BEAM POSITION PICK-UPS IN THE STRAIGHT SECTIONS OF THE HERA PROTON RING

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Abstract: Directional coupler pick-ups have been designed for the straight sections of the 820 GeV HERA proton storage ring. They maintain an electrical response similar to that of the pick-ups operating at 4°K in the cryostats of the HERA arcs while satisfying a variety of mechanical constraints including matching to beam apertures ranging from 60 to 150 mm, ability to bake at 300°C and to achieve ultimate room temperature pressures of 10^{-10} mbar, and suitability for production in small numbers. We describe the mechanical construction and electrical response.

Introduction

HERA, now under construction at DESY in Hamburg, is a pair of storage rings in which 820 GeV protons will be collided against 30 GeV electrons. Each ring will store 210 bunches, in buckets spaced 96 nsec apart. The proton bunches will be between 0.3 and 2.7 m long and will contain between 10^{9} and 10^{11} particles each. For the bunch and beam position measurements a directional coupler pick-up with 395 mm antenna length and 8% coupling has been chosen [3]. The bandwidth of this directional coupler is well adapted to the frequency content of the Fourier spectrum of the bunches. At the same time the length of the coupler is still acceptably small.

The straight sections of the HERA proton ring have a total length of roughly one kilometer. Here magnets and beampipe are kept at room temperature, in contrast to the arcs with their superconducting magnets. All pick-ups in the straight sections will be relatively easily accessible.

In order to reach the necessary vacuum of 10^{-10} mbar a bakeout at up to 300°C is planned. These strict vacuum demands and the different apertures, typically 60-80 mm, require the development of new pick-ups having, however, the same electrical properties as far as frequency response and signal amplitude is concerned. It is, however, not possible to keep the sensitivities and timings constant.

The pick-ups are located at each group of quadrupoles and next to the interaction region. They will be positioned with a precision of a few tenths of a millimeter relative to the quadrupole axis both horizontally and vertically. All warm pick-ups typically contain four electrodes and measure both the vertical and the horizontal bunch coordinates simultaneously.

In total there are six types of pick-ups, which have a similar design, as shown in Table 1.

Table 1 Planned warm position pick-ups

Type	R_i [mm]	Length [mm]	Sensitivity [dB/mm]	
Au	40.9	600	.7	standard monitor
In	31.75	779	.9	next to interaction zone; squeezed geometry
Hl	40.9	ca.500	.7	monitor in H1 left
Hr	82.2	700	.4	monitor in H1 right
Zr	>85	ca.500	-	monitor in ZEUS, special geometry
Lv,Ln	38	3600	-	special monitors for the tune measurement (2 antennas, capacitive)

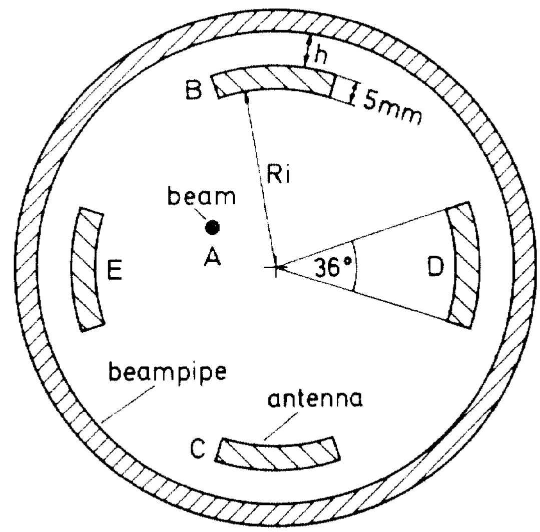

Fig. 1 Cross section through warm pick-ups type Au, In, Hl and Hr

Pick-up Design

Basic Geometry

We tried to choose the simplest possible geometry with the necessary apertures and the same electrical properties as the cold pick-ups [3]. The radius R_i varies and is given by the beam aperture. In the interaction regions the apertures for the scattered proton and photon beams have to be considered as well. The antenna width of 36° and length of (mostly) 395 mm ensures similar electrical properties to the cold monitors. The 5 mm thickness of a standard antenna ensures good mechanical stability over the entire antenna length.

The geometry of the monitor is modified in the pick-up within the ZEUS experiment in the south hall (type Zr). Here one has both to squeeze the pick-up into a 200 mm square box and at the same time to keep an aperture of at least 170 mm clear. The geometry foreseen for this type of pick-up is shown in Fig. 2.

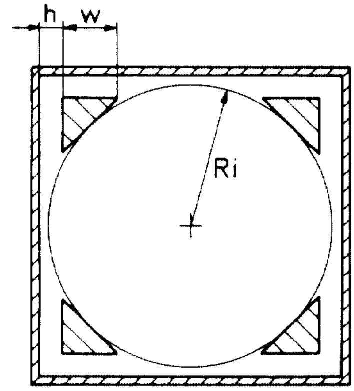

Fig. 2 Cross section through the ZEUS pick-up (type Zr)

Antenna Support
The antennas are, wherever possible, hung directly on leaf springs at the feedthroughs, which results in a combined electrical and mechanical connection (Fig. 3). The number of required ceramic insulators is thus minimized. The springs limit mechanical strain during the 300°C bakeout.

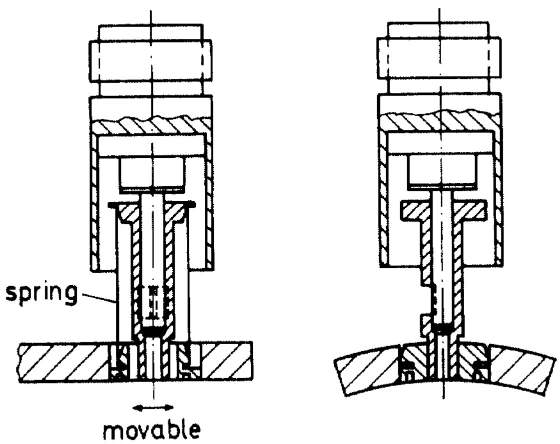

Fig. 3 Scheme of the antenna support

For the In monitors mounted in the direct neighbourhood of the electron beam this design is unfortunately not possible, because the space is so limited that the monitors' SMA feedthroughs must be parallel to the beam pipe. Here the following scheme is foreseen. The antennas will be connected electrically to the feedthroughs with spring contacts. Mechanical support will be provided by metal rings on the inner circumference of the beam pipe at each end of the antennas; a pair of dowel pins at the antenna end fits into ceramic bushings embedded in the ring. The tolerances must be carefully considered in the design; too tight may result in cracking of the ceramic during the bakeout, while too loose reduces the absolute position measurement accuracy and may permit rattling, which could break the ceramic.
A design with machined ceramic support rings was also tested. It has good electrical properties, but it is quite expensive and the cooldown after the bakeout would have to be done very slowly.

Antenna Wave Impedance
Each antenna must have a wave impedance of 50 Ω with respect to the beam pipe. For the standard geometry this was measured and computed with a SOR type code. One finds a measured relation of

$$h = (0.136\pm0.002)\cdot R_i + (1.75\pm0.09)\ \mathrm{mm}$$

for inner radii R_i between 30 and 90 mm. Computations were used to dimension the measurement set-up and gave a ca. 20% lower plate separation value h. The sensitivity of the wave impedance Z to changes in the distance between antenna and beam pipe, h, is measured in the same range to be:

$$dZ/dh = (-0.10\pm0.04)R_i\cdot(\Omega/\mathrm{mm}^2) + (10\pm2)\cdot(\Omega/\mathrm{mm}) \ .$$

This means that the tolerances in machining and assembling the antenna and the beam pipe are given not by wave impedance considerations, but by the required reproducibility in the absolute position measurement.

For the type Zr geometry a conformal mapping calculation was done by P. Duval [1]. The measurements give, in 20% agreement with the calculation,

$$h = 0.49\cdot w + 2.6\ \mathrm{mm}$$

and $$dZ/dh = R_i/10(\Omega/\mathrm{mm}^2) + 4\ \Omega/\mathrm{mm}$$

for a width w between 25 and 30 mm. Here also the height h is not very critical.

Transverse Beam Impedance
Finally the design of all pick-ups must insure that the transverse beam impedance is no higher than ca.100 kΩ. Computations have been done by E. Lawinsky using MAFIA [3] and measurements will be performed soon.

The Standard Pick-up Type Au

The most common monitor, Type Au, will be described in detail (Fig. 7); the differences from the other monitors have been described above. The type Au pick-up is used next to the outer (German: Außen) quadrupole of the straight sections with interaction zones and next to all standard quadrupoles in the west hall. It has the shape of Fig. 1 with an inner diameter of R_i = 40.9 mm. Its total length is 600 mm. This standard length allows maximum interchangeability with the other pick-ups in the machine. The effective antenna length is 395 mm. It will be used for position and tune related measurements.
Prototypes with machined ceramic rings and with metal rings with ceramic bushing support of the antennas have been built and successfully tested.

Transfer Function
The calculated transfer function is shown in Fig. 4.

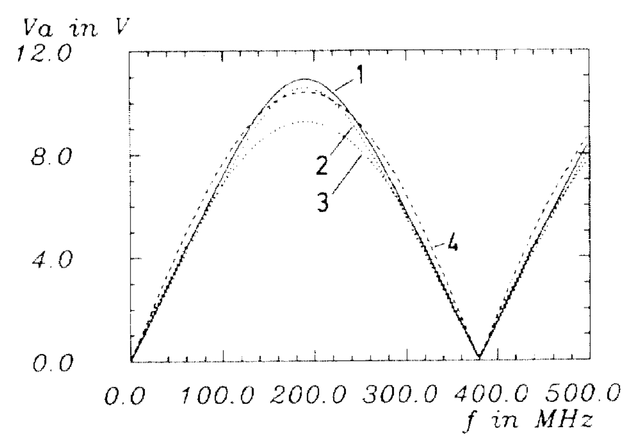

Fig. 4 Pick-up response as a function of frequency

Line 1 shows the result of a complete 10-port model [4], in 2 and 3 we have a 6-port (beam, antennas B and C) and a 4-port (beam, antenna B) model, and in curve 4 the normalized lumped circuit result is shown. Here we see the same effect as for the cold position monitor [3, 4]; the extra antennas result in a steeper frequency response. The calculated values agree within errors with the measurements.

Position Sensitivity
The pick-up response as a function of beam position along the antennas is shown in Fig. 5. The small circles show the measurements with their errors. The dashed lines 3 and 4 give the result of the wall current model [4] for the antenna radii, 40.9 mm and vacuum chamber radii, 53 mm. The effective radius to be taken is somewhere in between, namely 48 mm. Within the model it is impossible to determine this quantity. The n-port descriptions [4] give much better results. However, only the complete 10-port description, which takes full account of the actual

monitor geometry, shows agreement with the measured data within measurement errors.

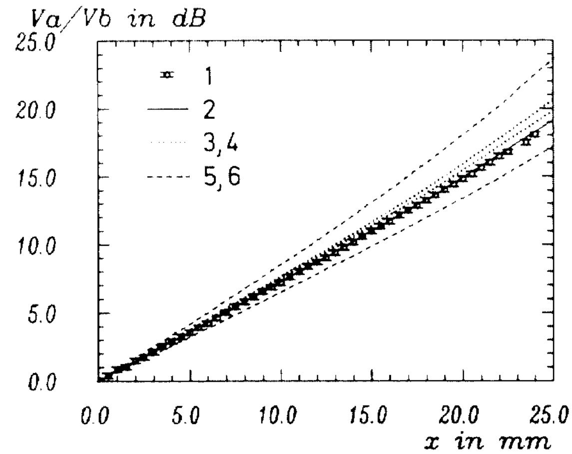

Fig. 5 Position sensitivity of the type Au pick-up along the major axis

Table 2 Sensitivities of the pick-up for the curves of Fig. 5

Curve	Explanation	Sensitivity[dB/mm]
1	- measured data	0.71
2	- 10-port models	0.72
3 (below)	- 6-port model (beam, antennas B and C)	0.74
4 (above)	- 4-port model (beam, antenna B)	0.76
5 (below)	- wall current model with vacuum chamber radius	0.64
6 (above)	- wall current model with antenna radius R_i	0.84

The pick-up type Au is less sensitive than the cold pick-up [3] (namely 0.71 dB/mm opposed to (1.17±0.03) dB/mm). This is due to the small inner radius of the cold pick-up (27.65 mm). On the other hand the type Au pick-up has a larger range of linear position response (more than ± 25 mm compared to ca. ± 10 mm). Also the response with respect to one coordinate depends less on the position in the other direction (see Fig. 6), i.e. the cushion distortion is reduced.

Conclusion

For the straight sections of the HERA proton ring special directional coupler position pick-ups are being developed. Both coordinates are measured simultaneously. They are linear over a larger position range, but less sensitive than the pick-ups in the arcs. Their position dependence is well described by the n-port model.

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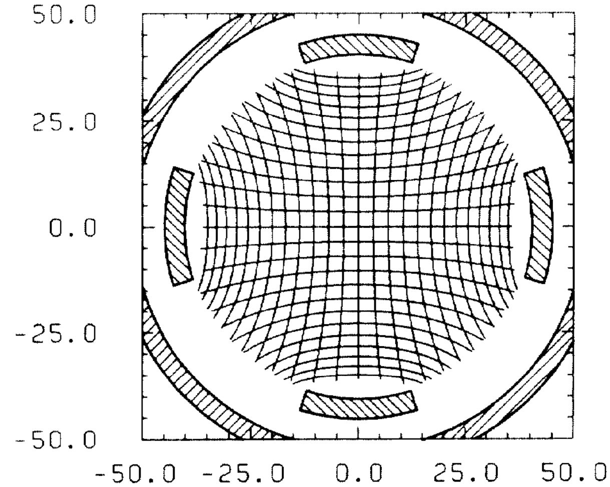

Fig. 6 Lines of equal position sensitivity in 2.5 dB steps as predicted by the wall current model

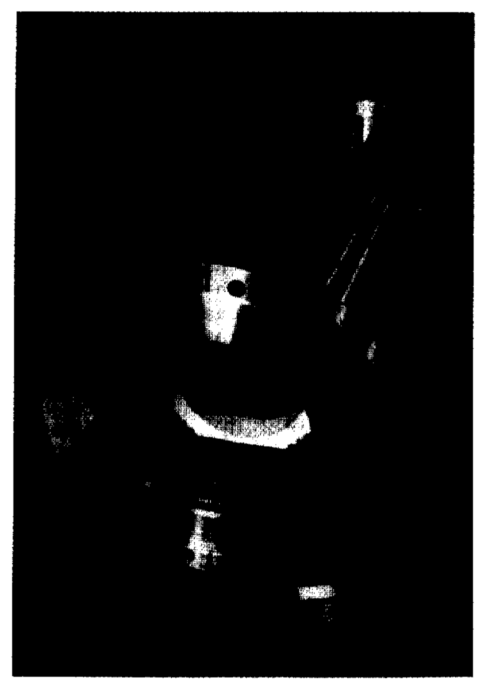

Fig. 7 Photograph of the pick-up type Au with ceramic ring support

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