EUROPEAN ORGANIZATION FOR NUCLEAR RESEACH

CERN/PS 85-33 (OP)
May 1985

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Paper presented at the 1985 Particle Accelerator Conference
May 13-16
Vancouver, B.C., Canada

A SCANNING WIRE BEAM PROFILE MONITOR

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The transverse profile of the circulating beam of the CERN PS is obtained from the interaction between the particles and a thin wire rapidly moving through it. The signal from a secondary particles monitor or the secondary emission current of the wire is sampled against the wire position every four beam revolutions in the machine. A stand-alone desk computer performs the real-time control of the wire displacement as well as the acquisitions and calculations necessary to display the profiles and the corresponding emittances. A traversing speed of 20 m/s in the measurement area is reached, using a high torque motor rigidly linked to a U shaped wire holder. All elements are carefully designed and chosen for low inertia and minimum load on the wire. This enables measurements of high energy beams of more than 10^{13} p/p in the PS with negligible emittance blow-up due to multiple scattering. This blow-up is still acceptable at injection energy. A link to the PS main computer allows operation from any one of the main consoles.

Introduction

Beam profile measurements are important for the detection and study of unwanted blow-up of beams dedicated to colliders.

A wire scanner had been proposed at the CERN PS years ago [1]. The first models were slow, so Coulomb scattering and wire heating by particle interaction were excessive. This new device is specially conceived for a higher velocity.

Mechanical device

Two monitors, a horizontal and a vertical one, are installed in the PS Ring (see Fig. 1). Each consists of:
- the motor and the parts fixed directly to its axis;
- the transmission system, in air and in vacuum;
- the stainless steel vacuum face;
- the U shaped wire support and its bearings.

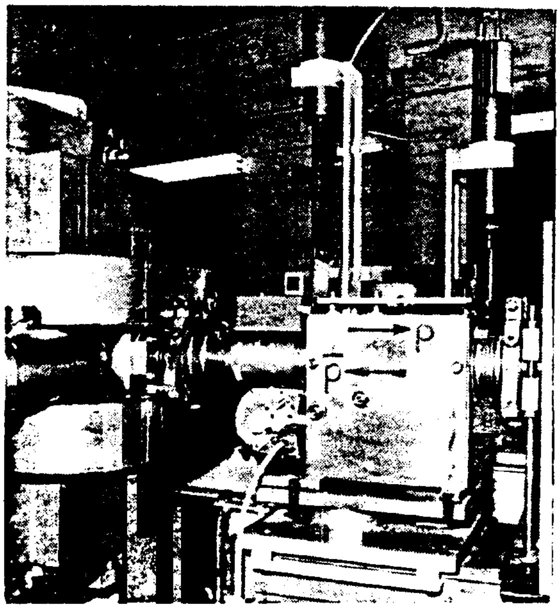

Fig. 1: Installation of the monitor in the PS ring

The arms of the U are built up of standard stainless steel tubes of 2 mm outside diameter, and 0.25 mm wall thickness (see Fig. 2). The ends are single, lightened by drilling, and separated from the rest of the arm by a short flexible part. The U is completed by a strong cylindrical tube which carries the two arms at its ends. Two small protruding axes pivot in Vespel [2] bearings. All the elements of this U are brazed together in successive steps [3] executed at different temperatures. Afterwards the wire is stretched between the two sprung arm-ends with a force of about 20 grams to prevent an excessive sag due to acceleration. Each end of the thin wire is crimped in a small aluminium insert, insulated from the arm. Between the "down" position, when the U support is entirely outside the beam aperture, and the "up" position when the wire is on the far side of the beam, the angle of rotation is 130°, brought about by four rolling tapes around the cylindrical tube. They are made from a special high-strength non-magnetic alloy and actionned by two pushpull rods which are connected to the mobile end flanges of two metallic bellows with a stroke of 7 mm.These are parts of the all welded vacuum face in the main flange of which are also welded two feedthroughs used to connect the ends of the thin wire to check continuity and to do charge measurements.

On the air side, the movements of the two push-pull rods are linked together via a single balance put into motion by the motor through a crankshaft.

The motor is a commercially available standard printed circuit permanent magnet D.C. device in a low inertia execution with aluminium current conductor [4]. Directly on its axis, it carries a tachymetric dynamo as a velocity captor and a potentiometer as a position indicator. Two opposed springloaded cam followers run on a cam with a single notch, defining precisely the two end positions of the stroke. They also interact with two micro-switches for remote indication of the status of the mechanism.

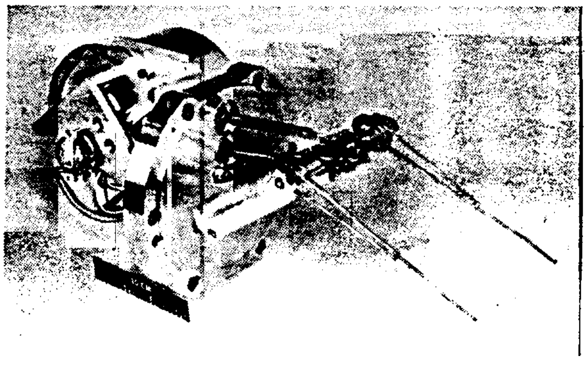

Fig. 2: The instrument with the wire holder "down"

Driving system

Digital control of the fast wire displacement has been chosen for several reasons:
- suppression of instabilities and oscillations;
- possible use of standard Camac electronics:
- high immunity against potentiometer noise.

The position and velocity captors are connected through a multiplexer to an analog to digital converter in the Camac crate of the microcomputer. Its output is acquired by four assembler written subroutines allowing forwards and backwards motion of both the horizontal and vertical mechanisms. When called, they choose which current should be fed to the corresponding motor. A double digital to analog converter is installed in the CAMAC crate which provides the input signals U for power amplifiers feeding the horizontal and vertical motors.

A functional diagram of one of these routines is sketched in Figure 3. The average time taken by the computer to execute the loop is of the order of 100 µs depending on the path taken at the branching points, so the loop is executed many times during the displacement of the wire which takes about 50 ms for its forward movement. At the first execution, it sets the mechanism in motion at full acceleration until a predetermined position (P1) is crossed, some distance from the centre of the vacuum chamber (see Fig. 4). The current in the motor is then reduced to keep the velocity almost constant as the central area of the vacuum chamber is being crossed.

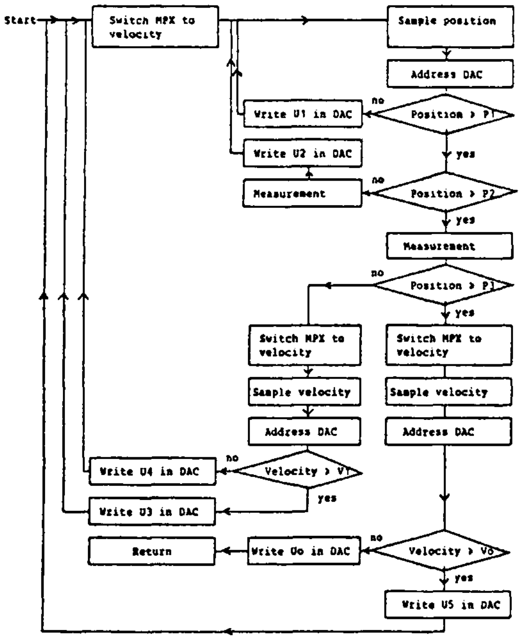

Fig. 3: Flowchart of the motor and clock control

When another reference position (P2) is reached, beyond the vacuum chamber centre, the mechanism is decelerated. It finally stops, shortly after a third reference position (P3), outside the normal aperture of the vacuum chamber when the spring loaded cam follower enters the notch.

The acceleration

About 16 ms after the current is switched on, P1 is reached and the wire holder has then a rotational speed of ≈ 135 rad/s and the wire itself crosses the beam area at the speed of ≈ 20 m/s. This requires a linear acceleration of close to 1400 ms^{-2}. Tests in air are not possible, which is confirmed by numerical evaluation of the forces due to acceleration, centrifugation and aerodynamic friction. Between P1 and P2, the wire is still further accelerated, in order to keep the projection of the rotational speed constant. Then the motor helps to establish the braking current, so P3 is reached with a very small velocity.

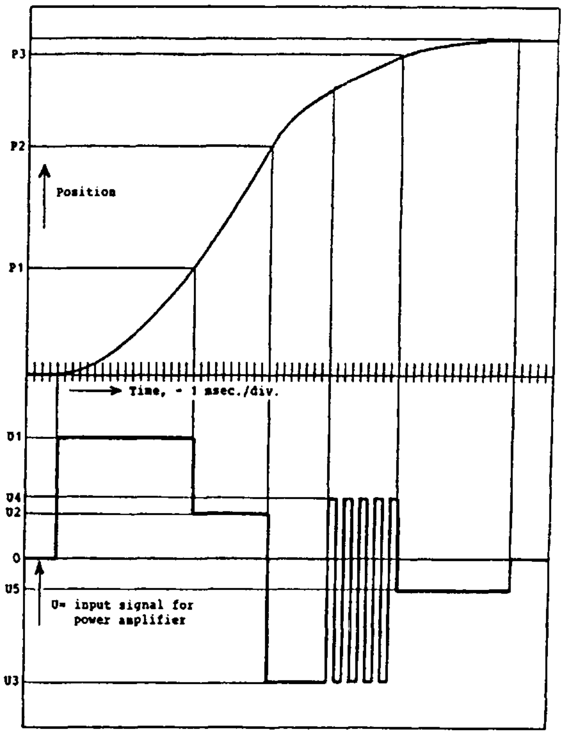

Fig. 4: Position and DAC output during displacement

Data acquisition and calculations

Beams of 10^9 to 2×10^{13} particles per cycle circulate in the PS depending on their type and destination. It has, therefore, been necessary to install 2 scintillators, each adapted to a dynamic range. Moreover, it is planned to use charge measurement as an extra possibility, especially suited to high intensities. The bunched structure of the beam is filtered out. A LeCroy 1 MHz waveform analyser samples simultaneously the position potentiometer voltage and the scintillator signal. The clock used is derived from the RF acceleration system and is thus synchronous with the particle revolution. This avoids beating phenomena with the bunch structure. The clock is switched on while the wire is between P1 and P2 to sample both position and scintillator output.

When the forward movement is completed, an assembler routine is called to read and sort out the data. To save memory space, only 100 values per measurement are stored, starting 10 data before a certain threshold is reached by the scintillator signal.

The data processing consists of:

- a linear least square fit of the potentiometer voltage over the 100 samples to eliminate noise;
- a calculation of the positions from the potentiometer voltages;
- a calculation of the root mean square value of the distribution using a 5% bias to avoid excessive effect of the tails.

Finally, the value of the emittance is given for a two standard deviations projected profile.

Measurement sequence

A main compiled BASIC programme takes care of the whole measurement sequence. The "HOME" page presented on the microcomputer screen corresponds to a waiting state on either a message from the main computer control system or an action by light pen among a choice in the first page of a tree structure. The measurement parameters are passed to the system by successive choices:

- the measurement plane (or both in succession);
- the "user", a parameter defined by the PS control system, characterizing the use of the accelerator during one cycle; a succession of users can be chosen for several measurements in a row (3 proton followed by 3 antiproton cycles to fill the SPS for one run during collision experiments, for instance);
- the timing.

The system is then ready and waits for the specified event. When it occurs, the forward movement(s) is(are) performed and then the reading, preprocessing and storage are executed, followed by the backward movement(s). Before the end of the PS cxcle, the system is ready for the next measurement.

When all cycles specified have elapsed, calculations start and eventually all emittances are displayed on the screen (up to 12 results). The program is back in the "HOME" state, waiting for the next session. But in the mean time, the operator can request the display of any one of the profiles collected during the last session (see Fig. 5).

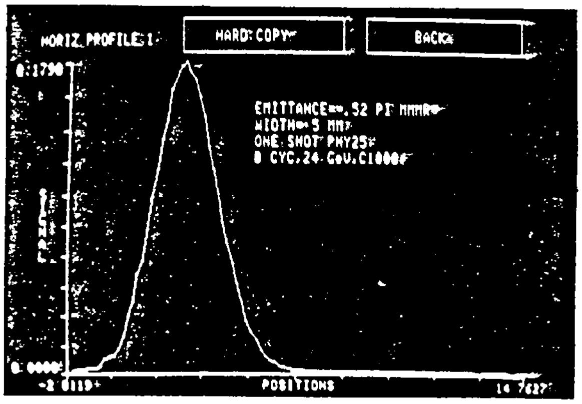

Fig. 5: Microcomputer output

Control from the main consoles

The use of the wire scanner is also available from the main PS control system consoles. This is made possible through a link between both sytems, using two PS standard interface modules [5]. One is situated in a CAMAC crate attached to one of the front end computers of the main system, the other is in the microcomputer crate. A RS 232 connection allows messages to be sent between the two modules in the form of ASCII character strings following a defined protocol. Instructions are thus transferred from the main console to the microcomputer and results are sent back.

The program displays a choice of measurement parameters on a touch-panel. When they are all defined, they are transmitted to the desk computer. When the whole sequence is processed, results are remitted back to the main console as directly displayed character strings. Video images of the profiles can be observed on any of the console TV monitors after a choice on the video multiplexer.

Beam wire interaction

Up to now, a 50 µm diameter Beryllium wire has been used. Silicon carbide is another possible choice.

Besides the high energy secondary particle shower detected by the scintillators, the beam wire interaction also causes scattering of the hadrons. At momentum p, the 2σ emittance increase is

$$\Delta E = \frac{4}{\pi} \frac{\beta_x d^2}{v \tau L_r} \left(\frac{15}{p}\right)^2$$

where β_x is the local Twiss amplitude parameter, d the wire diameter, v the wire velocity, τ the revolution period of the particles and L_r the radiation length in the wire material.

Calculation for two typical energies gives (results in π.mm.mrad, respectively, for the measurement plane and the other):

at 26 GeV/c	.00085	.0016
at 3.5 GeV/c	.047	.086

Another important effect of the beam wire interaction is the proton energy loss. The heat deposit causes a temperature rise:

$$\Delta T = \frac{1}{C_v} \frac{dE}{dx} \frac{\beta N}{v \tau} \sqrt{\frac{3 \beta \gamma}{\pi \beta_x \epsilon_x^*}}$$

where C_v is the heat capacity of the wire material, dE/dx the energy loss, β and γ the relativistic coefficients, N the number of particles in the machine and ϵ_x^* the transverse normalized emittance.

For $N = 10^{13}$ protons, an energy of 26 GeV/c and a normalized emittance of 30 π.mm.mrad, one finds $\Delta T = 650°$ C.

One can hope to stand intensities well above 10^{13} ppp since the effort on the wire is low and the melting temperature of Beryllium is 1287° C.

Further development

The velocity of 20 m/s obtained is probably not the limit which the mechanics and the wire can stand. It is intended to try and push the maximum wire velocity somewhat further using a more powerful amplifier. The aim is to measure beams of the highest intensities achieved in the PS at present.

One of the other improvements foreseen is the suppression of the potentiometer, which wears out rapidly and becomes noisy. It could be replaced by an inductive position captor, a digital encoder or a simplified 3 switch system sufficient for the displacement control. The waveform analyser could then sample the velocity integrated versus time during traversal of the central region of the vacuum chamber.

Another construction, to be mounted perpendicular to the vacuum chamber instead of lengthwise, and so taking less space, is also foreseen.

Conclusion

A high performance beam profile measurement system has been built for the CERN PS. It can measure a wide range of intensities, covering almost all the types of beams accelerated in the PS with very small disturbance. It is particularly useful for the study of beam qualities thanks to its operating ease and integration in the main PS control system.

Acknowledgements

The authors wish to express their thanks to those, with whom it was a pleasure to work and realize this project: V. Agoritsas, H. Bobillier, J.P. Bovigny F. Hoekemeijer, G. Martini and R. Pittin.

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