THE PS BOOSTER FAST WIRE SCANNER

S. Burger, C. Carli, M. Ludwig, K Priestnall, U. Raich, CERN, Geneva, Switzerland

Abstract

The very tight emittance budget for LHC type beams makes precise emittance measurements in the injector complex a necessity. The PS machine uses 2 fast wire scanners per transverse plane for emittance measurements of the circulating beams. In order to ease comparison the same type of wire scanners have been newly installed in the upstream machine, the PS Booster, where each of the 4 rings is equipped with 2 wire scanners measuring the horizontal and the vertical profiles.

The Booster wire scanners use new and more modern control and readout electronics featuring dedicated intelligent motor movement controllers, which relieve the system from the very stringent real time constraints imposed by the very high wire speed of up to 20m/s. In order to be able to measure beams at the very low injection energy of the PS Booster (50 MeV) secondary emission currents from the wire can be measured as well as secondary particle flows at higher primary particle energies during and after acceleration[1].

The solution adopted for the control of the devices as well as preliminary results obtained during measurements in 2002 are reported.

SYSTEM OVERVIEW

The new control of the PS Booster (PSB) fast wire scanner is subdivided into a data acquisition part controlled by the VME CPU and a motor control unit (MCU) provided by a VME slave processor board. The MCU is an independent embedded VME board featuring a 68332 CPU, an ADC, DAC and TTL parallel I/O piggyback module. A complementary interface card is used for signal conditioning.

The acquisition part uses sampling ADCs for position and analogue signals measurements. The VME CPU communicates with the slave processor exclusively through parallel I/O signals making motor control entirely independent from the VME bus. Fig 1a) shows an overview of the complete system.

Due to the very high acceleration and speed needed, a 400W DC motor and an associated servo amplifier with velocity feedback are employed. The complex wire scanner mechanism is depicted in Fig 2.

MOVEMENT CONTROL

The software in the motor controller waits for triggers on its parallel input lines to power up the system and to step through speed tables defining the motor current function V(t) through its DAC module. Currently 3 selectable wire speeds of 10m/s, 15ms, 20m/s are available. A resolver whose outputs are connected to the ADC determines the motor position. I/O channels see the end position switches (HOME and OUT). The speed tables are calculated by an offline program taking into account the geometry of the mechanism. They are linked to the embedded software, which is cross-compiled using gcc on a Linux workstation and downloaded into the MCU's flash memory.

The following constraints are taken into account:

1. The last crankshaft position $x(t_1)$ in [rad] given by the integration over the speed-table:
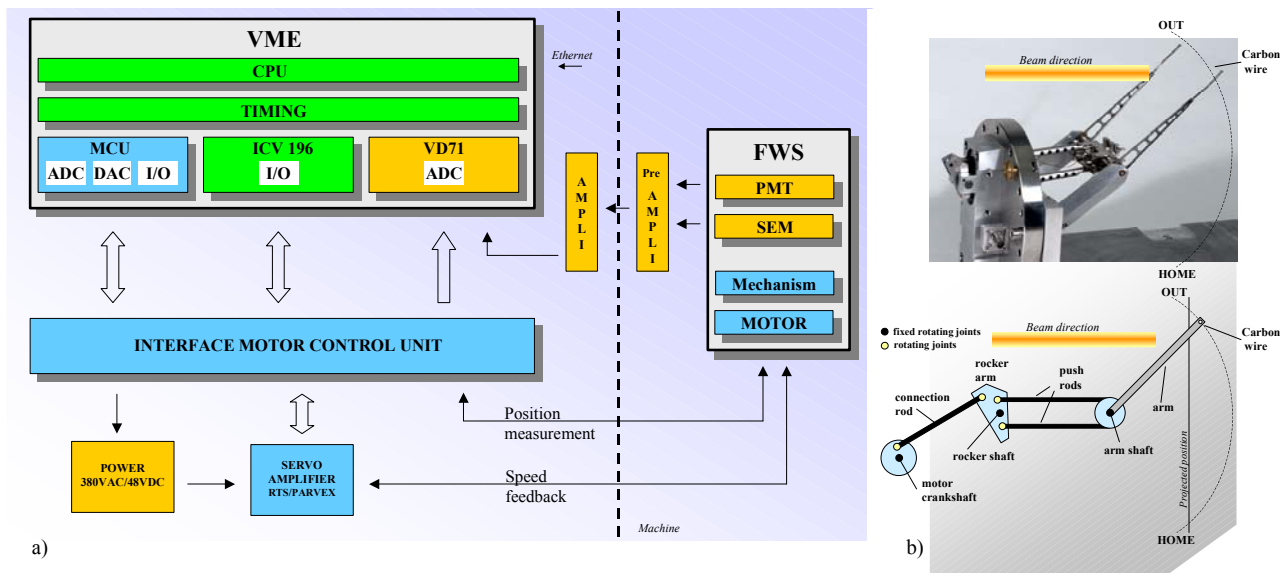

Figure 1: a) System overview of the fast wire scanner installed in the PS Booster. b) Picture and schematic of the mechanism of a fast wire scanner. Its complexity is due to stringent mechanical and physics constraints.

$$x = \frac{1}{T}\int_{t=0}^{t=t_1} V(t)dt$$ must be OUT for a forward

movement, with the tachymeter constant T=32.8mVs/rad given by the motor electronics.

2. The projected speed of the wire during the acquisition phase should be constant.
3. Acceleration peaks at the wire must be avoided in order to minimise mechanical stress.

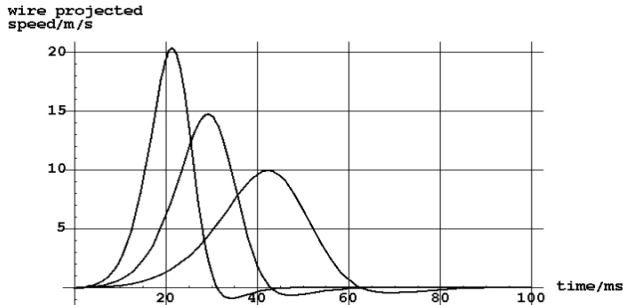The peak acceleration for 20m/s is approximately 200g.

Figure 2: Wire projected speed curves versus time. During the interaction between the carbon wire and the beam (1 to 3 ms), the speed is the maximum of each speed curve followed by the wire.

BEAM PROFILE MEASUREMENTS ON PROTONS

In order to measure protons from their injection energy into the PSB at 50 MeV up to their ejection energy of 1.4 GeV we use 2 amplifier chains. One chain amplifies the secondary emission current (SEM) onto the wire while the second one treats signals from a scintillator/photomultiplier tube (PMT) installed outside the vacuum chamber.
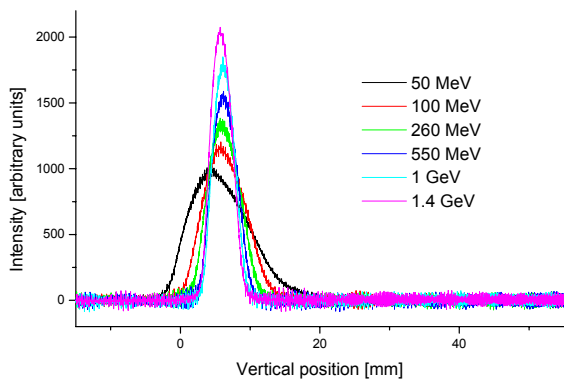
Figure 3: Evolution of the vertical beam profile along the PS Booster acceleration cycle, measured with the SEM detector. The amplitudes have been normalised taking into account the secondary emission efficiency for different kinetic energies and the revolution frequency.

The secondary emission channel is needed for primary particle energies below the pion production threshold. Fig. 3 shows raw data from secondary emission measurements along the acceleration cycle.

MEASUREMENTS ON PARTIALLY STRIPPED IONS

LHC will not only accelerate protons but also heavy ions (Pb^{82+}). During their acceleration in the PSB these ions are only partially stripped (charge state 53+) and the attempt of measuring their profile with the wire scanner will result in stripping and therefore in loss of the particles. However, the stripping effect can be used to measure amplitude distributions by slowing down the wire scanner to velocities slow enough so that it can be guaranteed that all ions will be lost.

In order to test this principle we used ions in the PSB produced for the SPS fixed target ion run in 2002. For the ion measurements a new speed table for 2 m/s has been defined.

Raw data containing the current measured with a DC beam current transformer (DCCT) as a function of time are plotted in Fig. 4. The last ions are lost, when the wire reaches the centre of the beam at a time t_0. The point corresponding to the beam centre is determined by fitting a half-parabola through the raw data close to the point where the intensity vanishes as indicated in Fig. 4. The fact that only a small part of the data is fitted well by the parabola indicates that the phase space density is high in a small region at the centre and falls off quickly. This can be explained by the multi-turn injection of a beam with negligible direct space charge effects and is qualitatively confirmed by profile measurements of the extracted beam. Due to the low intensity of the ion beam, the raw intensity signal is rather noisy.
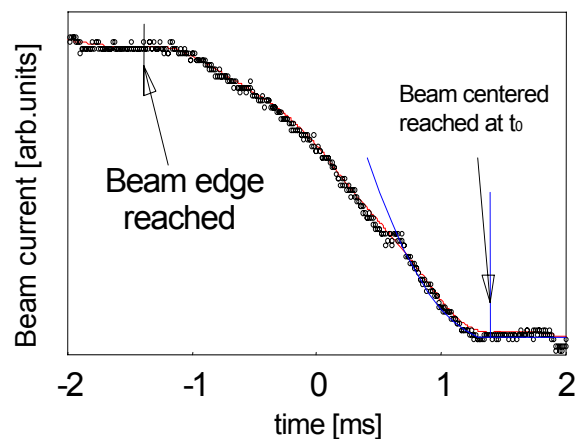
Figure 4: Raw intensity data recorded during scraping of the ion beam.

The oscillation amplitude A corresponding to the wire position at time t is given by $A=(t_0-t) v_{wire}$, where v_{wire} denotes the projected velocity of the wire. An amplitude density $\rho(A)$ can be derived from a normalized (varying from unity before the wire touches the beam to zero when the last ions are lost) current $I(A=(t_0-t) v_{wire})$ using $\rho(A) = dI/dA$.

In practice, it is difficult to apply above procedure due to the noisy signal. Figure 5 shows an amplitude density, which has been obtained by (i) smoothing the raw data using a Savitzky-Golay [2] smoothing filter, (ii) approximation of the smoothed data by a spline function (plotted in Fig. 4 in addition to the raw data) and, (iii) derivation of this interpolation .
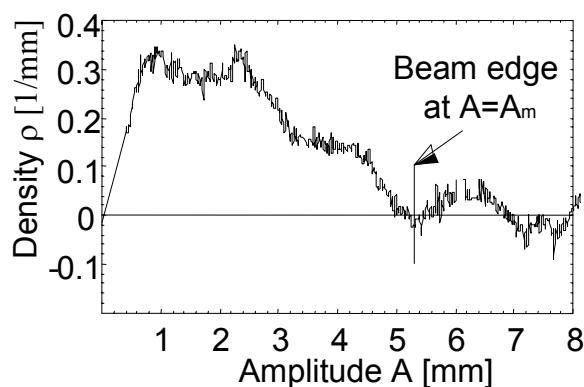

Figure 5: Amplitude density distribution

The rms transverse emittance of the beam is given by

$\varepsilon = <A^2>/(2\beta)$, with $<A^2> = \int_0^{Am} A^2 \rho(A) dA$ and $\beta=3$ m

the betatron function at the location of the wire scanner. If the density plotted in Fig. 5 is inserted in above integral, one obtains a transverse rms emittance of $\varepsilon = 1.1$ µm. One notes that it is tricky to determine the beam edge, which strongly influences the final result.

Another method to evaluate the transverse emittance circumventing the difficulties in deriving a function describing the amplitude density from the measured data has been applied. The sum

$S(A_n) = \sum_{A_i}^{n} \left(\frac{A_i+A_{i+1}}{2}\right)^2 (I_{i+1} - I_i)$ is introduced and

plotted in Fig. 6. The emittance of the beam is given by $S(A_n \geq A_m)/(2\beta)$. With the help of the plot, one finds the emittance $\varepsilon = 1.15$ µm.
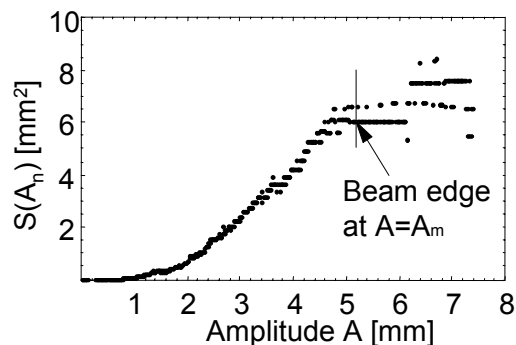

Figure 6: Approximation of the integral to determine emittance by a sum.

Comparative measurement have been done in a measurement line with the 3 profile method yielding rms emittances of 1.0 µm and 1.2 µm fitting the data with a Gaussian and, using spline fitting and integration afterwards, respectively. One concludes that, within the relative large uncertainties, the emittances measured by scraping the ion beam with the wire scanner agree with the reference measurement.

One should note that the measurements described above have been made for the vertical phase space and, thus, no contribution of the momentum spread via the dispersion had to be taken into account.

CONCLUSIONS

A series of 8 fast wire scanners has been installed in the PS Booster. These scanners are equipped with intelligent motor controllers capable of enforcing precise speed control avoiding acceleration peaks which would lead to high mechanical stress. The wire scanners can measure primary proton beams down to 50 MeV using secondary emission from the wire. For higher energies the flow of secondary particles, created through the interaction of the primary beam with the wire, is measured on a scintillator. Tests have been made on protons and on partially stripped ions where the scanners work like scrapers and beam loss is detected on a DCCT.

The wire scanners are now considered ready for routine operation.

REFERENCES

[1] Wire Scanners in Low Energy Accelerators
I. Elmfors, A. Fasso, M. Huhtinen, M. Lindroos, U. Raich

[2] W.H. Press, S.A. Teukolsky, S.A. Vetterling and B.P. Flannery, Numerical Recipies for Fortran 90
The Art of Scientific Programming, Cambridge University Press (1996)

PM13