WIRE SCANNER NEWS FROM THE CERN-SPS

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1. Introduction

Wire scanners have been used successfully to measure the transverse beam profiles of proton and antiproton beams in the CERN-SPS for about one decade. First a wire scanner came into operation with a fibre moving on a circular path at a speed of 4 m/s. In [1] we reported about a newly developped wire scanner which allows to measure the profile width with a resolution of about 1 µm. This improvement was achieved by moving the thin fibre through the beam on a linear path at reduced speed.

More recent developments of the wire scanner system are reported here :

a) since electrons and positrons are accelerated in the SPS for LEP injection the detection system of a wire scanner was modified and the instrument was used to measured lepton bunch profiles.

b) for the measurement of beam profiles of the high intensity proton beam in fixed target physics a limit was found for the beam intensity which the fibre can support without damage caused by heating. This allows the use of the wire scanners to measure the profiles at maximum beam energy and intensity without the risk of destroying the fibre.

c) with the development of high precision wirescanners for the SPS comes the need for a better data acquisition system. The new scanners will generate more data (up to 32K per scan) compared to the old wire scanners and will be driven from electronics residing in a VME system. Here we report about a prototype data acquisition system housed in a VME crate and connected to the operator consoles via the new (token ring) network.

2. The electron positron wire scanner

A carbon fibre with a diameter of about 36 µm passes through the beam at a given speed. The density of the particles traversing the fibre can be measured by measuring the secondary emission current or by measuring the secondary particles produced by the interaction between the beam particles and the atoms in the fibre. For each revolution the pulse generated by the interaction is digitized. The pulse height as a function of turns yields the beam profile. For leptons the dominant interaction process with the material is the emission of bremsstrahlung with a corresponding loss of electron energy. The photons have an energy up to the beam energy and are emitted into a very narrow cone around the beam with an opening angle of about 1/γ (with γ the Lorentz factor). In the downstream bending magnets the path of the photons and the electrons is separated.

In order to calculate the expected yield, the cross section for bremsstrahlung is needed. For relativistic electrons the cross-section for the emission of a photon
above the energy ε_s is given by:

$$\sigma(\varepsilon_s) = 57.3\ (6.37\ \varepsilon_s - 6.37\ \ln\varepsilon_s - 2.34\varepsilon_s^2 - 4.03)\ [\mathrm{mb}]$$

with $\varepsilon_s = E_{photon} / E_{beam}$

For a carbon fibre with a diameter of 36 µm the probability for an electron to emit a photon with an energy of more than 10% of the beam energy is $P = 2.88*10^{-4}$. With a bunch of $2*10^{10}$ electrons and a beam width of $\sigma = 2$ mm about $3.2*10^4$ photons will be emitted with an energy above 10% of the beam energy during one bunch passage with the wire centred on the bunch.

Electrons or positrons with less than the nominal energy are deflected in dipole magnets with a bigger angle than the beam. These particles will eventually leave the vacuum pipe where they can be detected with scintillators. The optimal position of such scintillators was found with a tracking program [2] : A sample of electrons with a realistic energy distribution was tracked from the position of the fibre to the point where the electrons are expected to leave the vacuum chamber. The scintillator was installed at the point with the highest particle flux, about 30 m downstream from the wire scanner. In Fig.1 the profile for a positron bunch is shown.

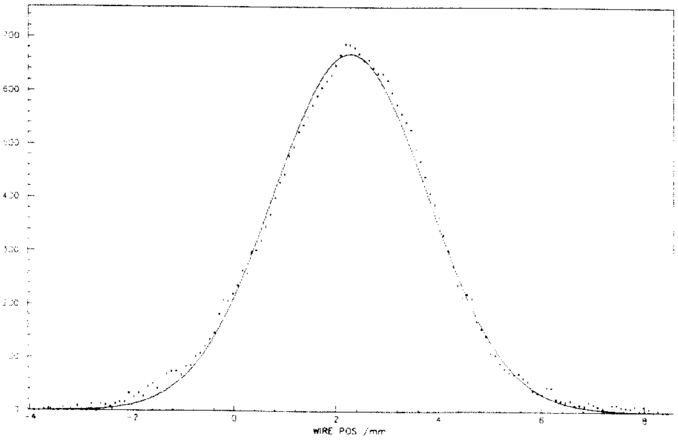

Fig.1: Vertical profile of a positron beam.

3. Destruction of a carbon fibre

The protons deposit energy in the fibre material via Coulomb interactions with the electrons. This energy is partially converted into heat. The fibre temperature increases and if it exceeds a maximum value the fibre breaks. This point is not reached if the fibre passes through a beam of maximum intensity and momentum at its nominal speed. In order to break the speed of the fibre had to be reduced. The breakpoint is expected at a temperature of 3000 to 4000 K. However if no cooling mechanism is considered, and all the energy lost by the protons is converted into heat the temperature would rise to a much higher value in the condition of the experiment (see table 1). Different effects reduce these temperatures :

a) the energy lost by the protons is not completely converted into heat [1], e.g. electrons may escape out of the fibre if their momentum is sufficient. The proportion of the energy converted into heat is the heating efficiency κ.
b) the fibre radiates power as a function of temperature

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according to :

$$P(T) = \varepsilon\ \sigma\ a\ T^{4}$$

with: ε.. relative emissivity of the surface,
σ.. $5.67*10^{8}$ $[Wm^{-2}K^{-4}]$,
a.. area of the radiating surface $[m^{2}]$

c) the heat conduction along the fibre. If the temperature has a Gaussian distribution along the fibre axis, the maximum temperature will drop to 50 % of its initial value in a time interval [3] :

$$\Delta t = 3\sigma^{2}/2D$$

with $D=\lambda/\varrho c$, λ.. thermal conductivity, ϱ.. specific weight, c.. heat capacity, σ.. width of temperature distribution (equal to beam size).

PARAMETERS FOR THE WIRE DESTRUCTION EXPERIMENT

Carbon parameters
Density = 1.42 ± 3 % gr/cm^{3}
Heat capacity = 2 J/(Kg*°K)
Diameter = 36 ± 0.5 μm

	Horizontal wire scanner	Vertical wire scanner
σ_h [mm]	1.3	1.3
σ_v [mm]	0.65	0.65
Number of protons	$2 * 10^{13}$	$2 * 10^{13}$
E [GeV]	450	450
Distructive speed [m/s]	<= 0.8	<= 0.12
Non distructive speed [m/s]	> 1	> 0.15
Expected temperature [°K] (no cooling, heating efficiency = 1)	15000	47000
Expected temperature [°K] (with cooling, heating efficiency = 0.3)	3300	3700

TABLE 1

With a simulation program the temperature as a function of time is calculated. The fibre is cut into segments which are small compared to the beam size (see Fig.2). The change of temperature in one segment is calculated taking into account the heating by the proton beam, the loss of heat by conduction into the adjacent (colder) segment, the gain of heat from the adjacent (warmer) segment and the loss of heat by radiation.

Model For The Temperature Change In An Infinitesimal Fibre Segment

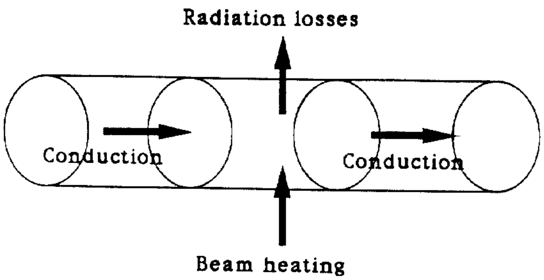


Fig.2: Model for the temperature change in a fibre segment.

For a meaningful simulation the material constants for carbon have to be known. The specific heat, the density and the fibre diameter are known within an accuracy better than 10% (although the specific heat might change above a temperature of 2000 K. No data are available at these temperatures [4]). The conductivity depends strongly on the type of carbon fibre and not even the order of magnitude is known. In the simulation a value of 50 [W/mK] was assumed [4]. For the thermal emissivity the values given in the literature vary between 0.3 and 0.9. A value of 0.8 was assumed. With these parameters and a heating efficiency of 0.3 the expected maximum temperature is slightly less than 4000 K (see table 1). Without cooling due to radiation the temperature would be about 20 % higher. The cooling by conduction is negligible.

Another way of estimating the temperature is the observation of the onset of thermionic emission. The current density of the themionic emission current is given by :

$$j = A\ T^{2}\ \exp(-\Phi/\ T)$$

For carbon: $A=6.02*10^{5}$ $[A/m^{2}K^{2}]$ and Φ = 46500 [K] [5]. The current emitted from a 1 mm long carbon segment is about 1 μA at 1800 K and 0.2 mA at 2200 K. The measurement of the thermionic emission was a sideproduct from the resistance measurements which are now discussed.

To measure the fibre resistance, the fibre formed one branch in a Wheatstone bridge. In Fig.3a the fibre passed the beam some milliseconds after injection. Before passing the beam, the resistance already changed because the fibre is heated by the electromagnetic fields of the beam. During the fibre passage through the beam, the fibre temperature increased again and the resistance changed substantially.

The next observation was done with the fibre passing the beam at an energy of 450 GeV. Before the passage the resistance was constant. After the fibre enters the beam, different effects were observed (Fig.3b) :

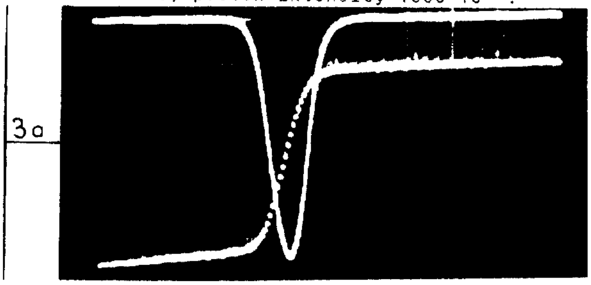
a) a pulse generated by secondary emission.

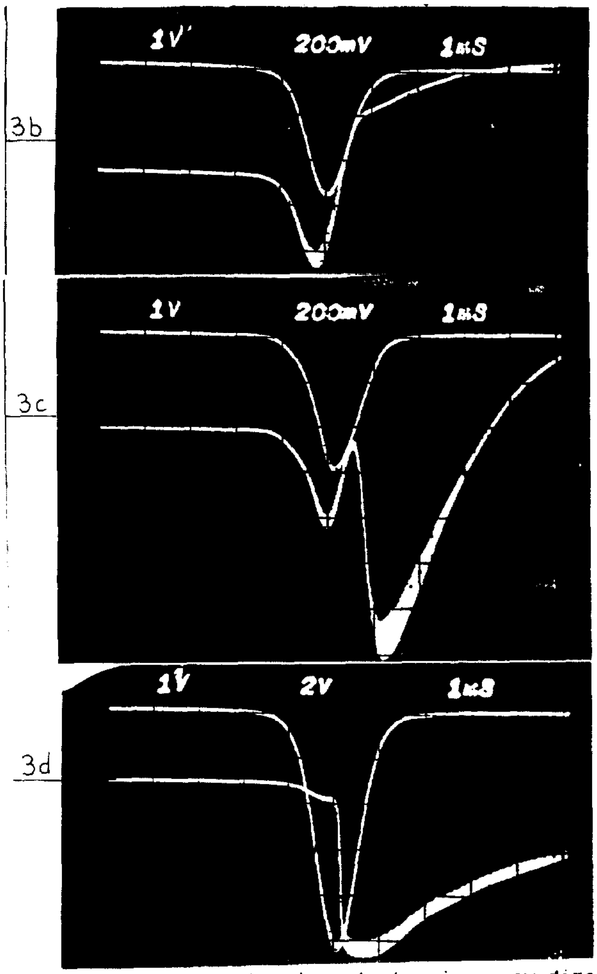
b) the onset of a thermionic emission current after the fibre passed the tail of the beam.

c) a change of the resistance due to the change of temperature. After the beam passage the temperature was still high and the resistance was different from the value before the scan. The temperature dropped within a time long compared to the beam passage time.

With the beam intensity increased by about 10 %, the thermionic emission became much stronger (see Fig.3c). The thermionic emission current was about 100 μA. This value is expected at a temperature around 2000 K. For this scan a temperature of about 1800 K is predicted with the simulation program. The thermionic emission stopped about 5 ms after its start. This time is needed for the decrease of the temperature below the onset of thermionic emission. With the intensity increased by another 10 %, the thermionic emission led to a saturation of the Wheatstone bridge (see Fig.3d).

Fig.3a: Wire scan shortly after injection at 14 GeV.
3b: Wire scan at a beam energy of 450 GeV, proton Intensity $1200*10^{10}$.
3c: As 4b, proton intensity $1400*10^{10}$.
3d: As 4b, proton intensity $1600*10^{10}$.





4. Wirescanner Electronics- A step in a new direction

The electronics for the new wire scanners will be housed in a VME system. The use of VME opens the door to local data processing and will allow an overall improvement in the scanner performance. A prototype system has been set up to enable some of the new problems to be tackled. A brief description of this prototype follows, together with some comments about the lessons learnt from the project.

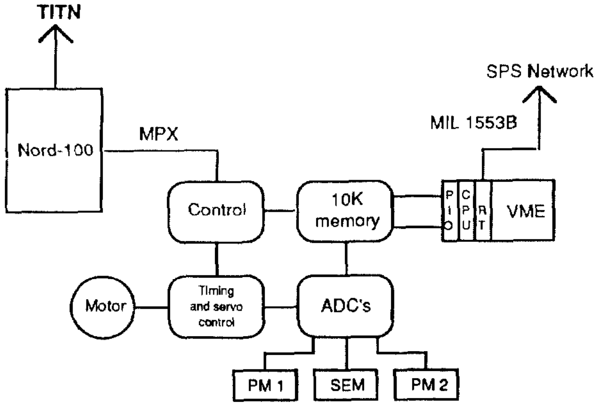


Fig. 4: Wire scanner electronics.

Within the VME crate there will be a processor card (MC680x0) with at least 1 Mbyte of memory, a network interface card, a timing card capable of generating the required interrupts with millisecond precision, a motor control card, and a data acquisition card including the ADC's. As a step towards this, it was decided to set up a single VME system with the ability to read out the existing buffer memory of the linear wirescanner. This allowed the development of the local data processing software, and the definition of a data structure for wirescanner data.

The prototype crate has a parallel interface to allow it to directly access the wire scanner's buffer memory. The memory was directly connected to the VME system via its PIO cards. The control of the scanner is still performed entirely with the old control system based on NORD-100 computers. This is illustrated in Fig.4. The VME system is connected to the new SPS network via a MIL1553B interface card.

The software in the VME system performs local data processing tasks. Provided a scan has been successful, the buffer memory contains the digitised profiles of the beam. The software searches and finds the profiles within the buffer, and fits Gaussian distributions to them. It then constructs a data structure and fills it with the trimmed profiles, together with the results from the analysis. The entire structure is then returned over the network to the console (see Fig.5). The definition for the data structure has allowed space for all the additional information relevant to a particular scan. For example, the time and date, scanner type and number, beam intensity and energy, and particle type (there are roughly 30 other items). The structure is general and can hold scan data from any sort of wirescanner.

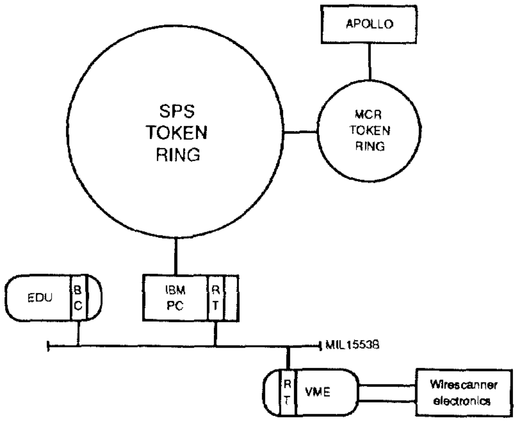


Fig. 5: Wire scanner readout over the network.

The wirescanner project has shown the use of a data structure and local data processing to be extremely valuable for efficient data acquisition and it is intended to extend this scheme to other beam monitoring systems in the future. The development of the prototype VME system has also stressed many points concerning the new network which will be relevant to other systems in the future.

5. Acknowledgement

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6. References

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