# AN OPTICAL BEAM SIZE MONITOR FOR ADONE

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## Abstract

The transverse beam size monitor built for the ADONE storage ring is presented. The monitor is composed by an imaging optical system, a commercial CCD TV camera as detector and an electronic circuit to measure the beam dimensions. A description of the optical system and its performances with extended source is given.The performances of the CCD based detector and the bloc schematic of the electronic are briefly described.

## The imaging system

The storage ring Adone in the Laboratori Nazionali di Frascati of INFN recently reverted to two beams $e^+ e^-$ operation and a new diagnostic system for the positron beam had to be done.

A new vacuum chamber with two output ports looking at symmetrical points with respect to the middle of a bending magnet was installed. The synchrotron radiation from $e^+ e^-$ beam hits the 45° metallic mirrors at the ends of the port noses and is reflected through the windows towards the diagnostic devices on the optical benches.

### The optical system

The optical system is mainly aimed at:

1) imaging the source on a suitable detector.
2) limiting the field view to avoid image smearing due to transverse and longitudinal beam motion.

The source point inside the vacuum chamber is $\approx 2.4\,m$ away from the exit window, so the optic elements have to be located rather far from the source. An iris of radius $w$ at distance $d$ from it defines the view limits tangent to the orbit arc between the angles $\pm\theta_0 = w/d$ [1]. It limits the apparent radial extention of a pointlike source to

$$\delta x = \rho(1-\cos\theta_0) \approx \rho\theta^2/2 = \rho w^2/2d^2 \qquad (1)$$

The iris defines in this way also the longitudinal extention of the source which should be within the field depth of the optical system. Actually the emission points extend behind $\theta_0$ both because of the angular opening of the emission cone and because transverse orbit displacements result in longitudinal displacements of the source observed through the iris [2], as shown in fig.1.

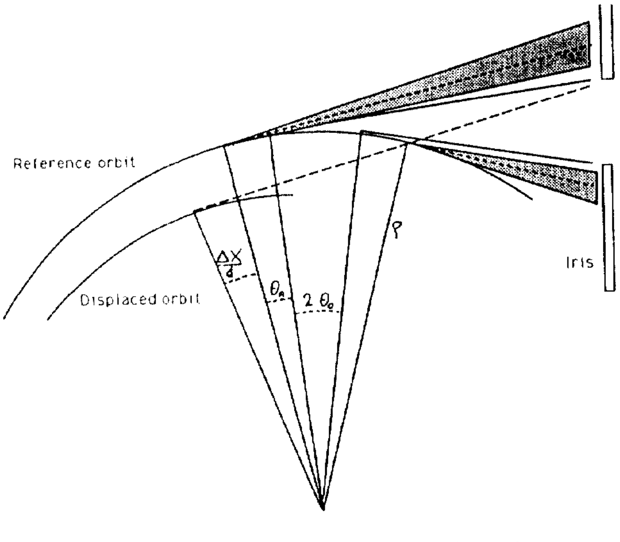

*Fig. 1 - Schematic of beam imaging with synchrotron radiation (top view).*

In Adone at the observation point $\sigma_x, \sigma_z \approx 0.5\,mm$ or larger so the resolution of $0.1\,mm$ is sufficient for a detailed measurement of the source.

Assuming $\delta x = 0.1\,mm$, $\rho = 5\,m$ from eq. (1) results

$$w < \sqrt{\frac{2\delta x d^2}{\rho}} = 15 \cdot 10^{-3}\,m \qquad (2)$$

A tighter constrain will apply to the iris opening to get the required field depth.

Usually the requirement 1) is fulfilled choosing an imaging ratio 1:1. Therefore the horizontal resolution of the detector must be $\approx 0.1\,mm$ which is well within the performances of standard CCD. However higher resolution could not be exploited if image blurring is not reduced to less than $0.1\,mm$.

Since the vacuum chamber pipe fixes $\overline{S_0 L} > 2.40\,m$ the same distance is required from a single lens system to the 1:1 imaging plane. In order to fit the optical bench size to the small room available around the storage ring a reduced optical path has been realized with a doublet of lenses of focal length $f_1 = .20\,m$ and $f_2 = -.10\,m$.

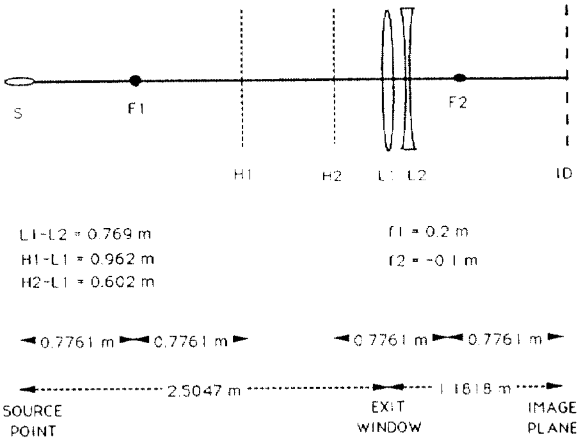

*Fig. 2 - Schematic of beam imaging with a lens doublet.*

A doublet of thin lenses $L_1$ and $L_2$, of focal length $f_1$ and $f_2$, at distance $d$ in air has focal length

$$f = \frac{f_1 f_2}{f_1 + f_2 - d} \qquad (3)$$

and the principal planes $H$ and $H'$ move nearest to the object and image points (see fig. 2). Assuming $\overline{S_0 L_1} = 2.50\,m$ and $f_1 = .20\,m$ and $f_2 = -.10\,m$ simple geometrical optical calculations give $d = .1261\,m$ and $f = .769\,m$. The distance between $L_2$ and $I_D$ is $\overline{L_2 F'} + f = 1.052\,m$. The distance between the first lens and the image plane is reduced to $\approx 1.2\,m$, simplifying the optical set up and alignment. Moreover, varying the lens separation it is possible to move the image plane position for best focusing, at expense of a different image magnification factor. This proved to be an useful tool since the access in Adone with the stored beam is strictly controlled and long setting procedures would not be possible.

The worst known parameter is the distance $\overline{S_0L_1}$, which depends on the inside vacuum mirror tilting and on the displacement between real and design orbit. The lens doublet is more sensitive than single lens to this parameter. The magnification factor $M = \overline{S_0F}/f$ and the image plane displacement $\Delta I_0$ are derived as a function of the distance $\overline{S_0L_1}$. The plots obtained assuming a doublet optimized for 1:1 imaging at $\overline{S_0L_1} = 2.5\,m$ are shown in fig. 3.

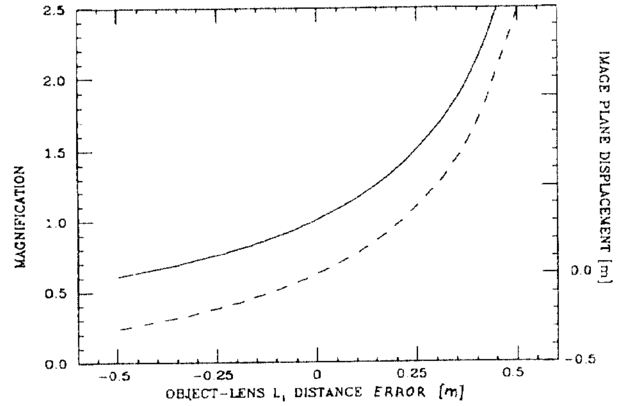

*Fig. 3 - Magnification factor M (continuous line) and image plane displacement $\Delta I_0$ (dashed line) vs distance error $\Delta\overline{S_0L_1}$*

### The quality of imaging

The field depth of a $\approx 1:1$ imaging system with long focal length is very small. The longitudinal extention of the observed field must be estimated taking into account the widening beyond $\theta_0$

The angular opening $\pm\theta_R$ of the radiation emission at constant wavelength below the critical frequency $\omega_c$ is independent of the energy [3]

$$\theta_R \approx \frac{1}{\gamma}\left(\frac{\omega_c}{\omega}\right)^{\frac{1}{3}} = \left(\frac{3c}{\rho\omega}\right)^{\frac{1}{3}} \tag{4}$$

In Adone at $\lambda = 6000\,A$ it is $\theta_R = 3.8\,mrad$ which is not negligible with respect to the iris limited arc $\theta_0 = \pm 6\,mrad$.

To estimate the effect of transverse displacement consider the reference trajectory, whose tangent in the azimuthal point $\theta = 0$ points to the center of the iris, and a parallel trajectory displaced by $\Delta x$. The slope of the line passing through the iris and tangent to the latter trajectory is $m = -\Delta x/d$. The source point is longitudinally displaced by

$$\Delta y = -\rho\Delta x/d \tag{5}$$

Since $\rho = 5\,m$ and $d = 2.5\,m$ a magnification factor 2 results between transverse and longitudinal displacement of the source.

The overall arc length $\Delta s$ which contributes to the image formation according to (1), (4) and (5), is

$$\Delta s = \pm\rho(\theta_R + \theta_0 + \Delta x/d) \tag{6}$$

The diffraction limits the value of $\theta_0$ to

$$\theta_0 > 2\lambda/\delta x \approx 3\,mrad \quad \rightarrow \quad w \approx 7.5\,mm \tag{7}$$

The depth of field is related to the iris radius $w$ and the confusion radius $r$ of a badly focused image of a pointlike source by

$$r = |(w\Delta s)/(2f - \Delta s)| \tag{8}$$

Assuming $\theta_0 = 3\,mrad$ and $\Delta x = 5\,mm$ the eq. (6) gives $\Delta s = 17\,mm$. The confusion radius according to eq.(8) is $960\,\mu m$ which is compatible with the assumed allowable error.

## The image detector

The final set up of this beam monitor will include two CCD cameras for each line optimized for beam behaviour observations at larger field and detailed profile analysis at smaller field.

The former camera is already operating providing through standard f=50/1:2 optics a satisfactorily picture of beam focused on a screen. The latter will be placed in the image plane and directly hit by the radiation; this will push the resolution up to the pixel size $\approx 25\mu m$ and the sensitivity will be increased providing good picture at beam current $< 100\mu A$. Since Adone operates with different orbit corrections to satisfy user requirements this set up needs an active pointing system, now under development, to keep the image within the CCD area.

However, the intrinsically high sensitivity and resolution of CCD ensures that the video signal from the existing camera provides an useful input for the following circuits.

The 'optics + TV camera' magnification is easily carried out by changing the RF frequency of the ring causing a radial beam displacement

$$\Delta x = \frac{\psi}{\alpha_c}\frac{\Delta f}{f} \tag{9}$$

where $\psi$ is the dispersion function at the observation point and $\alpha_c$ is the momentum compaction.

## The electronic circuits

The beam profile is obtained analysing the light spot during the scanning of one of two TV half-frames. At present stage vertical and horizontal profile are extracted with different technique.

The vertical profile is given by the envelope of the peak intensity along the lines (i.e. it is a projection of the 2-D intensity image on the vertical plane); the horizontal profile is given by the intensity along a line near the peak (i.e. it is a section near the peak of the 2-D image).

The vertical profile is obtained by a peak detector-&-hold to keep the maximum along every line and an envelope hold which keeps the level caught in the former line until updated by the next line (see upper part of fig. 4).

A similar technique is used to record the peak intensity in the whole frame. The horizontal profile is extracted when the line peak is approaching 95% of the frame peak (see lower part of fig. 4).

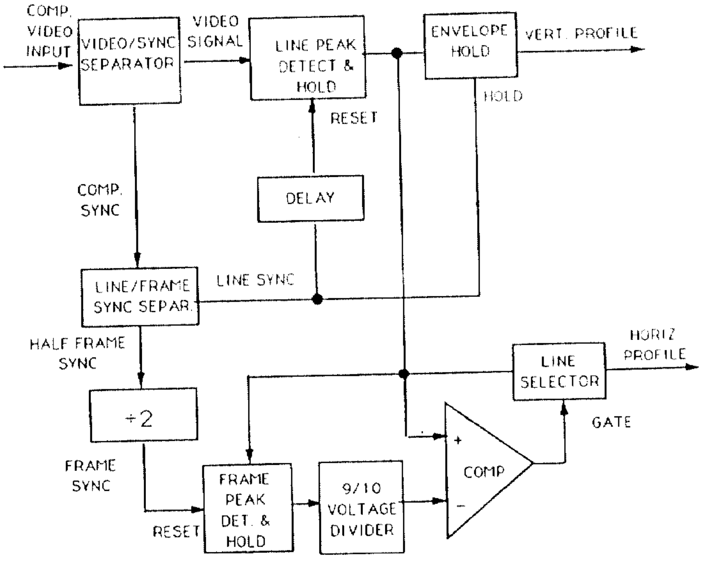

*Fig. 4 - Bloc schematic of the circuits for vertical and horizontal profile.*

The main drawback is that only a half-frame is used in vertical scanning, thus halving the intrinsic resolution of the CCD detector; moreover a different timescale is required for horizontal and vertical scanning.

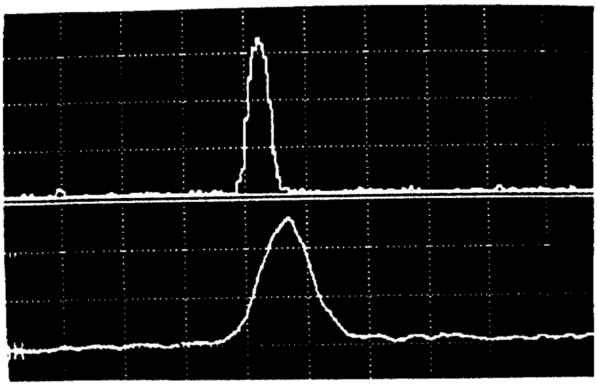

*Fig. 5 - Beam profiles obtained with vertical (upper trace) and horizontal (lower trace) scanning of video signal (scale 1 mm/div).*

A new circuit is under development to digitize the video signal and interpolate of the data from two half-frame. The same timescale con be used when displaying the profiles through a DAC output.

The vertical and radial shapes of a beam obtained with the existing set up is shown in fig. 5. The profiles have been obtained with a digitizing oscilloscope at different timebases, corresponding to the same spatial scale for vertical and radial scanning.

## Acknowledgement

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## References

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[2] D.W.L. Tolfree,'Syncrotron light monitors for use in storage ring and booster,' SRS/NS/76/79
[3] D. Jackson, 'Classical Electrodynamics'