \theta + t \sin \theta)^2}{2\sigma^2} + at\right]} dt \quad (1)$$

over the geometrical limits of the parallelogram-shaped region of fluorescence.

where:

t = depth within phosphor

a = optical extinction coefficient of phosphor averaged over the emission spectrum

σ = beam sigma in plane of diagram

θ = tilt of screen from the orthogonal position

Some results of these computations are presented in Figures 2 to 7 for various combinations of beam size and screen thickness. Each figure shows the

observed profiles for two values of the phosphor extinction coefficient: 1 mm^{-1} , corresponding to the chrome-activated alumina, and 25 mm^{-1} - a much more opaque phosphor. A constant specific luminescence has been used throughout. Alongside each curve representing the observed profile is a dashed curve showing how the beam would look on a screen of zero depth. To aid comparison these ideal curves have been normalised to the same peak heights as the real profiles.

The image of a narrow beam on a thick inclined screen (Figure 2) exhibits considerable broadening of the spot profile and distortion (a sloping 'top ') caused by the attenuation of fluorescence from within the screen. In contrast a 0.1 mm beam on a 0.025 mm screen (Figure 3) is only slightly misrepresented.

A reasonable thickness for the ceramic screens would be 0.1 mm. The supplier* has in the past produced screens of up to 100 mm^2 with this thickness. Figures 4 to 7 illustrate the relative broadening that would then be seen for beams from 0.1 to 0.01 mm (one sigma values). The integration has been made between the limits ± 3 sigma, and so two parameters of the beam spot profile can be identified: the r.m.s width (second moment) and the full-width corresponding to the 3-sigma limits of the incident beam. Both of these dimensions are sensitive to screen thickness, the latter more than the former, and in Figure 8 they are plotted as percentage broadening of the 1-sigma and 3-sigma beam sizes. For a given screen, these errors can be calculated with fair precision, the uncertainties being in the overall system linearity and the level at which to make the contour cut. This will depend on the system sensitivity. A first order correction based on a calculation of this type would appear to permit width measurement to within a few percent for beams of 0.1 mm and above, to about 10% at a beam sigma of 0.02 mm.

3. DEPTH OF FIELD LIMITATIONS

There is additional image broadening from thick screens, even those viewed

at normal incidence, which arises from the need for magnification in the camera optics. For example a lens of 135 mm focal length used at a magnification of 2 with an aperture 1:8 will, if focused onto the front surface of the screen, broaden a point image from the rear of the screen by: $0.04 \times t$ mm, where t is the screen thickness in mm. For a 0.1 mm screen this effect is negligible for Gaussian spots of sigma greater than 0.01 mm. It will only become important if much greater magnification is used.

4. REFERENCES

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*Morgan Matroc Ltd., Anderman Division, U.K.

Fig. 2

Fig. 3

FLUORESCENT SCREEN - BEAM SPOT DEFORMATION

Beam sigma (mm)= .1 Screen depth (mm)= .1 Tilt (deg.)= 60

Fig. 4

FLUORESCENT SCREEN - BEAM SPOT DEFORMATION

Beam sigma (mm)= .03 Screen depth (mm)= .1 Tilt (deg.)= 60

Fig. 5

FLUORESCENT SCREEN - BEAM SPOT DEFORMATION

Beam sigma (mm)= .02 Screen depth (mm)= .1 Tilt (deg.)= 60

Fig. 6

FLUORESCENT SCREEN - BEAM SPOT DEFORMATION

Beam sigma (mm)= .01 Screen depth (mm)= .1 Tilt (deg.)= 60

Fig. 7

PERCENTAGE SPOT BROADENING VERSUS BEAM SIGMA

Fig. 8