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THE ORBIT MEASUREMENT SYSTEM OF THE CERN 800 MEV PS BOOSTER

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General

The beam position measurement system[1] has been designed to satisfy a large number of requirements[2]:

- observation of beam trajectory
- reduction of coherent oscillations
- Q measurement
- closed orbit measurement
- accelerated beam position

} at injection

The special four superposed rings configuration of the booster and the value of Q($4 < Q < 5$) leads to a minimum of 16 x 4 ring position sensors to satisfy those requirements. In order to compute Q values right at injection the system has been foreseen for acquisition of the full orbit on two consecutive revolutions.

The sensor

Choice

Previous experience at CERN led to the choice of an electrostatic type sensor; different types have been envisaged[3]: circular, elliptic, parallelepipedic (rectangle, square, rhomb). Among various possible locations within a period the interior of the multipoles offers the maximum length and the circular cylinder is well suited to the shape of the beam there. One Σ electrode and one set of vertical and horizontal electrodes are all located on a same "pick-up electrode".

Electrode shape

Given two electrodes A and B, the necessary and sufficient condition to obtain

$$V_A - V_B = \lambda X$$

where X is the displacement of the centre of charge of the beam is that $\ell(\theta) = \ell|\cos\theta|$ [4](Fig. 1). This can be done by cutting the cylinder by two planes, perpendicu-

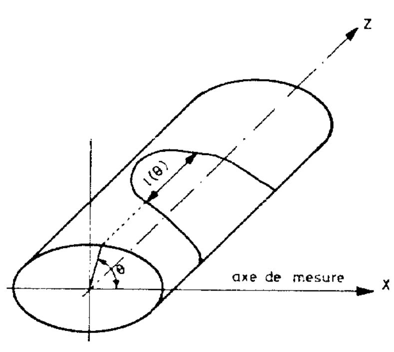


Fig. 1 : Co-ordinate system.

lar to the plane XOZ. On the other hand, it is possible to obtain electrodes which make a better use[9] of the space available and are easier to manufacture, if one abandons the arbitrary restriction of cutting by planes. Figure 2 shows the different steps leading to the solution retained and Fig. 3 one developed pick-up electrode.

Construction

The pick-up electrodes form part of the vacuum chamber and their location in the multipoles means that magnetic materials must be avoided.

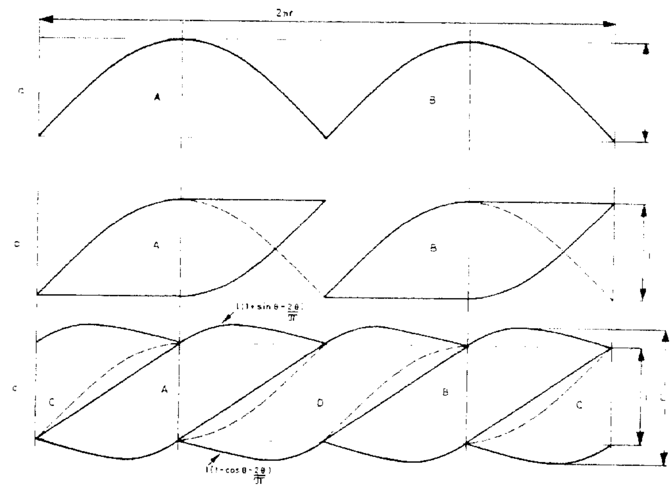


Fig. 2 : Steps of electrode development.

After precise grinding of the inner and outer surfaces of a ceramic tube, nine holes are drilled on the circumference, each surrounded by a grove in preparation for the vacuum tight feedthroughs. Two layers of 25 µ MoMn adhesive tape are applied on the inner surface and baked. To prepare for brazing, MoMn is painted on the edges of the ceramic and around the feedthrough holes, then baked in Hydrogen. One end of the ceramic is fitted successively with titanium and stainless steel intermediate rings, and brazed in one operation together with the feedthroughs. The other end is then brazed with the same intermediate rings. Electrolytic copper (a few µ) is deposited on the inner surface and stainless steel flanges are electron beam welded to the stainless steel intermediate pieces.

To cut the electrodes in the metallic layer of the inner surface of the ceramic, we built a very precise sand-blasting machine[5,6].

Results

Laboratory measurements have shown that the linearity obtained with these pick-up electrodes (Figs. 4 and 5) was better than ± 1 per thousand, over the whole chamber diameter (140 mm), in the two axis.

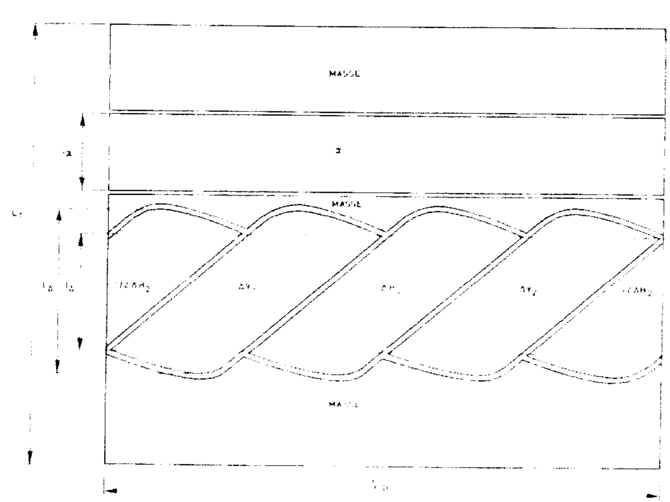


Fig. 3 : Development of a pick-up electrode

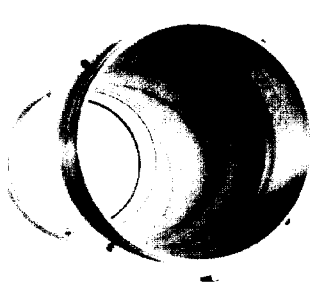


Fig. 4 : Inside of a pick-up electrode

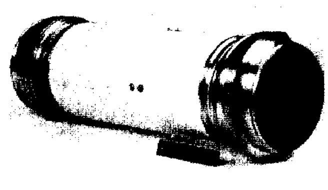


Fig. 5 : Pick-up electrode shown without shielding

The signals

Passive elements in the main tunnel

The basic idea was to avoid any active element in the ring. As suggested by D. Boussard, we studied a transformer which helps in two ways: it forms the difference between the two signals of an electrode pair, and increases the impedance so as to reduce the low frequency cut-off. The transformer developed has a 50 kHz - 50 MHz bandwidth and a ratio of 4:1 - CMRR is 50 db.

The signals taken from the electrodes via the feedthroughs are sent to an accessible junction box by means of polystyrene-bead leads (low capacitance, radiation resistant) passing between the ceramic and the ground tube shielding. The secondary windings of the transformers placed in the metal shielded junction box are connected to a balanced transmission.

Auxiliary tunnel (BAT)

Each station, located in the BAT receives 12 balanced signals from the main tunnel, corresponding to the ΔH, ΔV and Σ electrodes of the four rings. At this level, we make a selection among these signals, by means of analogue multiplexers, so that only four of them can simultaneously be observed and measured. Four signals mean two Δ and their corresponding Σ.

The electronic arrangement of a station is shown on Fig. 6. At the input of the amplifier the minimum signal corresponding to 1.5×10^{11} protons at injection located 0.5 mm from the axis is 200 µV. The capacitance of each Δ electrode is adjusted to 120 pF, which means with the impedance seen through the transformer, a low cut-off frequency of 550 kHz. As 50 kHz is required, an amplifier (balanced inputs and outputs), with a four intensity range selector, has been developed with a low-frequency correcting circuit.

A Base Line Restitution circuit (BLR) is needed for the digital measurement and is also very useful in analogue observation (Fig. 7). For this purpose, a two level discriminator triggers on the Σ signal (BLRC) and drives the BLR during 20 ns, to restitute the DC component within $\pm$ 1 mV.

A driver sends the signal to an analogue selector while two balanced outputs are connected to the linear gates situated at the input of the integrator.

Balanced design of linear gates and integrators has very much helped to obtain good performance. MOS FET linear gates permit $\pm$ 4 V signals to be gated with 15 ns switching times. Rather than an amplitude measurement, an integrating method has been preferred, because it is much less sensitive to noise and overshoots. Integration time may be selected among five discrete values[5]:

- 0.66 µs for 0.4 turn filling at injection
- 1.66 µs to measure one turn at injection (with a 3 MHz chopped beam)
- 20 µs to measure at any moment in a time short compared to a synchrotron oscillation period
- 100 µs, 1 ms — to measure with high precision at any moment during the cycle.

At the output of a BLR two linear gates and two integrators permit two measurements at any moment during the cycle (for example measurement of first and second turn, in the same cycle).

As soon as the gate signal reaches the linear gates, we open a low frequency loop on the integrator, which compensates zero drifts between measurements, and integration of the signals begins. At the end of the gate signal, the integrator holds its amplitude which is compared by means of a double comparison method to a linear ramp signal; this performs an amplitude to time conversion which is sent to a digital converter and buffer located at the center of the ring (BOR, see below). Measurements showed a ±2‰ linearity.

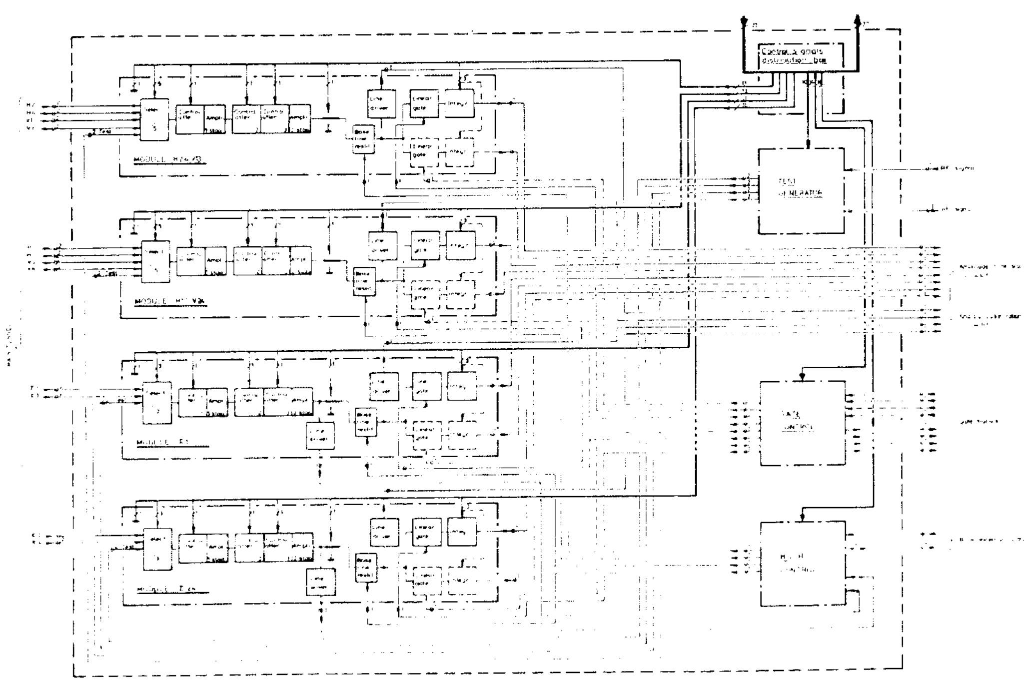
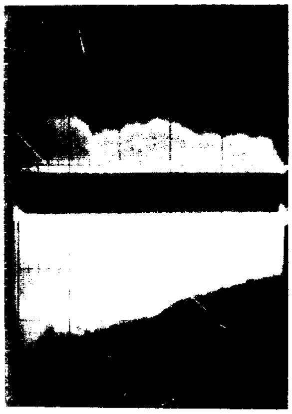


Fig. 6 : Station arrangement

Δ



Σ

Horizontal displacement (ΔH) 200 mV/cm

Intensity reference (Σ) 200 mV/cm

If $\Delta = \Sigma$ beam is 50 mm from the axis

Fig. 7 : Programmed beam acceleration

Booster Observation Room (BOR)

BOR is the hardware centre of the system.

- An analogue multiplexer receives 4 x 16 analogue signals coming from the BAT. Four of these signals (two Δ with their corresponding Σ) can be selected at the same time, observed in BOR and are sent to the Main Control Room.

- Time to digital converters receive 8 x 16 time signals from the BAT, convert them simultaneously and ensure their storage. At the end of each booster cycle the computer may acquire all the information.

- A Test Generator converts the RF signal from the accelerated system, which varies from 3 to 8 Mc, to half sinewaves which are sent to all the inputs of the amplifiers located in the BAT. Measurements on test signals give electronic calibration factors.

- Gate generators, triggered by delayed timing signals, give the appropriate gate duration to drive the linear gates, at the time which has been selected.

- An Analogue and Digital Control Unit (ADCU) permits one to select station, ring, plane, sensitivity, integration time and instants of measurement.

Main Control Room (common to PSB and CPS)

Another ADCU, identical to the one in BOR, allows manual selection by the machine operator.

Two of the eight planes of one selected station can be displayed on a dual beam scope. On the Program Request Unit, the operator can ask for different programs[7] of the orbit Observation and Measurement System. At each request for a program, the computer initiates a calibration of the electronics and stores calibration coefficients. Then, at each cycle the computer displays (Fig. 7) one or two of the eight planes selected, with possibly the value of Q. Specific hardware test programs allow quick checks of the whole system. Figure 8 shows an example of orbit display.

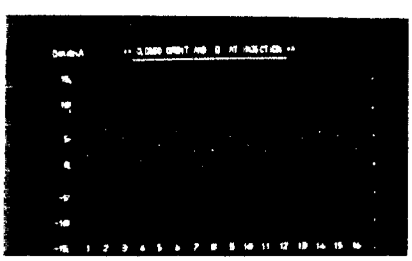


Fig. 8 : Orbit display.

Operation

We have here a direct manual control of all the system, which seems reasonable for initial operation of a new machine; in fact, we shall add the control by computer as an extra possibility to increase the flexibility of the system and allow future programs, which need different system settings and results to be fully automatic (example: optimization by computer). Possibilities of simultaneous observation and measurement on two planes of the same or two different rings permitted studies of coupled oscillations[8] as planned.

Assessment of accuracy of measurement of the system is still preliminary. A first indication is given by the measurements effected within the same booster cycle, on the same plane of the same ring, by two different channels integrating at 1 ms interval during 1 ms. The average position of the centre of charge of the beam was 5 mm and the two channels on the 16 stations showed a maximum difference of 0.1 mm.

The system has been operational since the first injection of protons into the booster and has proven very useful for the running-in of the PSB. Effort will now be concentrated on system maintenance, using the computer to detect hardware failures and imperfections. Test generators have been designed to give a maximum of information about the state of the electronic equipment. The idea is to have the computer performing a survey of the electronics and assisting in locating the failure as far as reasonable.

Acknowledgements

I wish to thank G. Nassibian for his essential contributions to the theory and design of the pick-up electrodes. G. Vismara and M. Boffard have realized very good electronic circuits. Thanks to G. Gelato for his electronic help, G. Chanel, D. Cafagno and H. Arandel for the elaboration and the construction of the sandblasting machine. Encouragements and helpful comments have been given by K.H. Reich. The following persons have also contributed: R. Boudot, M. Clément, A. Faugier, Miss M. Innocenti, J. Nebout, N. Pearce, A. Poyac, L. Sjögren, A. Trincat and M. Zanolli.

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