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WIDE DYNAMIC RANGE (7 DECADES) BEAM POSITION AND PROFILE MEASUREMENT FOR THE CERN LEAR

L. Bernard, C. Dutriat, J. Gabardo,
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Summary

The wide range of beam intensities to be used in the Low Energy Antiproton Ring (LEAR) has required the development of new instrumentation. For the measurement of injection and transfer trajectories and beam shape new secondary emission grids and electronics have been developed. They cover the range from 10^8 to 10^{14} particles satisfying both the LEAR and LINAC requirements. For closed orbit position measurement, an electrostatic pick-up system has been designed for bunched beams from 10^7 to 5×10^{11} p or $\bar{p}$. This paper briefly describes both these developments.

Closed Orbit Observation

General Requirements

Beam position measurements are required at 16 locations around the ring for a wide range of intensities (10^7 to 5×10^{11}) and bunch lengths from 5 metres to 40. The resolution is 0.1 mm with a small degradation below 2×10^8 particles. Analogue observation is required for machine studies with a bandwidth from 2 kHz to 50 MHz enabling oscilloscopes measurements of $\sim$5% accuracy to be made for intensities above 5×10^8 particles. The analogue signals are used for the Radial Loop of the Beam Control, for detection of betatronic oscillations and Q measurements, etc.

The use of 16 pick-up stations for the closed orbit measurements was dictated by the available space, machine symmetry and sufficient points for the anticipated Q value of 2.7. Eight stations are located in bending magnets whilst the others are in straight sections. Each station comprises a horizontal and vertical pick-up whose electrodes are polarized to -24 volts to provide a clearing field for positive ions. The machine works on the first harmonic with momenta from 0.2 to 2 GeV/c and the corresponding revolution frequencies vary from 400 kHz to 3.5 MHz. The pick-ups must be compatible with a UHV of 10^{-12} Torr and be bakeable to 300°C, returning to correct alignment after chamber deformation. Also the head amplifiers must function in high magnetic fields.

The beam position is determined from the ratio of the voltage difference (V_Δ) to the voltage sum (V_Σ) of the potentials induced on the pick-up electrodes. The resolution of the system depends ultimately on the ratio of extraneous signals to the sum signal. These unwanted components can be thermal noise, electromagnetic interference from RF or kickers, etc., inadequate common mode rejection and cross-talk especially in signal multiplexers. At each stage of the design these problems had to be fully considered.

Pick-Ups

Minimum capacitance electrodes could improve the signal to noise ratio at low intensities but problems of common mode rejection arise at high signal levels. Therefore, the electrode capacitance was chosen for a maximum electrode voltage of 2.5 volts peak. Beam and vacuum chamber sizes require different pick-ups for the bending magnet and straight sections; the former being rectangular (160 × 42.5 mm) and the latter round in cross-section (182 mm diameter). Both types have the same electrode capacitance (400 pf) and the same physical length (80 mm). They have been constructed using an Al_2O_3 substrate for stability and carefully aligned in the chamber to an external reference.

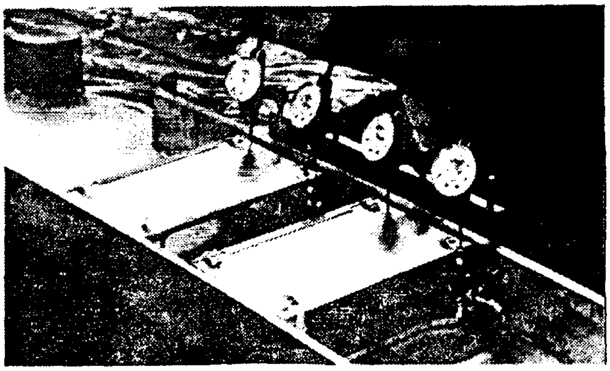

Figure 1 - Alignment of pick-ups in vacuum chamber.

Analogue Electronics

To cope with the wide range of signals and reduce the effect of external interference, 4 switchable amplifications will be available. Gains of +64, +36 and +14 dB are operational and the -14 dB stage has now to be added. As can be seen in Fig. 2 the gains are not selected in the head amplifier because the high magnetic field precludes the use of magnetic relays. Semiconductor switches could impair the S/N ratio and bandwidth whilst thermal relays are delicate and should be used only when there is no alternative. A "foot" amplifier has been mounted close to the head amplifier and a carefully screened multi-coax cable joins the two.

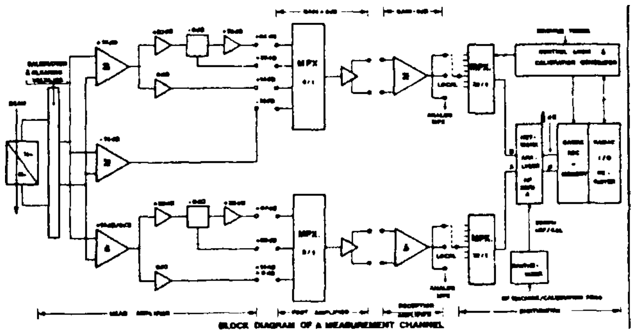

Figure 2

From the machine the signals are sent differentially on double screened coax to the equipment room where reception amplifiers with cable loss compensation provide 3 outputs for each signal (3 × 64). Additional outputs from 2 stations are provided for beam control with independent gain selection. A wideband 64 to 4 way multiplexer allows easy selection and observation of two analogue signals and an additional pair of 32 to 1 way multiplexers enable all pairs of outputs to be scanned by the network analyzer.

Figure 3 shows the analogue signal for a bunch of

$\sim 10^{10}$ protons in the machine and Fig. 4 gives the output voltage for different intensities of a 40 metre bunch. (The differential voltage transmitted from the machine is twice the output voltage and, for V_Σ, it can always exceed 100 mV at intensities above 2.5×10^7).

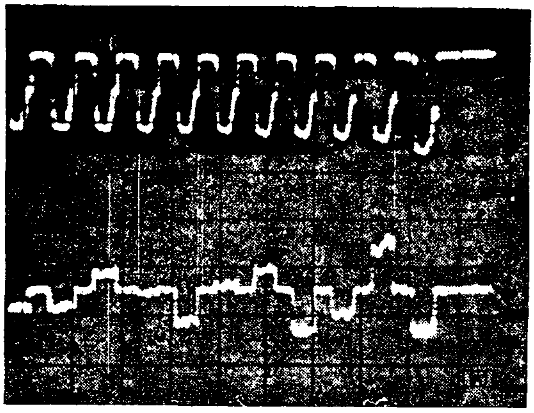

Figure 3 - Analogue signal of a bunch at injection.

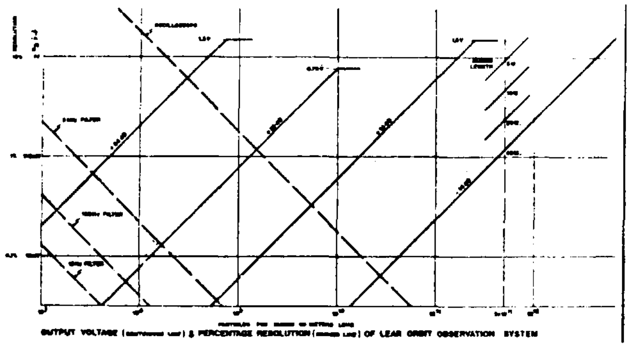

Figure 4

Network Analyzer

A Hewlett-Packard HP 3570A network analyzer is used to measure the ratio of V_Δ to V_Σ and their phase relationship. The ratio V_Δ/V_Σ for a centred beam will be $\sim$ -60 dB representing CMRR and cross-talk errors, and for a beam at the extremity of the chamber the ratio approaches 0 dB.

The phase angle determines the direction of the beam displacement. A small phase offset was introduced in the network analyzer to overcome the problems of measuring around ±180°. The analogue output of the instrument is digitized by a standard CAMAC ADC with memory because the internal conversion rate of the HP 3570A is too slow. The measurement time is a function of the bandwidth of the internal filter. Normally this is left at 3 kHz and each measurement takes 1.5 ms. When the measurement cycle is initiated all pick-ups are scanned. First the vertical followed by the horizontal - no significant change of position is anticipated in the 24 ms required to scan each plane. In exceptional cases it may be desirable to use the 100 Hz or 10 Hz filters of the network analyzer, in which case each measurement takes 25 ms or 250 ms, respectively.

Although the network analyzer itself has 100 dB dynamic range and apparently less gain is required in the head amplifier it was considered prudent to keep the transmitted signals as high as possible. These aspects of the design will be fully evaluated in future machine studies.

Calibration

Test and calibration signals can be injected at the head amplifier input but, when beam is available, the pick-up signals are used. A central beam can be simulated by shorting the electrodes whilst the extreme displacements are simulated by applying the total signal to the positive or negative input. These calibrations take into account all long term gain variations in the system and the resulting coefficients, with the individual pick-up offsets and sensitivities, are stocked in computer tables for subsequent closed orbit calculations.

Performance

Combined Head and Foot Amplifier

	Δ	Σ
CMRR up to 4.5 MHz	>60 dB	
Gain dB	+12.5/+36/+64	+14/+36/+64
Noise	<5 nV.Hz$^{-1/2}$	<5 nV.Hz$^{-1/2}$
Bandwidth	1 kHz to 70 MHz	
Max. V_{out} differential	±3 V/±1.5 V/±3 V	

Reception Amplifier

CMRR up to 4.5 MHz	>43 dB	
Gain variable	-1.5 to -11.5 dB	nom. -6 dB
Bandwidth	400 Hz to 80 MHz	
Cable loss compens.	0 to 4 dB at 100 MHz	

Observation Multiplexer

Bandwidth	Dc to 200 MHz
Crosstalk	<-80 dB at 4.5 MHz

Scanning Multiplexer 32/1

Attenuation	2 dB
Bandwidth (-3 dB)	10 MHz
Dynamic range	>4 V p̂-p̂
Crosstalk worst case adjacent input to output	<-74 dB at 4.5 MHz
Crosstalk all inputs in phase to one output	<-50 dB at 4.5 MHz

Overall Performance

Mechanical tolerance round p.u.	±0.1 mm
Mechanical tolerance rect. p.u.	±0.3 mm
Measurement of zero offset	±0.1 mm
Measurement of p.u. sensitivity	±0.2 %
Common mode rejection	±0.1 %
Crosstalk in multiplexers	<±0.2 %
Overall accuracy	±0.32 mm ±0.3 %

Beam Profile SEM Grids

To measure the Linac and LEAR beam profiles, a secondary emission monitor grid has been developed which is semi-transparent at the energies considered. It is based on the principle that when a primary beam passes through a thin metal foil a few percent of low energy secondary electrons are emitted from the superficial upper and lower layers of the foil, giving a corresponding electrical signal. Because of their low energies (<100 eV) the maximum depth from which the secondary electrons can escape, is about 80 Å. Thus the material and the surface conditions of the foils play an important role in the emission of electrons. This emission varies from 20% to 7% of the incident beam for energies from 5 MeV to 200 MeV, respectively.

There are two types of electronics; one for the Linac beam and one for the LEAR injected and ejected beams.

For the Linac the main characteristics of the beam are:

Type of particle	p, $\bar{p}$, H^-, D^+, alpha
Beam energy	10, 30, 50 MeV
Beam intensity	5 to 150 mA
Beam length	2 to 150 μs
Repetition rate	1 to 2 per second

and the LEAR injection line:

Number of particles	10^8 to 10^{11}
Beam length	Single bunch of about 300 ns

In the LEAR the monitor is placed in ultravacuum and must stand repeated baking at 300°C. Hence it is manufactured from titanium strips and frame, stainless-steel connectors and ceramic supports. The strips are chemically machined from an 8 μm titanium foil and they are formed, assembled and tensioned in the aluminium oxide combs (Fig. 5) by a specially constructed tool. Stainless-steel wire connections are spot welded to the titanium strips. A mechanism, incorporating a pneumatic piston and bellows, which allows a rotation of 16.5 degrees, is used to automatically position the SEM grid detector. Each monitor consists of 15 titanium strips 1.5 to 3.5 mm wide (depending on the beam profile to be measured) and spaced 0.5 mm apart. On each side of the grid, large 100 mm strips permit the measurement of that part of the beam exceeding the dimensions of the grid.

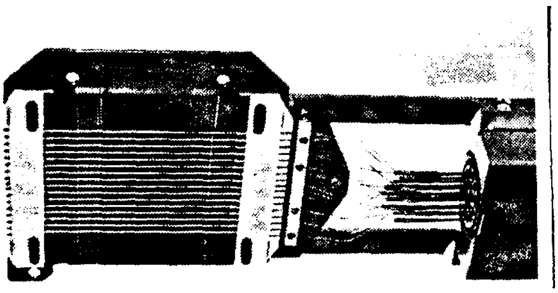

Figure 5 - SEM grid-beam profile detector head.

SEM Grid Electronics and Data Treatment

For reasons of economy, either the vertical or horizontal detector strips are switched to the local electronics, whose role it is, to provide clean beam signals in electrically noisy surroundings, and to raise the signal levels, so that they can be transmitted without degradation over a distance of about 100 metres. In the case of the Linac beams, it is sufficient to use, for each channel, an operational amplifier followed by an inexpensive integrated sample and hold circuit. The resulting 16 quasi-DC signals can then be transmitted over a multiwire cable to a CAMAC crate with a multiplexer and a fast 12-bit converter filling a 16-word buffer memory. In the case of the LEAR low intensity beams with a beam bunch integration time of only 300 ns, the local electronics is slightly more elaborate (Fig. 6), using an ungated integrator built from a JFET operational amplifier with an input resistance of $>10^{12}$ ohms feeding, on its most sensitive range, a polystyrene capacitor of 2 pf in parallel with a 10 megohm resistor. This intetrator is followed by an amplifier having a gain of 10 to 100, as desired, and feeding a sample and hold circuit via a high pass filter.

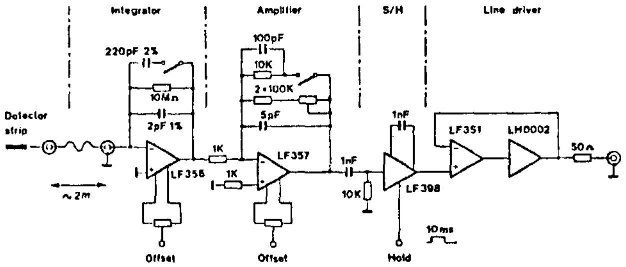

Figure 6 - One channel low intensity beam integrator.

The equivalent input noise of the complete circuit corresponds to 3×10^{-13} coulombs.

Line drivers then feed a multiwire cable for transmission to the digitizing equipment which, in 4 ms, can convert 32 signals.

At a maximum update rate of 2 Hz, a histogram display of the 16 detector signals together with significant parameters is produced by the LEAR PDP-11 control computer on a colour TV monitor (Fig. 7).

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SEMGRID-FAST  *14-DEC-82*17:00:59
 ZONE:E4  LOC:11       HORIZONTAL
 ++++++++++++++++++++++++++++++++++++++
 +                                    + TSAMPLING=
21-+++                                +       8µs
 +-++++++++++++                       +
14-+++++++++++++++++++++++            +HWGAIN0.100
 +-+++++++++++++++++++++++            +SWGAIN=4.00
 7-+++++++++++++++++++++++            +
 +-++++++++++++++++++                 +
 0-++++++++                           Q-PARTIAL=
 --+                                  -  100.0 %
 7                                    +
 -                                    -   MEAN=
14                                    +    9.5 mm
 -                                    -   SIGMA=
21                                    +    5.8 mm
 -                                    -
QR                                    Q-RESIDUAL=
 ++++++++++++++++++++++++++++++++++++++      0.0 %

STATUS: O.K.                          Q-TOTAL=100%
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Figure 7 - Typical output from a profile measurement of an antiproton beam of 10^9 particles.

Acknowledgements

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