The Micron Wire Scanner at the SPS

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Summary

Fast wire scanners have been used for some time to measure the transverse emittance of circulating beams in the SPS over a wide range of intensities for both fixed-target and collider operation 1], 2]. The precision obtained with these devices is of the order of a few percent for the emittance and a few tenths of a millimeter for the beam centre. Although in general this is quite adequate, in the particular case of the proton-antiproton collider operation of the SPS it is desirable to improve the precision substantially in order to measure slow phenomena such as intrabeam scattering or beam cooling over a reasonably small time interval. In order to achieve this, a new wire scanner has been developed, based on a linear movement instead of the rotating mechanism used previously. The device moves a 30 μm carbon fibre through the beam at a speed of 0.3 $m.s^{-1}$, an order of magnitude slower than normally used for the fast wire scanners. The position of the fibre at any time is measured with a high precision linear optical transducer with an accuracy of 4 μm.

Due to the slow speed and consequent heating of the wire by the beam the use of the device is limited to the relatively low intensity of the collider. However, it has been found that the temperature rise of the fibre is smaller than expected. This effect has tentatively been explained by the fact that electrons leaving the fibre take a non-negligible part of the deposited energy with them.

Mechanical Considerations

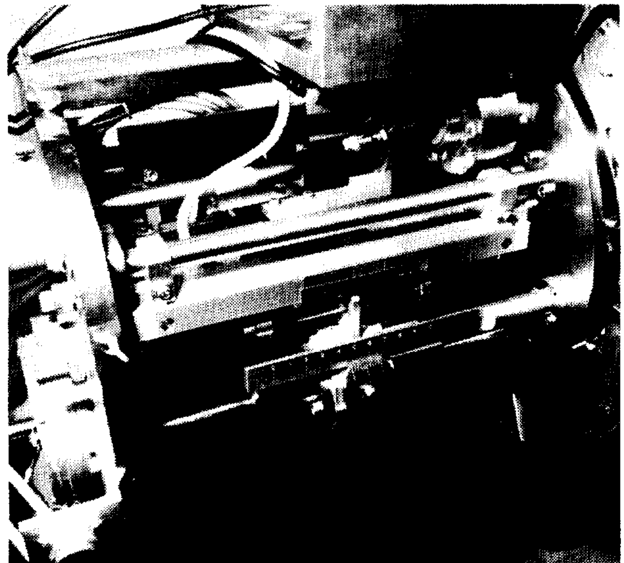
The linear drive (fig. 1) was based on a standard existing SPS mechanism, normally used for moving much heavier objects. Therefore the speed was limited to 0.3 $m.s^{-1}$ although a speed of up to 1 $m.s^{-1}$ would easily be possible with a mechanism designed specifically for that purpose. The stroke is 90 mm.

The 30 micron carbon fibre is mounted on a fork with a gap of 40 mm. This gives much less problems of wire vibration than that encountered with the fast scanners, where the wires are 140 mm long.

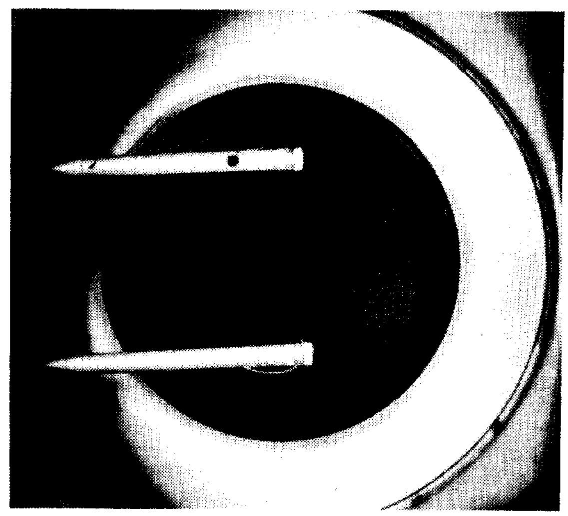
The position of the fibre is measured using a high precision linear transducer produced by HEIDENHAIN. 3]. A glass rod with rulings every 20 μm is scanned with the help of a light emitting diode and detector (fig.2). As the rod moves the detector counts light pulses, giving a measurement of instantaneous position with a precision of 4 μm. A reference mark is also coded onto the glass rod which allows the absolute spatial position to be fixed.

Acquisition System

The beam profile is acquired in an identical way to that used for the fast wire scanners 2]. Two scintillators placed close to the beam pipe and downstream of the wire in both proton and antiproton directions intercept high energy secondary particles emitted from the wire by the impact of the beam. Photomultipliers connected to the scintillators emit pulses proportional to the instantaneous bunch intensity.



a)



b)

Fig. 1 a) The linear drive mechanism
b) Inside the vacuum tank

These pulses are digitised with a 10 bit ADC and stored in a memory together with the instantaneous position measured from the linear transducer. On each revolution of the proton or antiproton bunch the wire moves about 7 μm, allowing a very precise profile to be built up. The acquisition system is shown schematically in fig. 3.

Heating of the wire

The expression normally used to compute the temperature rise in the wire due to heating by the beam is 2].

$$\Delta T = 3.8 \times 10^{-18} N \frac{dE}{dx} \cdot \frac{f}{V.h_{eff} \cdot S} \qquad (1)$$

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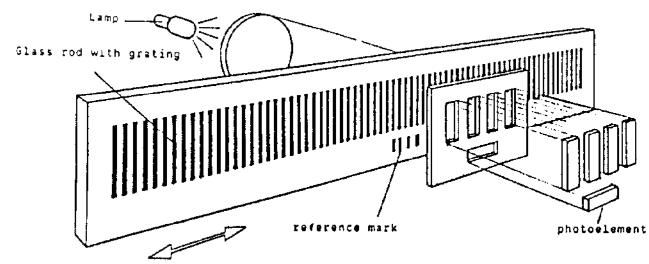

Fig. 2 Schematic drawing of the high precision linear transducer used for the wire scanner (copied from Numerische Positionanzeigen, Heidenhain, D-8225 Trauneut).

where dE/dx is the energy loss (1.78 MeV/(g/cm²)), N is the number of particles in the machine, f the revolution frequency (43 kHz), V the wire speed ($0.3\ m.s^{-1}$), S the specific heat of carbon (0.45 cal. $g^{-1}\ °C^{-1}$ at high temperature) and h_{eff} is the effective beam height (m) ($h_{eff} = \sqrt{2\pi}\ \sigma_y$ for a Gaussian).

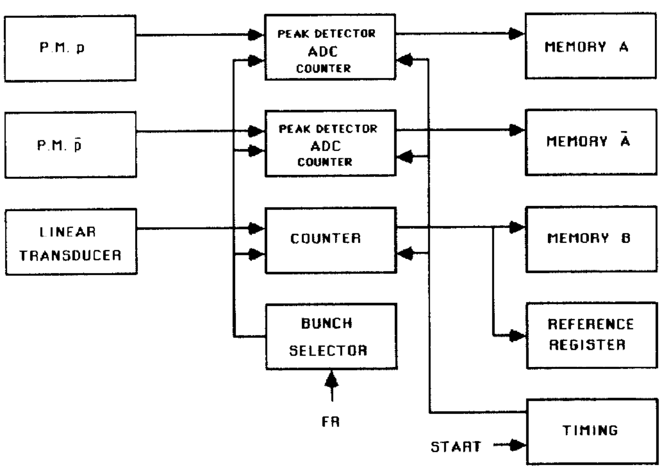

Fig. 3 Acquisition System

The linear wire scanner was installed at the focus of one of the low-beta insertions ($\beta_H = 1.0$ m, $\beta_V = 0.5$ m, $\sigma_y \simeq 100$ μm). It was found that the wire passed through a beam of 6×10^{11} particles without damaging it although from equation 1) one expects a temperature rise of more than 5000°C. The above expression clearly gives a far too pessimistic estimate of the temperature rise. The reason for this can be understood if one takes into account the fact that the energy transferred from the protons to the electrons in the material by Coulomb scattering is not all trapped in the wire. Electrons with sufficient energy will escape, so will not contribute to the heating. Rough calculations 4] have shown that up to 70% of the incident proton energy loss can be accounted for in this way. More detailed measurements of the temperature rise as a function of beam intensity are planned.

Experimental Results

At the wire scanner location the standard deviation of the beam size during storage with low-beta insertion at 315 GeV/c is of the order of 100 μm and the whole beam is contained within about 600 μm. The bunch profile is made up of about 100 measurements.

Figures 4 and 5 show the horizontal profiles obtained with a single proton bunch of about 1.5×10^{11} profiles and a single antiproton bunch of 7×10^9 particles. The data are analysed to give both the bunch centroid $< x >$ and the standard deviation of the beam width σ. These can be estimated from the raw data in the usual way

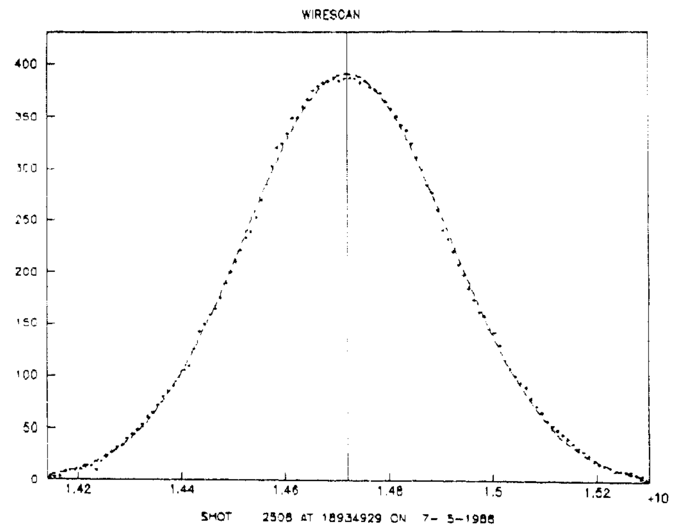

Fig. 4 Profile of a proton bunch, the horizontal scale is given in relative units. The value of sigma for this measurement is 120 micron.

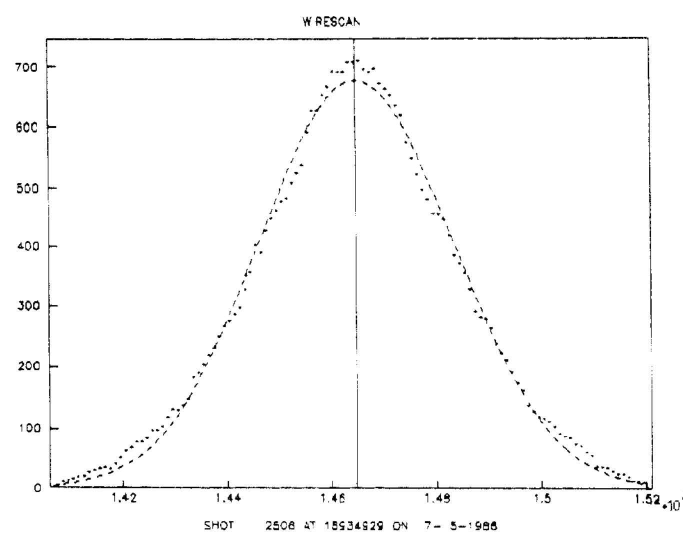

Fig. 5 Profile of an antiproton bunch, the horizontal scale is given in relative units. The value of sigma for this measurement is 120 micron.

$$< x > = \sum_i x_i P_i$$

$$\sigma^2 = \sum_i (x_i - < x >)^2 \qquad (2)$$

with P_i the normalized pulse amplitude in channel i

$$P_i = A_i / \sum_i A_i$$

This method suffers from the disadvantage that small errors in the tails of the distribution can change the value of σ considerably. Another method of treating the data which makes use of the fact that the beams are almost always Gaussian is to make the best fit

$$N(x_i) = A \exp\left(-(x_i - \langle x \rangle)^2 / 2\sigma^2\right) \qquad (4)$$

The three variable parameters A, $\langle x \rangle$ and σ are fitted to the measured data using powerful minimisation routines available in the CERN program library. This method is much less sensitive to noise in the tails of the distribution but assumes a Gaussian profile. The curves fitted to the data in figs. 4 and 5 using this method show that the distribution is extremely close to Gaussian for the proton bunch and reasonably close for the antiproton bunch.

Figure 6 shows the measured readback of position from the linear transducer turn by turn. Although the precision of a single position measurement is 4 μm, this is improved by about a factor of 5 by fitting to the measured data as long as the errors are random.

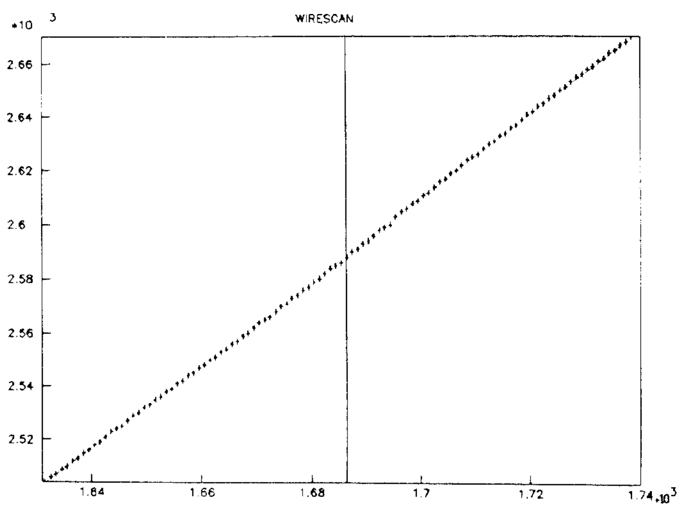

Fig. 6 Measured position as a function of the time, measured by the revolution period.

Conclusions

The linear wire scanner allows emittance and position measurements of the proton and antiproton bunches in the SPS collider with a precision which could not be achieved in the past. Even at a location where the beam size is only 120 μm the error for the measurement value of σ is only of the order of 1 μm as well as the difference in position between the proton and antiproton beams.

Experiments have shown that previous estimates of the temperature rise due to heating by the beam were much too pessimistic. This had been explained by taking into account the energy removed by secondary electrons.

References

1] A. Barisy et al., IEEE Trans. Nucl. Sci. NS-28, 2180, 1981.

2] J. Bosser et al., NIM, A235, 475, 1985.

3] Heidenhain, Numerische Positionsanzeigen, Catalog 1985, D-8225 Traunreut.

4] J. Bosser et al., CERN SPS/86-26 (MS), 1986.