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CERN-PS-95-06-BD-OP

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CERN - PS DIVISION

CERN/PS 95-06 (BD/OP)

THE FAST WIRE SCANNER OF THE CERN PS

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Abstract

The Fast Wire Scanners of the PS measure the horizontal and vertical profile of the circulating beam and are important instruments for obtaining beams of high performance, in particular those destined for the LHC.

The system has been upgraded over the last few years. Two new units were built, for improved availability in case of wire breakage, and, through new technology, to provide much longer wire life time, higher precision of measurement, and greater ease of operational use. After the success of the new units, the old ones were upgraded to the same standard. Carbon strands, made of twisted fibres, cross the beam at velocities of up to 20 m/s. Secondary particles, created by the collision of beam particles with the carbon nuclei, are detected with scintillators coupled to photo-multipliers. Their signals are acquired simultaneously with the wire position.

This report describes the physics underlying the method; the mechanism; the electronics; and the software for control, data acquisition and treatment, and display of results.

Geneva, Switzerland

27/3/95

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1. Introduction

To attain highest energies, particle accelerator are nowadays cascaded, one injecting into the next with the last stage often being a collider. The chain from the first injector to the collision ring must be optimised for maximum luminosity. Accurate measurement of the beam profile and transverse emittances in circular accelerators has therefore become a primary concern. One of the most reliable instruments is the fast wire beam scanner, now installed in several machines throughout the world. At the CERN PS, a first version was developed almost ten years ago [1]. Two units were installed, one for each plane to measure the proton and antiproton beams destined to the SPS in collider mode. They were thus limited to beams of low intensity. Their reliability was poor and the precision questionable so that an improvement project was launched in 1991. Two new devices were installed and first used as prototypes during the tests of the PS as LHC injector in December 1993 [2]. The installation was completed when the two old ones were upgraded in March 1994. The system became fully operational and integrated in the controls system by the end of the year 1994. The total of four devices, two for each horizontal and vertical plane profiles, are designed to measure all beams available in the PS at present: protons, antiprotons, ions, electrons and positrons, in the energy range of 1 to 25 GeV (for protons) and intensities from 10^9 to 2×10^{13} particles per pulse (ppp).

2. Physics of the system

2.1 Principle

A wire is stretched between the two prongs of a fork, perpendicular to the beam and moved rapidly through the circulating beam (Fig.1). Secondary particles, produced by the interaction of the circulating particles with the wire material, hit a detector, which consists of a scintillator and photo multiplier. The output signal is sampled together with the wire transversal position. The projected beam profile is thus obtained, and also the emittance assuming the β function, the dispersion and momentum spread are known at the device location.

2.2 Multiple scattering

The beam blow-up of the 2σ emittance due to multiple scattering after one traversal is given by [3]:

$$\Delta\varepsilon_x = \frac{\pi}{2}\frac{\beta_x d^2}{v\tau X_o}\left(\frac{15}{\beta p}\right)^2$$

where β_x is the local Twiss amplitude parameter in the measurement plane, d the wire diameter, v the projected transverse wire velocity, τ the revolution period of the particles around the machine, X_0 the radiation length in the wire material, β the particle velocity in units of c, and p the particle momentum (in MeV/c).

In order to minimise the blow-up, the following measures are taken:

- the largest feasible velocity (20 m/s) is aimed at, particularly at injection energy. At higher energies, a lower velocity can be chosen to reduce strain on the mechanism.
- the wire diameter is chosen as small as strength and reliability permit (30 μm).
- Carbon was chosen as wire material replacing the previously used Beryllium, since it has a larger radiation length for the same mechanical strength.

The resulting blow-up factors at three typical PS energies are given in Table 1.

Table 1: Emittance blow-up at 20 m/s velocity

Energy or momentum	Blow-up in meas. plane	Blow-up in other plane	Normalised blow-up in meas. plane	Normalised blow-up in other plane
1 GeV (injection)	0.11	0.20	0.19	0.36
3.5 GeV/c (intermediate)	0.025	0.046	0.094	0.173
26 Gev/c (maximum energy)	0.0005	0.0008	0.013	0.023

2.3 Interaction and temperature rise

The wire scanner must be able to measure the highest beam intensities achieved at present in the PS. Due to interaction with the circulating beam, the temperature of the wire increases during traversal of the beam. Beam traversal is so fast that conduction along the wire and heat radiation are negligible. While measuring the emittance ε_x, the temperature rise is then [3]:

$$\Delta T = \frac{k}{C_v}\,\frac{dE}{dx}\,\frac{\beta N}{v\tau}\sqrt{\frac{3}{p\,\beta_z\,\varepsilon_z}}$$

where k is the fraction of ionisation loss converted into heat, C_v the heat capacity of the wire material, dE/dx the ionisation loss of the particles in the wire, N the number of particles and ε_z the emittance in the other transverse plane.

The coefficient k has been estimated [4] to 1/3, so that, for an intensity of 2×10^{13} ppp à 26 GeV/c and a normalised emittance of $\varepsilon_z^{*} = 30\,\pi\,\mu$rad:

for $v = 20$ m/s $T \cong 530°C$

for $v = 10$ m/s $T \cong 1060°C$

The tensile strength of the Carbon wire remains good up to 1300 °C [5], so that one can be confident that the measurements can be made on the highest intensity beams possible today in the PS (2.7×10^{13} ppp).

2.4 The monitor

2.4.1 Choice of scintillator and Photomultiplier

As mentioned in paragraph 2.1, the projected beam distribution is obtained by observing the nuclear interactions of the moving wire material with the circulating beam.

The monitor consists of a small scintillator made of NE110, a long air light guide, a set of optical filters, and a new mesh-type photomultiplier (PM).

The chosen PM, Hamamutsu R2238, has 12 stages of proximity mesh dynodes. The tri-alkalide photocathode can deliver up to 600 mA. The gain varies from 10^3 for an anode voltage of 500V up to 4×10^5 at 1500V. Linearity is good, as shown later.

Two monitors are installed for each wire scanner. One detects the secondaries at small angles in the forward direction of clockwise circulating positively charged particles, the other one looks at the negatively charged particle rotating anticlockwise.

The monitors are designed to detect secondaries with the same efficiency for all possible beam sizes and to keep the background to signal ratio as low as possible. There are optical filters to adjust the photon flux hitting the photocathode. They are neutral grey filters with transmission factors from 0.2 to 100 %, mounted on a Carousel assembly allowing an easy selection. The PM can thus be chosen to obtain a linear response along the whole dynamic range of particle energies and intensities. The optical filters also allow to check the linearity of the PM's for various anode voltages.

2.4.2 Sensitivity

The beam intensities vary from almost 3×10^{13} ppp down to a few 10^9, and the momentum ranges from 0.6 to 26 GeV/c, leading to large differences in secondary particle production rates. Moreover, the dynamic range must include the density variation between the core of the beam and its tails.

The PM dynamic range of a factor 500, given by the manufacturer, is thus not sufficient and a set of optical filters was introduced between scintillator and PM to enlarge it.

The PM sensitivity needs to be described for automatic setting of the filters and PM voltage. The semi-empirical approximate formula is:

$$S \cong K\,p\,I_p\,(1+50T)\,V^8$$

where S is the signal in ADC bits, p the momentum in GeV/c, I_p the beam intensity in 10^{10} ppp, T the transmission factor of the optical filter and V the PM voltage.

The linear dependence on the beam momentum was checked experimentally between 1.7 and 24 GeV/c (Fig. 2). The sensitivity law of V^8 was found from experimental data (Fig. 3) where laws in V^7 and V^8 are compared using a beam intensity around 18×10^{11} ppp, a 20% filter, at 24 GeV/c, with a PM voltage varying from 600 V to 950 V.

2.4.3 Linearity

Linearity is essential for the measurement precision. It was experimentally checked in two ways:

a) By varying the beam intensity: At two different energies, the proton intensity was changed at the PS Booster injection energy of 50 MeV by the standard procedure of varying the number of injected turns. The integral of the output signal over the whole scan is plotted versus intensity on Figure 4. The linearity was found to be better than 5 % up to 3×10^{12} ppp. But this method, in fact, involves a much larger scale since the integration applies also to the tails of the beam where the density is low.

b) By observing the beam at low energy and intensity first (1.7 GeV/c and 9 10^{12} ppp), then at higher energy and intensity (14 GeV/c and 900 10^{10} ppp), with various optical filters (Figs. 5 and 6.). By this method, which is more rigorous than the previous one, the linearity is found to be 2%. One notes that for zero transmission (a blank instead of a filter), one still observes a signal due to direct radiation on the PM.

3. Mechanism

The mechanical assembly consists of three parts (Fig. 7 and 8):

1) An electric motor with a crankshaft and a connecting rod.

2) A push-pull device connecting by bellows the motor in air to the fork in vacuum.

3) A fork with the wire strung between the prongs, hinged along the axis of its base.

3.1 Motor

The mechanism is actuated by a permanent magnet DC motor, with a printed-circuit rotor for small inertia. The axle carries a tachometric dynamo and a position transducer (resolver) on one side and a crankshaft on the other. This crankshaft moves a connecting rod, with needle bearings on both ends, which transforms the circular motion into a linear one. The motor shaft rotates through 180° for the total travel of the wire.

3.2 Push-pull device

The small end of the connecting rod acts on one side of a rocker, hinged at its middle. Both ends of the rocker act on arms which thus make a push-pull movement. These two arms traverse the wall of the vacuum vessel of the wire scanner, by two bellows with a stroke of 7 mm. Inside the vacuum the push-pull arms act on 4 rolling ribbons, fixed around the cylindrical base of the fork such that the linear movement of the arms is translated into the circular movement of the fork.

3.3 Fork

The prongs of the fork are stainless steel tubes, outer diameter 2 mm with 0.25 mm wall thickness. The parts closest to the wires have holes drilled for greater lightness. The wire is in fact a twisted strand of about 20 carbon fibres, each 7 µm thick. Their ends are copper plated to allow them to be soldered. The last cross drillings of the prongs bear a ceramic cartridge for electrical insulation (Fig. 9). Inside the cartridge is a copper connecting piece into which the end of the carbon wire is soldered. Electrical control wires inside the prongs of the fork, are soldered to the outside of the connecting piece.

The ends of the prongs are flat to act as a leaf spring. The wire is under a tension of about 20 grams. This is the breaking strength of a single fibre, hence there is a great margin.

The length of the wire is 107 mm. It moves over an angle of 130°: accelerating, coasting across the beam of, at 20, 15 or 10 m/s and then decelerating to a stop.

The base of the fork is a tube supported at both ends by bearings made of Vespel charged with MoS_2. This is a poly-imide, resistant against ionising radiation and able to stand baking up to 300°C.

3.4 Testing

The original wire scanner of 1984 was equipped with a 30 µm diameter Beryllium wire which usually broke after a few hundred measurements, presumably by fatigue, as the broken ends never showed signs of sputtering or melting. This was the reason to find another material, of low atomic weight, but with a greater mechanical resistance and about the same effective cross section.

The choice fell on a wire consisting of multiple carbon fibres, as there does not seem to be commercially available carbon fibres thicker than about 7 µm. Life time testing was performed on one mechanism only and was stopped after 5000 to-and-fro movements, the wire being still intact. In the PS, where 4 units are installed, no wire breakage has occurred after a year of operation.

4. Electronics

4.1 General

The electronics is housed in two racks placed close to the PS ring (Fig. 10). One rack contains the VME system, motor power supply and control modules. The high voltage supplies and stepping motor controllers are in the other rack. The VME system is connected to the PS control network via Ethernet and is used as a DSC (Device Stub Controller, front end intelligence part of the CERN standard for accelerator control).

4.2 Motor control

The motor controller module consists of a velocity servo loop, current limiter, fault detector and standby switches. The velocity servo compares the input command voltage with the tacho-generator voltage. The amplified difference feeds the motor. The output amplifier is a switched-mode bipolar supply working at about 18 kHz. It is capable of 30 A output current, but we limit it to 15 A in order to reduce the stress on the mechanism. The amplifier delivers a 95 V peak to peak square wave with very fast rise times. Possible interference on the tachometric feedback signal is avoided by a low pass filter connected to the output of the amplifier.

An 8-channel 12-bit DAC VME module (Pentland MPV954) delivers the input command voltage to the motor controller. The ±5 V full-scale output corresponds to ±1500 rpm. Motor speed is 1207 rpm for a wire speed of 20 m/s at the centre of the vacuum chamber. The acceleration time for this velocity is about 17 ms over an angle of 60°, then the speed is constant for the next 60° which takes about 8 ms. After that, it decelerates over about 50° to slow speed. It then continues until the 180° are completed and stops. The whole sequence takes about 50 ms.

The power supply for the motor controller consists of a 380V to 61V 3-phase transformer and full-wave rectifier delivering 95 VDC to the module. Because of the rapid magnetic circuit breakers and the size of the transformer (1 kVA), it is necessary to switch on the transformer in two steps. First, 46 ohms resistors are connected in series with each phase to limit the inrush current. Then, when the voltage on all 3 phases have increased to more than half of the mains voltage, the resistors are shorted out.

4.3 Position measurement

The angular position of the motor shaft is measured by a resolver, connected to the shaft of the drive motor via a nickel bellow coupling. The input to the resolver is a 7.8 kHz sine wave of 20V peak to peak. The resolver delivers two signals with amplitudes proportional to the sine and cosine of the resolver shaft angle. The position of the wire in the PS vacuum chamber is derived from the motor angle.

The resolver input signal is generated by a simple function generator. It consists of a counter, an EPROM and a DAC. The counter is clocked at 500 kHz and the 6 lowest bits are used as an address to the EPROM. The EPROM is programmed with the sine values for 64 points on a period.

The resolver signals are directly sampled. This avoids errors caused by the dynamic behaviour of the converter and is cheaper. The resolver is connected to two VME modules. One is a 32 channel ADC with a conversion time of 10 μs (Pentland MPV908A) for real time control of the motor. The other is a 16 channel 12 bit transient digitiser capable of 1 Megasamples/s (Hytec VTD1612). It has a memory of 128 kilosamples and is used for data taking.

The resolver signals are sampled twice per period at 90° and 270°. Taking the difference between the two samples, we get the sign of the signal and any DC offset is eliminated. Therefore we get 13 bit resolution from a 12 bit converter. This corresponds to an angular resolution of 0.014°. The precision of the resolver is better than ±3 arc-minutes = ± 0.050°. The calculated error of the wire position is then < ± 0.14 mm.

4.4 Electronics for Photomultipliers and optical filters

The PM is used in proportional mode. To send the signal over 300 m of coaxial cable, a buffer amplifier is installed in the PS ring about 2 m below the concrete floor level, shielded from radiation. It is connected to the PM by a 3 m long 50 Ω coaxial cable (RG 58C/U). The 300 pF capacity of the cable acts as integrating capacitor. The output impedance of the PM is 50 kΩ and the input one of the buffer amplifier is 5.1 kΩ, which gives a time constant of 1.4 μs. The bandwidth of the system extends from DC to 200 kHz.

A variable high voltage supply is used to set the gain of the PM. It is controlled by a VME module via a serial link.

The optical filters described in § 2.4.1 are mounted on a disk. A stepping motor rotates the disk to select the filter. The stepping motor controller receives pulses from a VME digital I/O module (ICV196). These pulses are generated by software before and after the profile measurement. A microswitch actuated by a cam on the disk signals the home position, allowing a precise reset after each measurement.

4.5 Data acquisition

Two VME modules are used for data taking, one for the PM signals, the other for position data from the resolvers. The PM signals are sampled once per revolution (about every 2.1 μs at high energy), synchronised with the revolution frequency delivered by the RF acceleration beam control of the machine to avoid ripple on the signal due to the bunched structure of the beam. The samples are stored in the VME module memory and read out when the measurement is finished.

The sine and cosine signals from the resolver are connected via a screened twisted-pair cable to the differential inputs of a transient digitiser and sampled every eighth PM sample. The period of the resolver signal is 128 μs so there are slightly less than 8 samples per period. These samples are also stored in the memory of the module and read out afterwards, for data treatment as explained in § 5.5.

5. Software

5.1 General

The specific software for the fast wire scanner is installed in the DSC. It was developed in C under the LynxOS operating system. It can run either in stand-alone mode, controlled from a terminal connected to the DSC, or in integrated mode, controlled from a workstation on the PS control network via the new PS/SL control protocol.

5.2 Setting-up of the Measurement

The system accepts a wide variety of measurement settings, in order to allow measurements under the different conditions in the PS machine.

A measurement can be made with one wire scanner or with two simultaneously. Any combination of two out of the four devices is accepted. The measurement can be carried out at a velocity of 10, 15 or 20 m/s of the carbon wire when it traverses the beam.

The measurement can be selected for any of the existing so-called PS "users" (which are labels describing the various cycles within the supercycle). The operator may choose whether to measure on the next occurrence of that "user" or on a specific occurrence (1-6) of the "user" in the supercycle. Moreover, there is a so-called "pbar" option, which allows the operator to let the instrument wait for the next occurrence of antiprotons in the machine.

One or two profiles per device, so-called single or double-sweep measurement, can be obtained on the same cycle. The sweeps of the measurement can be carried out at any C timing (PS general distribution 1 ms clock train) after injection (~215 ms), but a short dead time is necessary for the mechanism to settle between two sweeps.

For each device, the operator can either select the optical filter and the PM voltage manually or request an automatic setting, in which case he must supply an expected value of the beam intensity. A combination of filter transmission and PM voltage is calculated from this intensity and the momentum of the particles, which is deduced from the magnetic field corresponding to the preset C trigger (see below).

5.3 Measurement Procedure

Before a measurement can take place, a number of checks are performed in order to ensure that the system is operational and to obtain information needed for the measurement.

The vacuum in the sector of each of the devices selected for the measurement is verified, because the carbon wire may break when swept in atmospheric pressure. The measurement is cancelled if good vacuum is not confirmed.

Each device must begin the movement from the home position. Therefore, the position of each device is checked. If a device is not in its home position, it is first moved there at very low speed.

The resistance of the wire is measured. It is compared to the resistance and the number of fibres in the wire at the time of installation and yields an estimate of the present number of fibres in the wire. If any fibres seem to be broken, a warning is issued, but it is not considered a fatal error and does not inhibit the measurement.

If an automatic calculation of optical filter number and PM voltage has been requested, an approximate value of the magnetic field, B, is needed. This is obtained from a B pulse readout at the "user", occurrence, and C timing selected in the measurement settings. Since this must be done before the measurement can start, an automatic filter and PM voltage calculation costs a further supercycle or a further occurrence of the requested "user".

Information from the "user" matrix (the data base giving the basic properties of the PS "user", as defined in § 5.2) is used to find the particle type for the "user" requested for measurement. The charge of the particle, hence its direction of movement in the accelerator, decides which of the two photo multipliers associated with each device to use for the measurement.

If an automatic calculation of optical filter and PM high voltage has been requested, these values are calculated according to the sensitivity formula in § 2.4.2 in such a way that a filter with the highest possible transmission is chosen. If two devices have been selected for the measurement, they are treated individually with respect to the automatic calculation setting, i.e. it is possible to have an automatic setting for one and a manual setting for the other.

When all of the above steps have been completed, the selected optical filter is turned into position, the PM voltage is set, and the ABB power supply for the wire scanner motor is switched on. When the cycle corresponding to the requested "user" and occurrence arrives, the measurement is carried out at the preset C timing.

Immediately after the movement of the device has finished, the power supply and the PM voltage are switched off and the optical filter device turned back to its home position. Then the data from the sampling of the PM and the resolver sinus and cosine channels are read out.

5.4 Movement of the Wire

Each time a measurement is carried out, the device is moved first through the beam to its outer end position and then back to its home position again. In the case of a double-sweep measurement, the sweep back to the home position yields the second profile. In the case of a single-sweep measurement, the device is moved to the home position after the measurement cycle has finished and before the next cycle starts, i.e. when there is no beam in the machine.

When the measurement cycle begins, the motor is taken from standby to ready-mode. The DAC is loaded with a value corresponding to the speed set by the operator and started at a time such that the device will pass the centre of the machine aperture at the C timing set for the measurement. As soon as the movement has started, the beam intensity signal is sampled.

When the resolver signals, which are read out every 64 μs, indicate that the motor axle has reached 60 degrees, data taking is started. This point corresponds approximately to where the wire enters the machine aperture, and by this time the motor has finished accelerating and reached its nominal speed. The B pulse is read out immediately after the start of data taking. This train, generated from the PS main magnet field, delivers a pulse for every increase by one gauss.

The data taking will continue autonomously until a preset number of samples have been taken, by which time the wire will have exited from the machine aperture on the other side. When the data taking has finished, the B value is read out again. The movement continues at full speed until the motor axle reaches 120 degrees, which is approximately where the wire leaves the machine aperture. At this point, the DAC is loaded with a small value that will make the motor brake and continue at very low speed. Just before the end position, 180 degrees, is reached, the DAC is set to 0 volt and then stopped, so that the motor stops at 180 degrees.

The movement in the other direction, back to the home position, is carried out in exactly the same fashion. In the single-sweep case, the movement is started at a time that allows the device to pass the centre of the vacuum chamber at the C timing requested for the second measurement, and in the double-sweep case, it is started when the cycle ends. When the second sweep has finished, the motor is put into standby.

5.5 Data Treatment

The principle for the data treatment is to convert the resolver sine and cosine data for each profile obtained from the measurement to corresponding positions of the wire and then to find the rms (root mean square) of the distribution of the PM signal with respect to the position.

The beam width, the emittance, and the normalised emittance are calculated from the rms. This procedure is done in several steps. First the offset of the PM signal is calculated. This value will be subtracted from the distribution later. Then the amount of PM and resolver data is reduced by selection of a smaller range centred around the peak of the PM signal. A parabola is fitted to the maximum of the PM profile in order to obtain a better value for the maximum of the distribution.

The value of the magnetic field at the time of traversal of the centre of the beam is calculated by interpolation of the two B values sampled before and after the data taking. They are interpolated linearly at the location of the fitted maximum of the PM signal. The momentum p is calculated from the interpolated B as $p = 2.2279 \times B\rho$, where B is the field and ρ the bending radius of the PS magnets.

The fitted PM maximum is also used to calculate a level at which the tails of the profile will be cut off. The tails of the distribution, which is approximately gaussian, will thus be replaced by true gaussian tails, in order to avoid the tails strongly influencing the calculation for the bulk of the beam [6]. The cut-off level is chosen as 7.5% of the value of the fitted PM maximum corrected for the offset.

The resolver cosine and sine values are converted to wire positions via a conversion to angles of the axle of the wire scanner motor. First, a set of angles is calculated by simply taking arctan of each sine value divided by its corresponding cosine value. Theoretically, these angle points should lie around a very short section of a sine wave period, if the motor is assumed to be moving with constant speed during the traversal of the beam. A parabola is used as an approximation of this sine wave, and a least-square fit of a parabola is made to these angles. Then the coefficients obtained from the least-square fit are used to calculate eight times as many angle points as there were sine and cosine samples from the beginning, since the PM signal was sampled with a frequency eight times that of the resolver signal sampling.

The angles of the motor axle are converted to corresponding positions of the wire projected on a plane perpendicular to the beam. The conversion is made with a formula based on the static geometry of the mechanics holding the wire (see Appendix). Therefore, a correction for the dynamic case is necessary. This correction is based on interpolation in tables established from calibration measurements in the lab.

These calibrations are made with a laser beam hitting a photo diode indicating a position in the vacuum chamber. The signal from the photo diode is sampled as the wire moves during a sweep. The interruption of this signal as the wire traverses the laser beam is used to calculate the angle of the motor axle and then the corresponding theoretical position at that particular real position. The laser beam and the photo diode are moved to different positions in order to obtain a series of pairs of real and theoretical positions to make up a calibration table. A separate table is kept for each combination of device, velocity, and sweep direction.

The rms value of the new distribution obtained from the position samples and the PM samples subtracted by the offset and the 7.5% tails is calculated. The rms value is multiplied by 1.1764 to compensate for the cut-off tails. The emittance ε is then calculated from $\varepsilon = (2\sigma)^2/\beta_t$, where $\sigma = 1.1764 \times$ rms and β_t is the Twiss parameter for the location in the machine where the wire scanner is installed. β_t has been taken from the MAD simulation program [7]. The normalised emittance ε^* is calculated from $\varepsilon^* = \beta\gamma\varepsilon$. β and γ are the classical relativistic parameters and $\beta\gamma = p/m_o$, where p is the momentum calculated earlier and m_o is the rest mass of the particle type read out from the "user" matrix during the preparations of the measurement. The beam width is calculated from $w = 4\sigma$.

5.6 Integration with the PS Control System

The integrated version of the wire scanner system consists of three major components, namely the wire scanner program itself running on a DSC and constituting the hardware interface; the "user" interface which runs on a PS control workstation; and a server program, a so called equipment module, which runs on the DSC and which relays the communication between the application program and the hardware interface.

The communication between the wire scanner program and the equipment module is maintained via two message queues. One message queue holds control messages that the server sends to the wire scanner program when it receives requests from the application program. The other queue holds acquisition messages that the wire scanner program sends in reply to some of those control messages.

The wire scanner program is built on the skeleton program 'body', which facilitates the integration of DSC instrumentation software with the control system protocol [8], [9]. It consists of four POSIX threads (threads are parallel execution paths within a process sharing the same process context, and LynxOS provides a library conforming to the calling sequences proposed by POSIX, the so called "POSIX threads"). One of these is dedicated to reading incoming control messages and deciding upon the action to be taken. One thread executes the measurement itself, and another one processes the acquired measurement data and assembles an acquisition message to be returned to the server. The fourth thread deals only with exceptional cases, such as program abort, reset, and recover signals. The communication between the threads in the program takes place via LynxOS signals.

5.7 Application program

The application program is available from the standard Toolbar in the PS Operation environment on the workstations [10]. It allows to launch a measurement after specification of the conditions:

- the choice of device(s) and plane(s) (among the two horizontal and two vertical mechanisms) and the number of measurements to be executed on the same cycle (1 to 4 for forwards, backwards, horizontal and vertical),
- the "user" and its occurrence in the supercycle, or "pbar" option,
- the timing in C-train and the timing of the second measurement if requested,
- the expected beam current at the time of the measurement,
- the required velocity with a limited choice of a few values (10, 15 or 20 m/s).
- the PM voltage specified by the operator and the choice of optical filter, or the request for the EM to calculate the best voltage (from the expected I_b, the type of particle and the measured B train).

The results can be obtained from the last measurement performed or from any archived data. The display contains (Fig. 11):

- the measurements conditions: "user", occurrence, plane and monitor, timing, requested wire velocity, PM voltage,
- the measured beam intensity, particle type, B acquired, calculated p,
- the emittance and beam width measured and the normalised emittance $\varepsilon^*=\beta\gamma\varepsilon$
- the profile display: PM signals and positions 4σ before and 4σ after the beam maximum for the maximum of four profiles taken at each measurement.

6. Conclusion

The main feature of the first generation wire scanner, installed in 1985, was its high velocity, obtained with a high-torque motor and low inertia mechanism. The upgrading, completed in 1994, allows to reap the full benefit from this performance after improvement in many respects. New photomultipliers provide better linearity and wider dynamic range. The beryllium wire was replaced by a strand of carbon fibres with a new method of fastening to the prongs of the fork. The position measurement and acquisition have been completely changed to attain a better precision. Electronics and controls software are totally new, which improves the measurement quality as well as the ease of operation, while bringing the system up to modern standards. Though then not completely operational, the new system was extensively used in December 1993, during a test run in which the PS produced a LHC-type beam of high luminosity [2]. During, this run, it performed more than 1300 measurements without failure and was essential in the success of these tests. It is estimated that the emittance, proportional to the square of the beam dimension, was determined with a precision of about 5% [2] [11]. During 1994, refinements were made to the software and the system as a whole was rendered fully operational. It is now one of the basic instruments for the evaluation of the PS beam quality.

6. Ackowledgements

The authors wish to thank all those who contributed to this development, and especially G. Benincasa, J.P. Bovigny, R. Cappi, S. Hancock, M. Hansen, H. Koziol, G. Martini, M. Martini, L. Merard, D. Pearson, T. Pettersson, K. Priestnall, U. Raich and M. van Rooij.

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APPENDIX

Calculation of the wire position

The wire fork angle at the home position is calculated first, then it is expressed for the current crankshaft angle. After that, the wire position is calculated from the difference between the two fork angles plus the initial fork angle (Fig. 12).

The crankshaft angle at the home position is:

$$\alpha_0 = \arccos\left(\frac{(C+B)^2 + V^2 + H^2 - A^2}{2\cdot(C+B)\cdot\sqrt{V^2+H^2}}\right)$$

where:
- C = crank radius
- B = length of connecting rod
- V = vertical distance between motor shaft and rocker centre
- H = horizontal distance between motor shaft and rocker centre
- A = radius of rocker arm

The distance from motor shaft to rocker centre is:

$$d = \sqrt{(H - C\cdot\cos\alpha)^2 + (V - C\cdot\sin\alpha)^2}$$

where:

α = angle between crank shaft and a line from crank shaft centre to rocker centre

The angle of d is:

$$\beta = \arcsin\frac{H - C\cdot\cos\alpha}{d}$$

The angle between d and A is:

$$\gamma = \arccos\left(\frac{d^2 + A^2 - B^2}{2\cdot d\cdot A}\right)$$

The connecting rod lever angle is:

$$\delta = 270° - \beta - \gamma - \varphi$$

where:

φ = angle between rocker arm and connecting rod lever

Distance from rocker centre to fork shaft centre:

$$K = \sqrt{X^2 + Y^2}$$

Distance from top lever to fork shaft centre:

$$l = \sqrt{L^2 + X^2 + Y^2 - 2\cdot L\cdot(X+Y)\cdot\cos\left(\delta - \arctan\left(\frac{Y}{X}\right)\right)}$$

where:
- Y = vertical distance from rocker centre to fork shaft centre
- X = horizontal distance from rocker centre to fork shaft centre
- L = radius of lever arm on rocker assembly

Angle between K and l:

$$\phi = \arccos\left(\frac{X^2 + Y^2 + l^2 - L^2}{2\cdot(X+Y)\cdot l}\right)$$

Distance from bottom lever to fork shaft centre:

$$m = \sqrt{L^2 + X^2 + Y^2 - 2\cdot L\cdot(X+Y)\cdot\cos\left(180°-\left(\delta - \arctan\left(\frac{Y}{X}\right)\right)\right)}$$

Angle between K and m:

$$\chi = \arccos\left(\frac{X^2 + Y^2 + m^2 - L^2}{2\cdot(X+Y)\cdot m}\right)$$

Length of top push rod:

$$p = \sqrt{l^2 - (R+O)^2}$$

Length of bottom push rod:

$$q = \sqrt{m^2 - (R+O)^2}$$

Average length of the two push rods:

$$s = \frac{p-q}{2}$$

Fork angle is:

$$\eta = \frac{s}{R} + (\chi - \phi)$$

The vertical position of the wire is:

$$w = F\cdot\sin(\eta - \eta_0 + \psi)$$

where:
F = distance from fork shaft centre to wire centre
ψ = home angle of the fork
η_0 = fork angle at the home position ($\alpha = \alpha_0$).

FIGURES

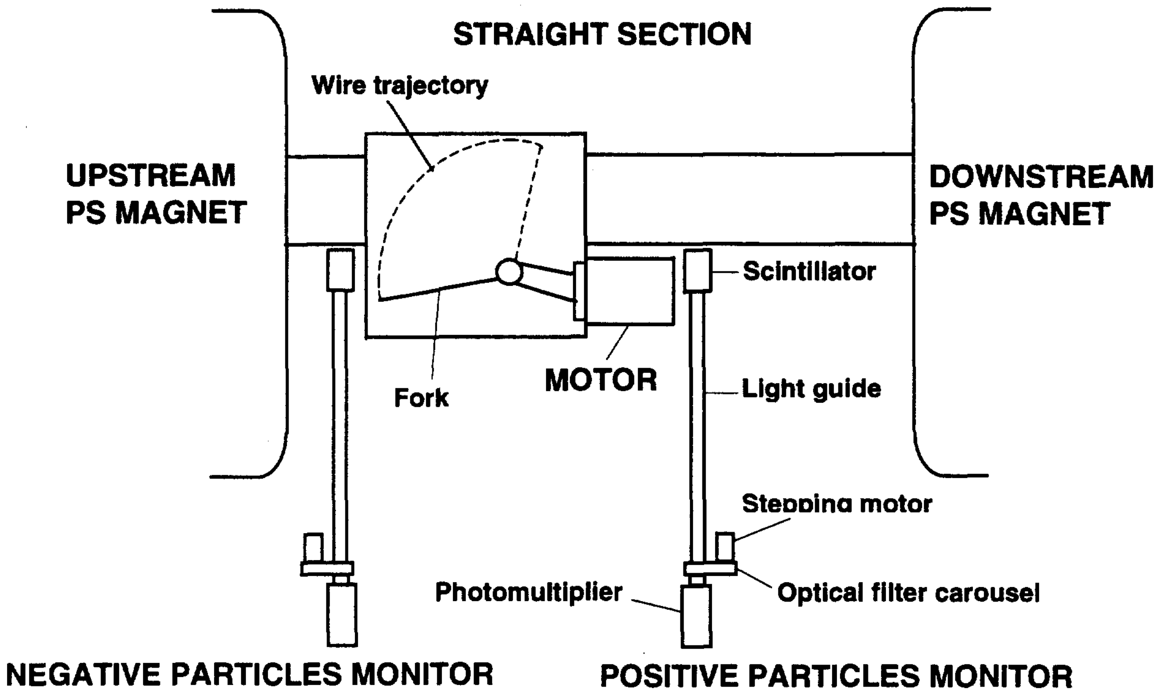

Fig. 1 - Schematic view of a vertical plane measurement device in the PS ring

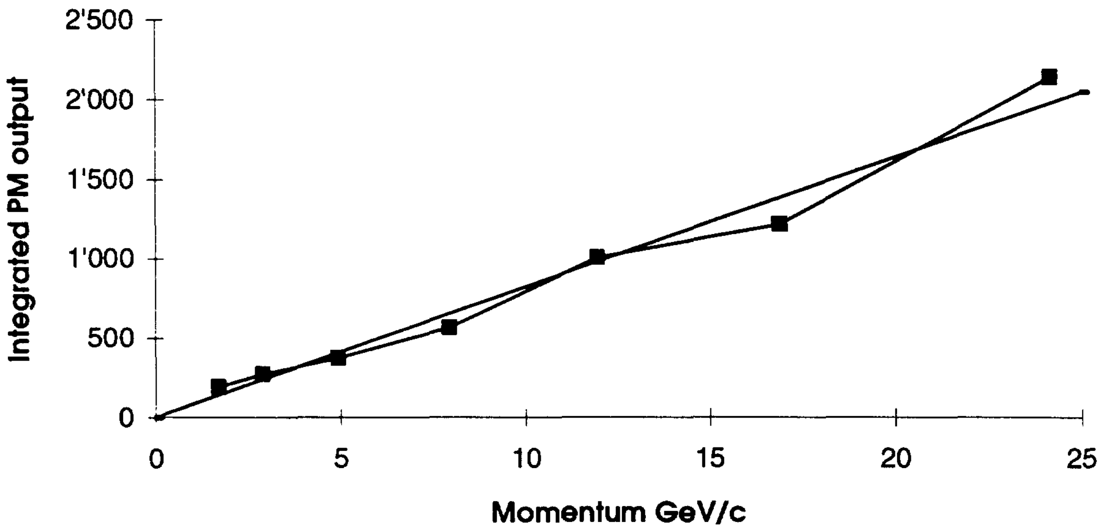

Fig. 2 - Momentum dependence of the integrated PM signal in arbitrary units for a beam intensity of 3×10^{11} ppp, a PM voltage of 800 V and an optical transmission of 100 %

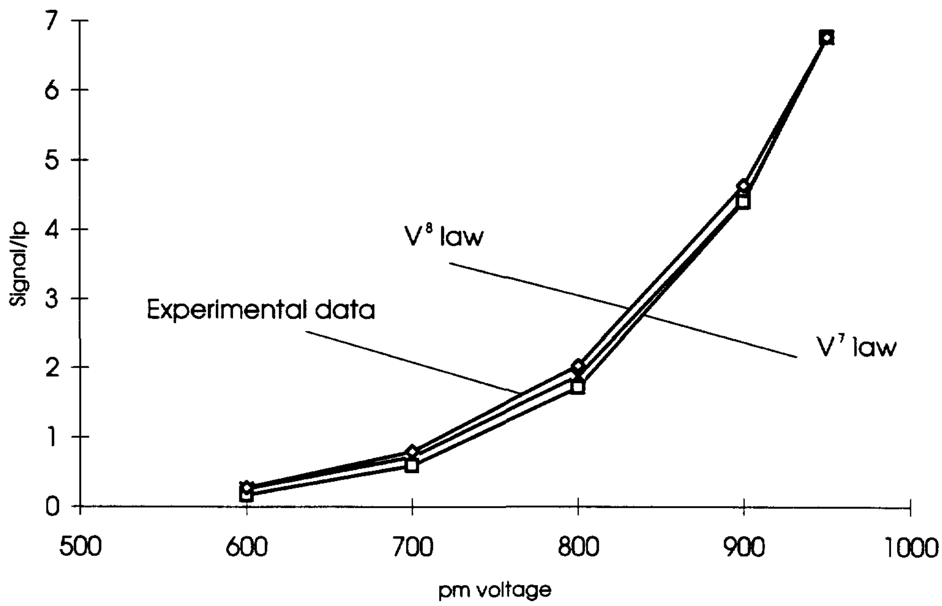

Fig. 3 - Experimental signal/beam intensity (in arbitrary units) versus PM voltage, compared with equation in 2.4.2

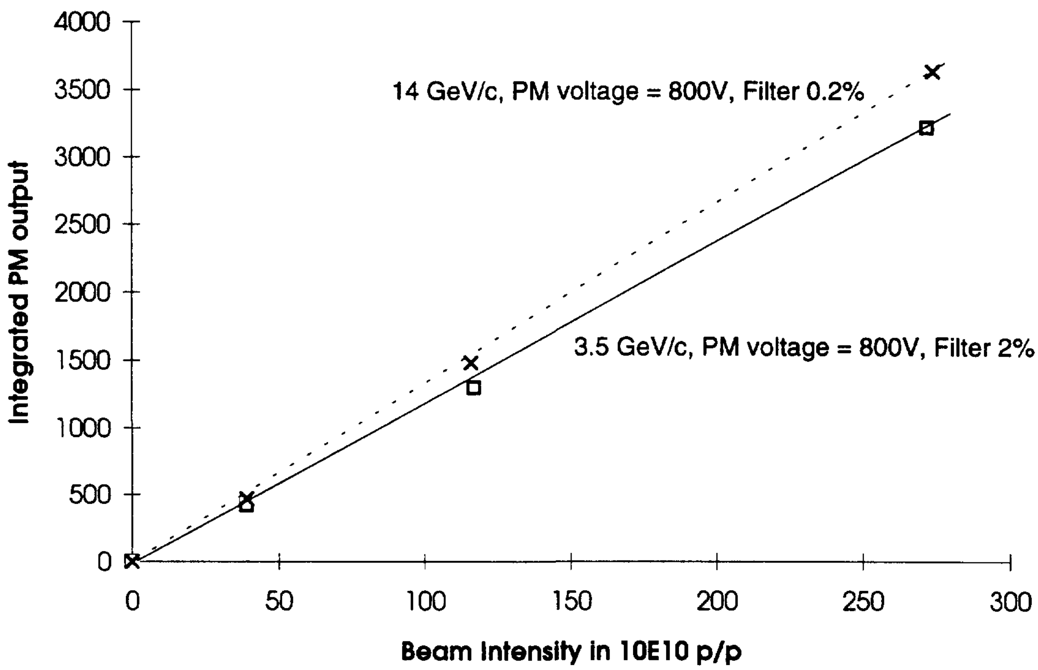

Fig. 4 - PM linearity check showing the integrated signal (in arbitrary units) versus intensity, at 3.5 GeV/c and 14 GeV/c

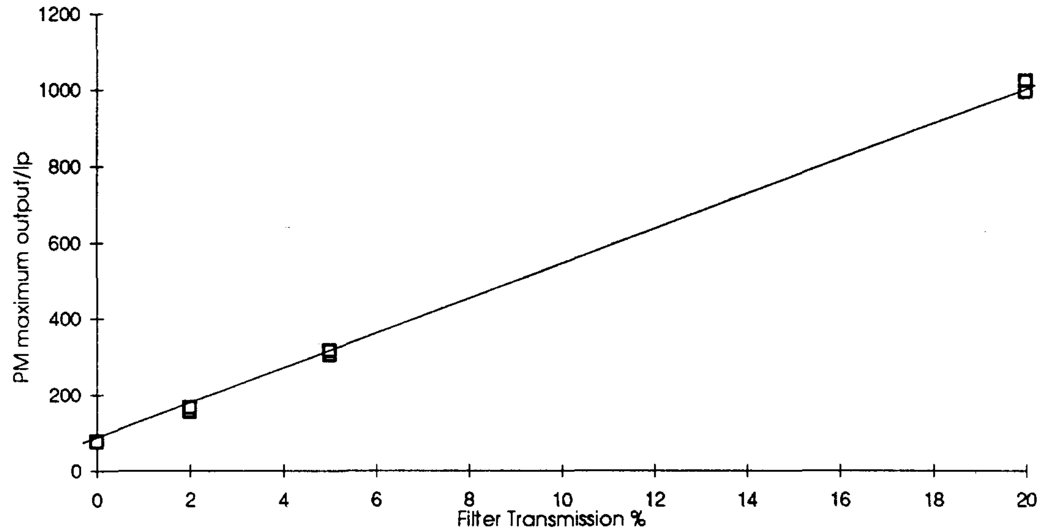

Fig. 5 - PM linearity check showing the signal maximum (in arbitrary units) normalised to the beam intensity versus the optical filter transmission factor at 1 GeV energy and an intensity of about 3×10^{12} ppp

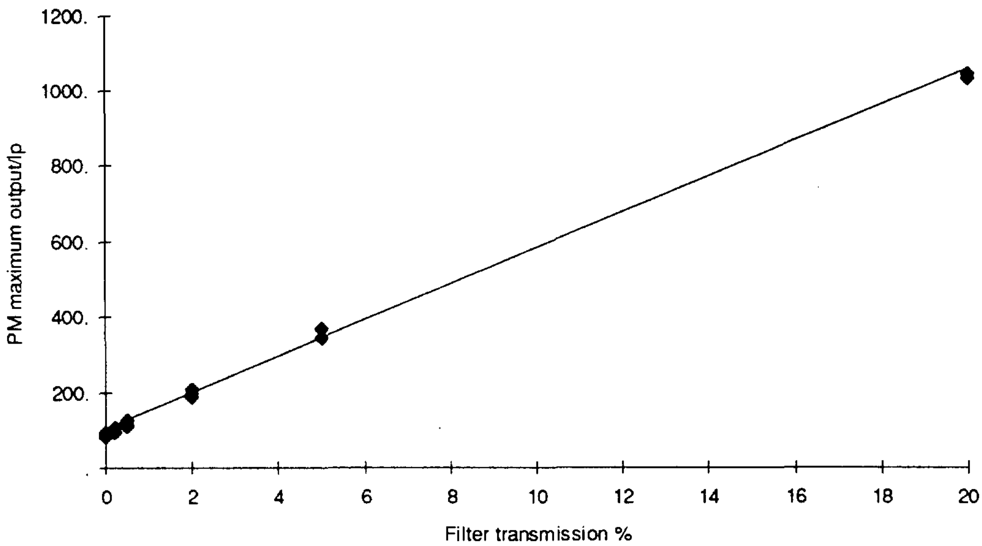

Fig. 6 - PM linearity check showing the signal maximum (in arbitrary units) normalised to the beam intensity versus the optical filter transmission factor at 14 GeV/c momentum and an intensity of about 9×10^{12}ppp

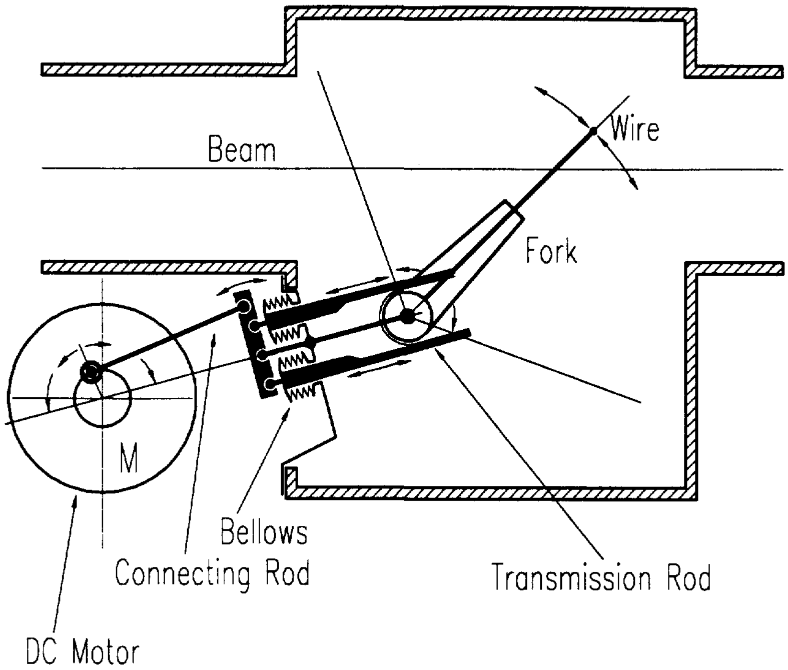

Fig. 7 -Schematic view of the wire scanner mechanism

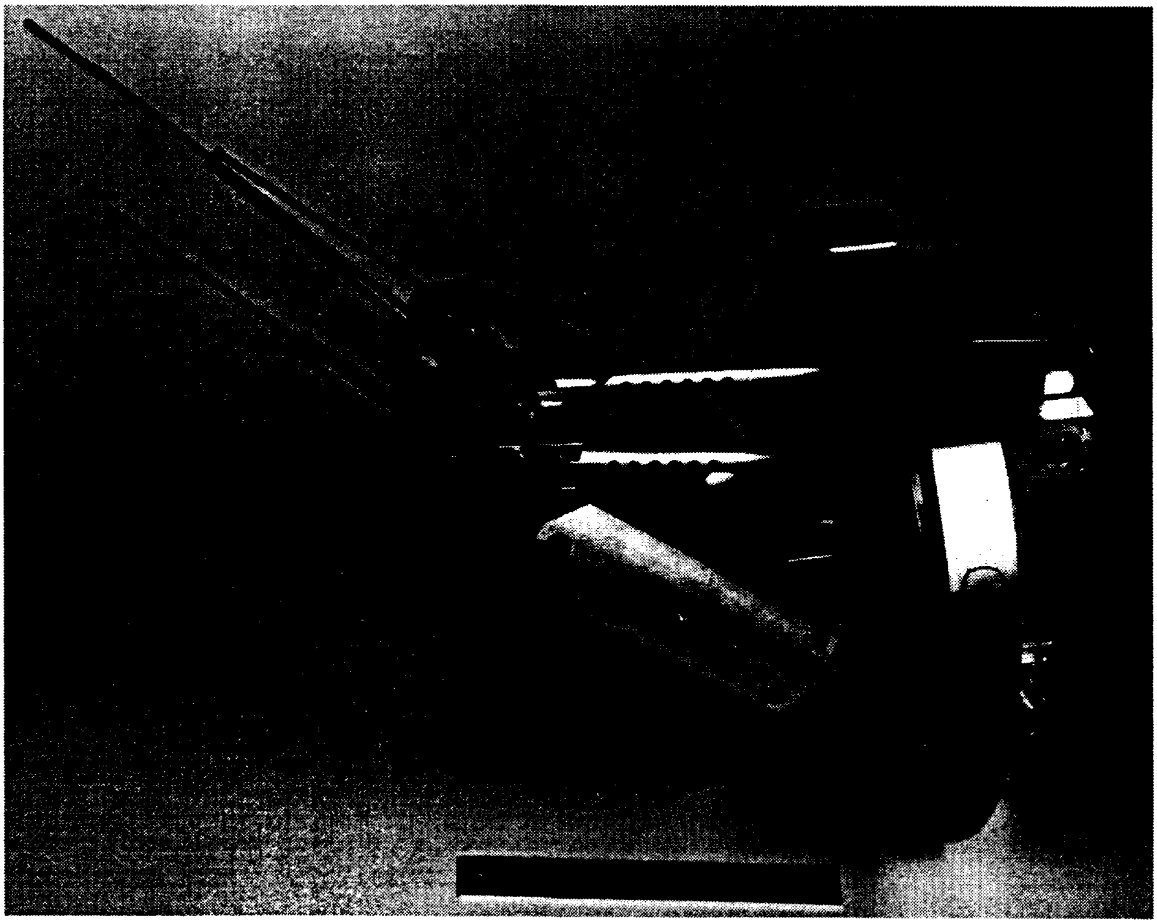

Fig. 8 - View of the mechanical assembly

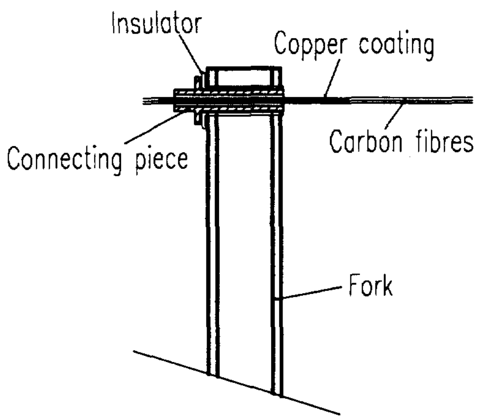

Fig. 9 - The extremity of one of the prongs, showing the wire fastening

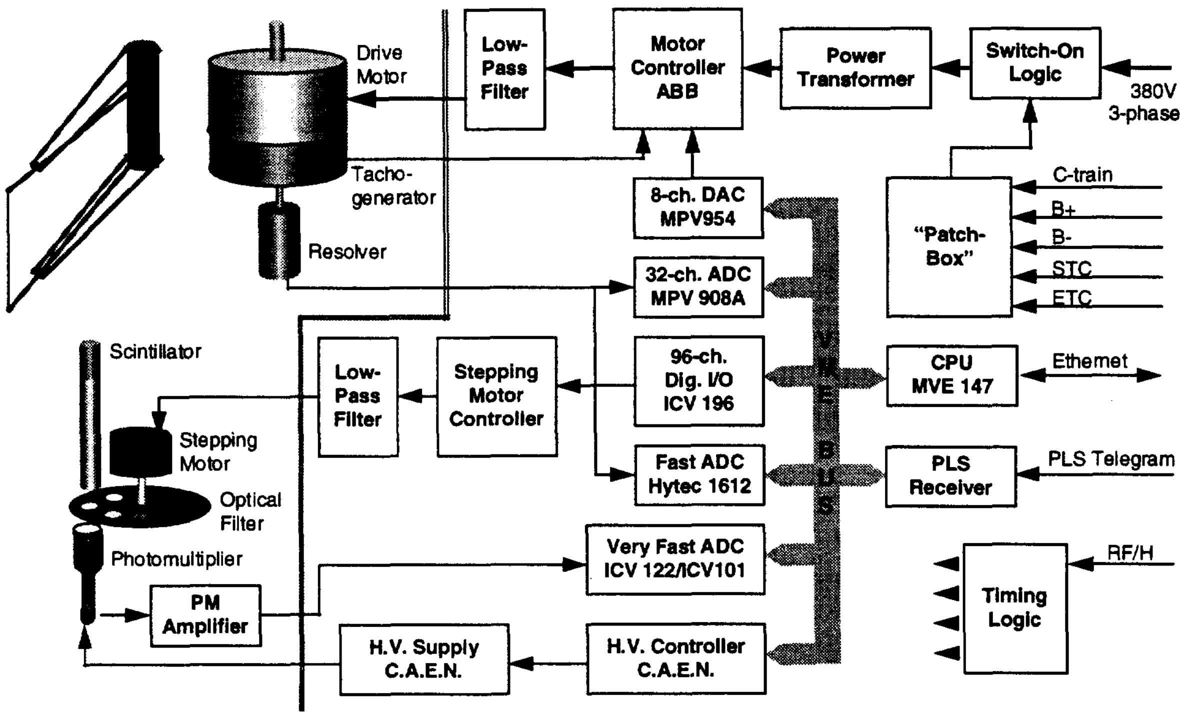

Fig. 10 - Block diagram of the electronics

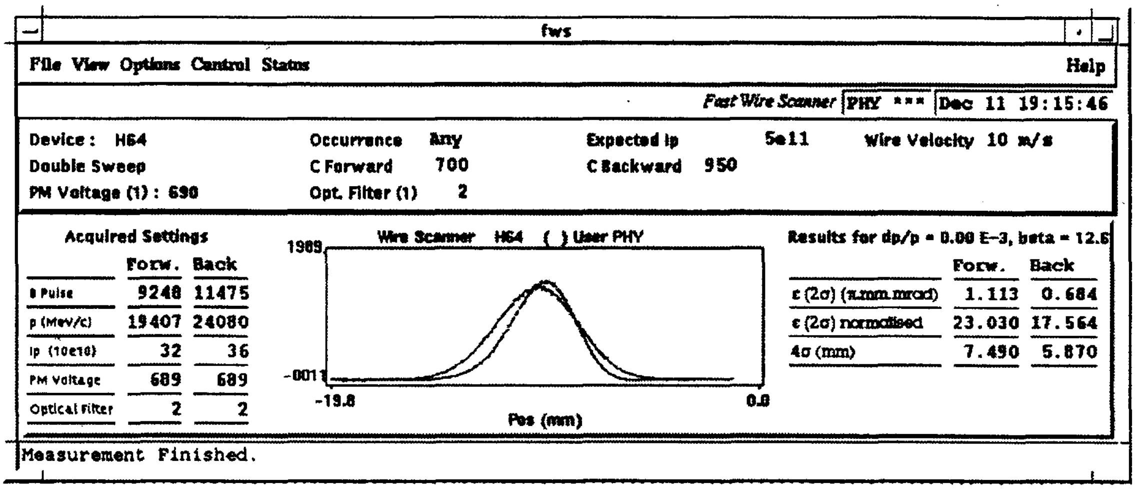

Fig. 11- Results from application program showing a forth and back scan

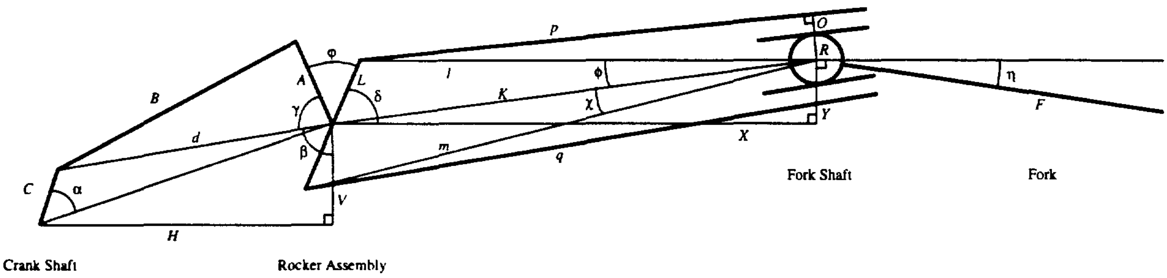

Fig. 12 - Geometry of movements