COMPUTERIZED TREATMENT OF IONIZATION BEAM SCANNER (IBS) SIGNALS

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Abstract

Data acquisition and treatment of IBS profiles are used to improve precision of beam size measurements by applying corrections for instrumental broadening and for errors due to the beam space-charge potential.

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The CPS Ionization Beam Scanner (IBS) is an electron-optical crossed-field beam scanner deriving its signal from the electrons liberated by ionization of residual gas in the beam vacuum chamber$^{1)}$. The proton beam is scanned in such a way that the electrons collected at any instant come from a slice of the beam close to the equipotential of the collector. This equipotential is driven through the beam to give, in time, an electrical signal proportional to the projected proton density distribution in a certain plane.

In order to gain maximum benefit from the use of this device in machine studies, e.g. those on circulating beam emittance evolution, and to facilitate calibration, including various instrumental corrections, a prototype data acquisition system has been built$^{2)}$.

Data Acquisition

This is essentially an ADC which measures sequentially points on the IBS profiles and stores them in 10 bit buffer memories prior to transmission by the STAR system to the IBM 1800 computer$^{3)}$. In its present form the system samples 32 points of a selected beam profile in an overall time of 0.5 to 1.0 ms, as required. This permits a beam scanning frequency of 300 Hz. Two profiles per machine cycle are acquired and also a voltage signal from the IBS. This is related to the position of the collector equipotential and is used for the spatial calibration.

Calibration

The IBS spatial calibration can be made either by careful measurement of its electrical parameters, or by producing a known beam closed orbit displacement of, say, ± 10 mm, which implies Q measurement in both planes, and comparing this to the observed shift in the IBS signal. Both methods have been used in these studies. The closed orbit displacement is known to 2% and gives a calibration within 3% of that obtained from the electrical parameters. Over a period of three months these calibrations have varied by less than 2%.

Data Treatment

Together with the IBS profiles, corresponding mean radial position and beam current Ip values, are acquired by the IBM 1800. At each request for IBS data, 10 PS pulses are measured and limits set for Ip, outside which subsequent pulses are rejected (in future a moving average of Ip will be used for this purpose). Then the preselected IBS profiles are acquired and summed over ten good pulses. This removes noise due to statistical fluctuations of the profiles when operating at low gas pressures (below 5.10^{-7} Torr). On-line data treatment provides for the user a display of selected beam profile parameters. Although this facility was used initially for this work, most of our results have been achieved by off-line treatment of the data (via punched card output) in the CERN CDC computer. This gave us greater software flexibility. Although the 1st, 2nd and 3rd moments of the IBS profiles are readily calculated from the 32 measured points, giving respectively: position, width and a measure of skewness, these simple operations, particularly for the higher moments, are very sensitive to non-zero base-line slope and other tail errors. In order to overcome some of these difficulties, the following procedure was used. Curve fitting using polynomials was applied to obtain the best fit to the measured points. Standard deviations, σ, were then calculated for the complete curve and also for those portions within certain limits set by the intercepts with the curve of thresholds at 4%, 6%, 8% and 10% of the peak height. This was done with the purpose of finding a beam size parameter which was not too dependent on the tails of the distributions.

That the measured profiles were often close to Gaussian is shown for a typical case in Table I, where the measured values of σ for different thresholds are corrected to the values for zero threshold by applying Gaussian correction terms. For a Gaussian profile the second row of figures should all agree, and this is nearly the case.

Table I

Threshold	0%	4%	6%	8%	10%
$\sigma_{(mm)}$ calculated within limits, see text	2.405	2.310	2.274	2.243	2.208
$\sigma_{(mm)}$ for full curve: Gaussian correction	2.405	2.411	2.418	2.429	2.434
$\sigma_{(mm)}$ after unfolding instr. broadening	2.35	2.36	2.37	2.38	2.38

Comparison of IBS Profiles with Target Data

Beam size measurements by targets were made by removing various percentages of the beam between 5% and 30%. Two targets approaching the beam from opposite sides and with a variable spacing were used for these measurements$^{4)}$. Assuming Gaussian proton distributions one can relate target losses to beam dimensions. Here we have calculated σ of the projected distribution, as measured by the IBS, and the results for the beam already treated in Table I are given in Table II. The agreement between IBS and target results in this case is good to 1%.

Table II

Proton loss on targets* %	σ (mm) for projected proton distribution
4.6	2.64
8.1	2.10
13.3	2.29
22.9	2.33
30.9	2.33

* The precision of these measurements increases with the percentage removed by targets

IBS Instrumental Broadening

The IBS spatial resolution is fixed by the potential difference across two plates at the entrance to the collector electron multiplier. This gives rise to a potential interval on either side of the collector equipotential and electrons originating within this interval may reach the collector. Due to the cycloid form of the electron trajectories, some electrons starting near to one or other of the potential limits can strike the collector plates and be collimated out.

Another factor influencing the spatial resolution is the distribution of velocities of the primary electrons created in the ionization process. The overall effect of the initial electron velocity distribution is to increase the cycloid radii so that some electrons starting well within the potential limits may be collimated out. Thus the IBS collector has an entrance slit with non-uniform transparency. Note that the spatial resolution is increased by this effect since the effective slit width becomes less. The exact slit transparency depends on IBS parameters and the initial electron energy distribution. Since the latter is not known exactly, in Fig. 1 we give examples of slit transparencies calculated for an energy distribution varying as $1/E^2$ where E is the energy.

Fig. 1 Slit transparencies for two values of slit width

Fig. 2 IBS profiles of pencil beam for different slit widths, normalized to equal areas

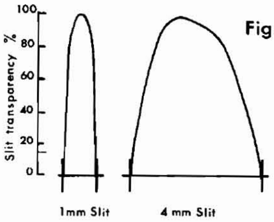

Fig. 1

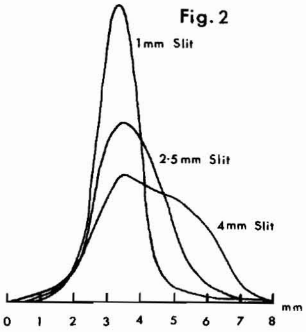

Fig. 2

In the PS we have made a simple experiment to check this. A highly collimated debunched beam with a vertical size of about 1 mm was produced by target collimation on a "flat-top" at 10 GeV/c. The vertical IBS profiles obtained from this beam for various slit widths are shown in Fig. 2. For large slits the shapes of the curves approximate to the slit transparencies since the beam dimension is small. Using this information we are able to unfold true beam profiles from experimental profiles by means of fast Fourier transforms, although if we are only concerned with the simple moments of the distribution these can be unfolded using standard analytical formulae.

Effects of Beam Space Charge

When working with high intensity beams the self potential due to the beam deforms the electric field within the IBS. This effect has been investigated by numerical calculation using the CERN CDC computer. The computation made is as follows: for the actual IBS electrode structure and the true beam distribution the electrical potential is solved using fast Fourier transform techniques5). One example for an unbunched beam of 10^{13} protons in the CPS is shown in Fig. 3. This is equivalent to the instantaneous condition at the bunch centre for 1.7×10^{12} p with a bunching factor of 5.7 (the present 10 GeV/c operating conditions of the PS). A simulation of the IBS collection process using many electrons distributed in 4D phase space and in time gives information on the space charge perturbation.

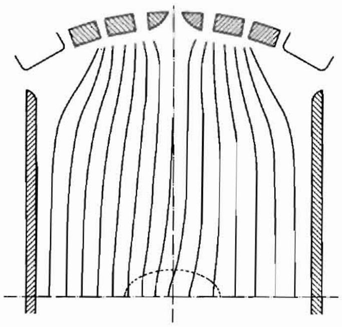

Fig. 3

IBS EQUIPOTENTIALS WITH BEAM : 10^{13} PROTONS

These computations, which are confirmed by experiments, show that the effect of an unbunched proton beam is to produce odd-moment deformations; principally a shift in position and skewness. Here the calculations accurately predict the observed effects. Second-moment errors are in all practical cases negligible. However, bunching of the proton beam is shown to affect also the even moments of the profiles and thus to change the σ. Enlargement of IBS profiles due to bunching has been observed and can be well understood on the basis of the calculations. Using these results a procedure can be adopted in the data treatment to restore the beam profiles. If the IBS parameters are set so as to limit these profile errors to a few percent, with such a treatment it should be possible to define and to measure beam sizes to 0.1 mm.

Future developments include faster acquisition, improved baseline restoration and increased electric field strength for higher beam intensities.

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