

## NEW ELECTROSTATIC PICK-UPS FOR THE PS

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**Abstract**

As part of the adaptation of the PS to the acceleration of electron and positron beams for LEP, new electrostatic pick-ups for the closed orbit measurement have been developed. An all metallic design of interlaced electrodes has been adopted to satisfy the stringent requirements of the new vacuum system. The careful layout of the signal pick-off on each of the four electrodes as well as the use of a special hybrid coupler were essential to cover the large frequency spectrum associated with the acceleration or deceleration of p, p, d or e<sup>±</sup> beams. The sensitivity of the system can be controlled over a range of 66 dB fast enough to follow the pulse-to-pulse modulation (ppm) operation of the PS.

**1. Introduction**

The existing electrostatic pick-up electrodes [1] had to be replaced. The outgassing of these electrodes and their unavoidable alignment mechanism would have meant a considerable load for the vacuum system after installation of the new vacuum chamber of the PS. Furthermore, the electron/positron bunches being much shorter (0.7 - 5 ns) than the proton/antiproton bunches (3 - 100 ns), the new electrodes and the attached electronics have been carefully designed in a frequency range up to 300 MHz.

The electrodes are still located inside the vacuum pump manifolds which however, in the design of the new vacuum chamber, present a well defined reference plane relative to the ideal closed orbit. The alignment mechanism could be abandoned and the pick-up body could be optimized for better high frequency performance. Any remaining alignment error can be treated by the computer during the calculation of the closed orbit.

**2. The Electrodes**

Based on the arguments discussed in the introduction an all metallic design of linear cut electrostatic electrodes was adopted. A rectangular aperture was chosen for ease of manufacture. The four electrodes of the two planes are interlaced [2] in such a way that the coupling of one plane to the other is balanced (Fig. 1). This means that the dependence of the signals in one plane to the displacement of the beam in the other plane is minimized without the use of compensating capacitors.

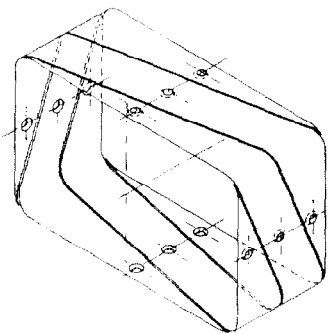


Fig 1

The transversal dimensions of the electrodes are given by the dimensions of the elliptical vacuum chamber whereas their longitudinal extension is limited by the diameter of the access hole to the pump manifold (125 mm). The horizontal and vertical dimen-

sions are 168 mm and 82 mm respectively thus exceeding the dimensions of the vacuum chamber on each side by 10 mm in the horizontal plane and by 6 mm in the vertical plane. This guarantees the protection of the electrodes from direct illumination by synchrotron radiation from either the electron or positron beam. The extension of the ensemble of the four electrodes in the longitudinal direction is 61 mm thus leaving only 30 mm for each electrode.

**3. Mechanical Construction**

The electrodes are cut by a laser beam from a precisely folded rectangular tube of 1 mm thick stainless steel sheet (DIN 304L). This tube has been baked out beforehand at 950°C under vacuum of  $10^{-4}$  Torr to relax internal mechanical stress and to reduce the outgassing (mainly H<sub>2</sub>). The cutting has been realized on a numerically controlled machine tool by moving the rectangular tube in three directions and by rotating it in front of the fixed laser. This process delivers the electrodes cut to a precision of  $\pm 0.1$  mm in all dimensions.

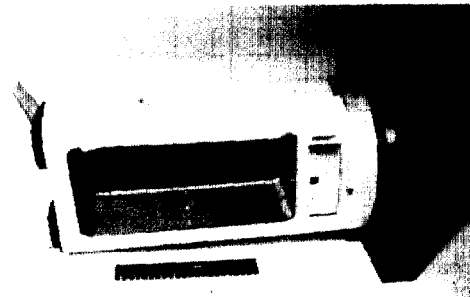


Fig 2

The electrodes are mounted in a massive support (Fig. 2) which is milled to  $\pm 0.1$  mm in a body of aluminium alloy (Al Si Mg). They are screwed in place at three points using precise alumina spacers, which define the distance between the electrode surface and the body to  $1.5 \pm 0.05$  mm. Since this is not sufficient to ensure equal capacitances for the electrodes belonging to the same measurement plane, threaded plugs have been foreseen in the body which function as trimmer capacitors. Four channels are drilled in the body to form the coaxial interconnections from each electrode tap to the alumina vacuum tight feedthrough.

To separate the earth potential of the pick-up from the vacuum chamber, the mounting flange is covered by an enamel layer on the surface facing the surface of the pump manifold to which it will be mounted. This layer resists to radiations and supports the pression of the aluminium gasket.

The exact position of the pick-up is given by the mounting surface of the pump manifold and two dowel-pins which fit precisely in holes on the flange. After installation the real position relative to the ideal orbit is verified to  $\pm 0.1$  mm on the external surface of the mounting flange, which is also the reference plane for the measurement of the electrical position error.

**4. Electrode characteristics**

The position measured by linear cut electrodes can be written as

$$\text{Horizontal position} = C_H \frac{H_1 - H_2}{H_1 + H_2 + V_1 + V_2}$$

$$\text{Vertical position} = C_V \frac{V_1 - V_2}{H_1 + H_2 + V_1 + V_2}$$

$H_1, H_2, V_1$  and  $V_2$  are the signals from the horizontal and vertical electrodes.  $C_H$  and  $C_V$  are horizontal and vertical calibration factors expressed in mm.

Since interleaving of four electrodes in a rectangular cross-section is not possible [3] one has to accept a reduced position sensitivity by a factor of two with respect to an electrode pair measuring in one plane only. The position sensitivity is further reduced by the coupling capacitances between adjacent electrodes [1].

The measured factors for 42 electrodes including the resistive divider and the hybrid coupler are  $C_H = 174,25 \pm 1,5 \text{ mm}$  and  $C_V = 82,30 \pm 0,5 \text{ mm}$ .

The linearity error is  $\pm 1\%$  or less over  $\pm 50 \text{ mm}$  displacement in the horizontal plane and over  $\pm 25 \text{ mm}$  displacement in the vertical plane with respect to the measured (0,1 mm resolution) zero position error in each plane. The deviation of the position measurement from a straight line is random. Therefore the linearity error cannot be corrected by an algorithm valid for all electrodes.

The distribution of the measured electrical zero error, for 42 standard electrodes showed a standard deviation of

$$\sigma_H = \pm 0,43 \text{ mm}, \sigma_V = \pm 0,26 \text{ mm}.$$

The transmission characteristics of the electrodes as a function of frequency has been measured in a coaxial set-up constituted by the pump manifold with the pick-up installed and two lengths of standard PS vacuum chamber on both sides.

First measurements of the electrodes, showed resonances in the frequency range from 250 MHz to 350 MHz which could be partly attributed to 1) the pick-up forming a stub inside the pump manifold and 2) the unmatched short coaxial line between the electrodes and the vacuum feedthrough. To damp the resonances of the stub, capacitive coupling using absorbing ferrite tiles, has been realized at the hot end of the pick-up body to the vacuum chamber. The resonance of the short coaxial line is damped by an RC network to ground on the signal path.



Fig 3  
10dB/div  
Sweep 4-1000MHz

The final results are shown in Fig. 3 for a horizontal electrode.

### 5. Signal Processing

Traditionally the pick-up signals at the PS reflect the charge distribution in the bunches. Also the closed orbit acquisition system works with this kind of signals of a minimum bandwidth of 100 kHz to 30 MHz. The higher frequency limit ensures the proper functioning of the base line restoration and the acquisition gating for multibunch operation. The lower frequency limit keeps the differentiation even of the longest bunches to an acceptable level and the droop

rate of the base line (at injection) can still be handled by the base line restorer.

The electrode signals are processed by a 50Ω hybrid coupler. Precise double screened 50Ω coaxial cables, 5m long, are used between the electrodes and the analog signal processing system (Fig. 4).

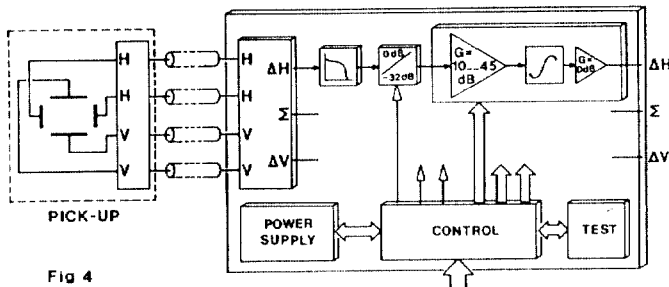


Fig 4

A resistive divider located in the connector plug of the pick-up ensures back-matching of these cables. It reduces the frequency range over which the signals are differentiated due to a higher resistance which loads the electrodes. The gain of the active integrator needed to compensate the signal differentiation over the desired frequency range is proportionally reduced.

The plug houses also the adjustable capacitors which couple the test signal to the electrodes. These capacitors are set so as to simulate a beam at precise positions in two opposite quadrants of the aperture of the electrodes. After mounting in the PS machine, this test allows the adjustment of the gain of the amplifiers, as a function of the intensity of the beam to be measured, by adjusting the level of the test signal. The complete closed orbit acquisition system is calibrated using these test signals.

### 6. The Hybrid Coupler

The hybrid coupler [4] is a broadband seven port network (Fig. 5). Four inputs ( $Z_0 = 50\Omega$ ) are provided: two for the horizontal plane and two for the vertical plane of the pick-up.

Each pair of signals is processed in the so-called 180° hybrid junction to give a sum and a difference output related to one plane. In fact, two hybrid junctions are combined physically into a single device to deliver separate ΔH and ΔV outputs and a common I output.

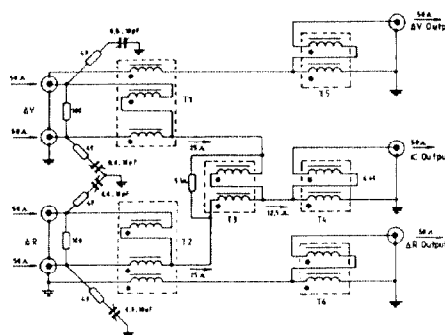


Fig 5

Basically, 180° hybrids possess high isolation between the input ports. However, since such a device is reciprocal, a good matching is needed at the output ports, particularly at the sum output. Considering the current distribution on the sum path, the impedance is  $Z_0/2$  at the center tap of  $T_1$  or  $T_2$ , which falls to  $Z_0/4$  at the center tap of the summing transformer  $T_3$ . A 1:4 transformer matches the sum

output port to  $Z_0$ . In the same way, the differential winding of  $T_1$  or  $T_2$  is matched to the 50Ω  $\Delta$  output port.

Balancing resistors equal to  $2Z_0$  are connected between two adjacent input ports in order to keep the VSWR  $< 1.2$  up to 200 MHz. An RC network, the time constant of which is adjustable, shunts each of the input ports to achieve the best  $\Delta/I$  balance performance needed to reach a position resolution of 0.1 mm (Fig. 6).

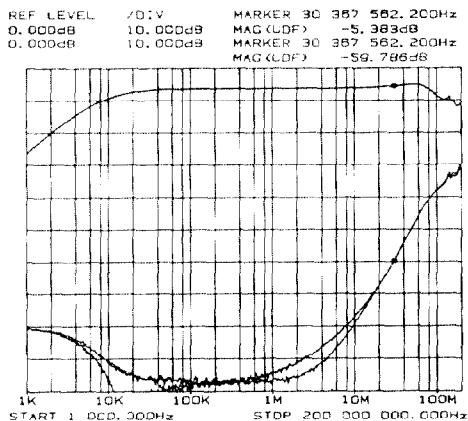


Fig 6

This resolution could not be obtained, using available commercial devices, over the covered bandwidth which extends from 50 kHz to 200 MHz. However, the use of compensating elements is at the expense of additional losses.

To be independent of the bunch shape, the frequency response of the 3 channels are normalized by Bessel low pass filters, inserted between the hybrid coupler and the amplifiers (Fig. 4). These filters are calculated from reference tables  $N=6$  [5] but used in reversed connection [6] such that their input impedance can be more easily compensated by a simple RC network (typical VSWR  $< 1.1$  up to 200 MHz).

A 32 dB attenuator can be switched on, in front of the amplifiers, to handle large amplitudes from high intensity beams. This module uses SPST long life ( $10^7$  operations), high isolation Reed relays.

#### 7. The amplifier and integrator

The amplifier board includes two identical stages consisting of conventional common emitter RC amplifiers. Their gain ( $S_{21}$ ) is controlled by a fast D-MOS Field Effect Transistor acting as a non linear variable resistor in the emitter feedback network.

A flat frequency response is obtained for the two cascaded amplifier stages over the whole gain control range, exceeding 35 dB (typ. 37 dB). Noise figure measurement using the Y factor method indicates a typical value of 3.8 dB ( $10 \text{ MHz} < f < 100 \text{ MHz}$ ) excluding the fast integration process. The integrator stage is located at the end of the amplification chain to obtain the largest possible dynamic range, as far as the signal to noise ratio of the whole system is concerned, but any low frequency distortion in the first stages will be magnified by the integration factor.

The sensitivity variation of more than 66 dB covers the beam intensity range from  $5 \cdot 10^{12}$  particles/bunch to more than  $5 \cdot 10^{13}$  particles/bunch. At the highest gain the total noise of the system corresponds to an error of  $\pm 2$  mm for  $5 \cdot 10^{13}$  particles/bunch.

#### 8. Control Circuits

The voltage for the continuous gain control is delivered by DACs with internal memory and the attenuators and test relays are driven by buffered D-flip-flops. All these memory components are sequentially loaded with predetermined values according to the selected cycle in the PS machine. The control card is equipped with photocouplers in order to avoid problems due either to ground loops or noisy signals on the bus.

The remote control system is able to control 50 pick-up electronics installed around the ring. It receives, from the PS computer, the necessary information to follow the various cycles of the accelerator. A manual control is provided to set the gain of each pick-up during the calibration procedure.

#### 9. Conclusion

Forty pick-ups are used for the closed orbit measurement system which give satisfactory results for low intensity electron and positron beams as well as for high intensity proton beams. The orbit calculation program corrects the measured position of each pick-up by the combined errors of the electrical zero and of the physical position of that pick-up in the machine.

Ten electrodes with modified connector plugs serve in the phase and radial loop of the beam control even for the 114 MHz RF - system for  $e^+$  acceleration. Two electrodes with electronics are used in the transversal feedback system for beam instability cures. Furthermore one electrode is used for wideband position measurements (0.1 - 125 MHz) and another for high sensitivity betatron oscillation observation.

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