RESULTS OF MEASUREMENTS ON THE "WARM" HERA PROTON BEAM POSITION MONITORS

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Abstract: A beam position monitoring system has been designed for the 820 GeV HERA proton storage ring accelerator. There will be 26 pick ups of the directional coupler type in the "warm" sections of the ring [1]. The mechanical, electrical and vacuum properties of each must be measured. These measurements ensure good quality and form the basis for determination of the beam orbit position relative to the corresponding quadrupole axis. The results of these measurements are described.

Introduction

HERA, now under construction at DESY in Hamburg, is a pair of storage rings in which 820 GeV protons will collide against 30 GeV electrons. The proton bunches will contain between 10^9 and 10^{11} particles. The bunches will be between 0.3 and 2.7 m long. Up to 210 such bunches will be placed in 220 equispaced RF buckets. The required accuracy is considerably better than 1 mm_{rms} [2] relative to the quadrupole axis. This shall be achieved with a directional coupler position monitoring system. The read out is done with the method of amplitude ratio to phase difference conversion [3]. The position will be digitized with an eight bit flash ADC. The position and the average position, i.e. the orbit, will be stored locally for the last 1024 and 256 turns [4].

In HERA the arcs and straight sections are made quite differently: the arcs are totally equipped with superconducting magnets and are operated accordingly at 4K temperature, while the straight sections are at room temperature and will be baked out occasionally in situ at 300°C. There are 220 directional coupler pick ups in the arc [5, 6]. They measure only one transverse direction each and will not be considered further in this paper. In the straight sections there is a total of 26 bidirectional pick ups [1].

The position monitors are used for three different purposes: to measure the orbit relative to the quadrupole axis, to help the fine steering so that the electrons and protons actually collide in the interaction zones [7] and for special applications as tune measurement and radial/phase loop input. For the first purpose a pick up is placed next to each quadrupole group, i.e. two pick ups on each side of one of the three interaction zones and seven pick ups in the machine destined straight section West. All those are of the standard type PMAu (Position Monitor Außen"=Outer") except the six ones next to the interaction regions. Here the PMIn (Position Monitor Inner), a special development for the extremely limited space next to the electron proton ring separation, is used. All those position monitors are directly fixed to the next quadrupole by means of a very solid stand. The three special purpose pick ups are all of the PMAu type and located close to the quadrupoles on the right side of the straight section West. They are only supported by standard vacuum chamber holds. The pick ups for the monitoring of the ep collisions are all individually designed. There are two for the experiment H1 (PMHr & PMHl Position Monitor H1 right/left), one for the straight section east (PMAO Position Monitor Type A for Osten"=east") and one for ZEUS (PMZr Position Monitor Zeus right). All are situated in the common ep vacuum chamber and are able to detect both electron and proton beams with the same plates using the directivity and different passage times. No special care is taken here for an absolute and reproducible position measurement since only the proton and electron beam difference in position is important. All warm pick-ups are designed in such a way that their electrical properties should be similar to the majority of the pick ups, i.e. the cold ones in the arc. The signal levels are kept similar by giving the plates the same opening angle of 36°, the frequency response is kept similar by choosing the same electrode length (395 mm). Only the position sensitivity could not be kept similar. It is mainly given by the allowed aperture.

A round geometry was chosen wherever possible (see fig. 1). Only the ZEUS pick up PMZr had to be square.

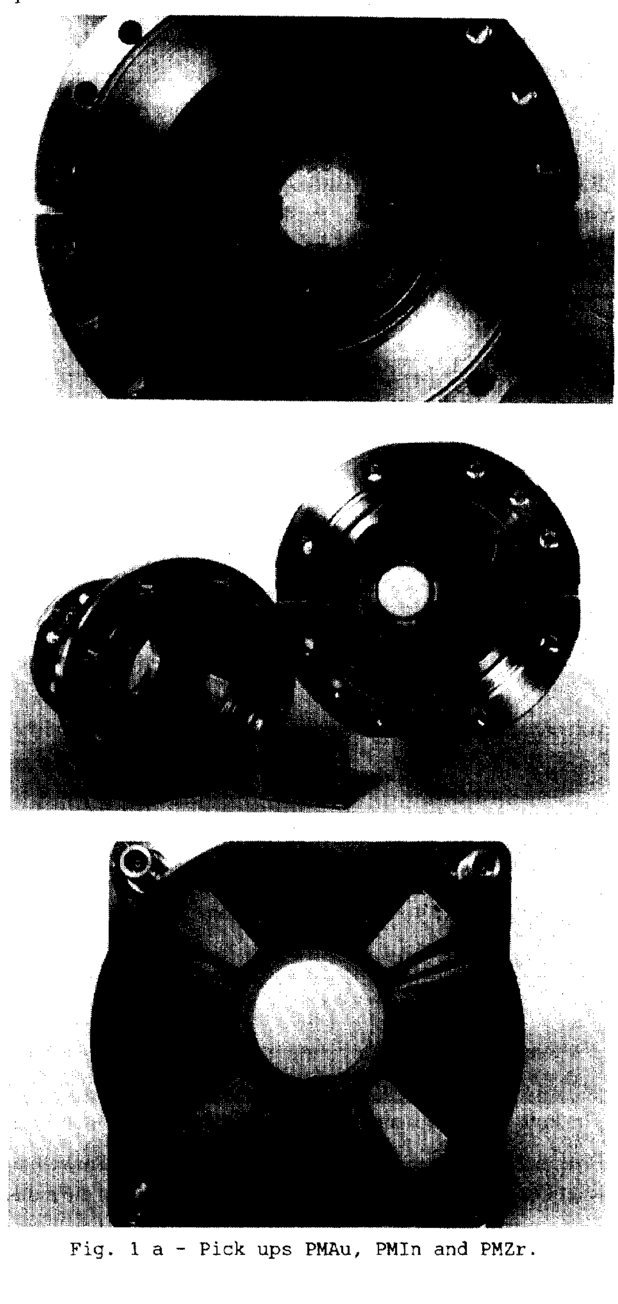

Fig. 1 a - Pick ups PMAu, PMIn and PMZr.

A listing of the basic properies of the pick ups can be found in table 1. As opposed to the cold pick ups no copper coating of the inside of the pipes was necessary.

Table 1 Overview of warm pick ups

Type	Number needed/ built	R_i* [mm]	h** [mm]	Length [mm]	Antenna support	Feed-through	
PMAO	1	40.9	6.9	600	spring	N	tapered PMAu
PMAu [1)]	16/18	40.9	6.9	600	spring	N	standard monitor
PMIn	6/7	31.75	6.1	600	ceramic	SMA	extreme slender
PMH1	1	40.9	6.9	680	spring	SMA	in bulge of H1 beampipe
PMHr	1	82.2	12.5	700	spring	N	similar PMAO
PMZr	1	94.3	9.0	680	ceramic adjustable	N	square bulge of ZEUS beampipe

* pick up aperture (radius)
** distance between antenna and pick up pipe

General Properties

Each pick up was visually inspected first. The big PMHr pick up was badly packaged and the two opposing antennas tore their spring suspensions totally apart. All other welds were of sufficient quality and no ceramic feedthrough was broken. All antennas were parallel to the pipes. There were no fingerprints or oily smells. There were no kinks or scratches on the cutting edges of the conflat flanges. No other deficiency was found either.

Next the basic mechanical properties were measured. The length and pipe diameters were within tolerances. The flange alignments were all checked by rotating the pick ups in two parallel prisms.

The required vacuum properties (leak rate < 10^{-9} Torr•l/s, absorption rate < $3\cdot10^{-12}$Torr•l/s•cm^2) could be reached after a bakeout at 300°C. This was done at the company which built the pick up and was repeated at DESY after the completion of all mechanical and electrical measurements. For the twelve monitors in the straight sections of the three interaction zones a special high temperature vacuum annealing was necessary to get rid of the remnant hydrogen gas. This was done at CERN for all major metal parts of the PMAu and PMIn pick ups.

The basic electrical test consists in searching for a short circuit between the antenna and the pick up body. For all spring supports this was no problem. For the ZEUS pick up we had a lot of trouble with the copper leaf connection screwed to the feedthrough and antenna. It tended to bend against the pipe when we had to adjust the antenna to an unexpectedly close position to the monitor body. So we cut it shorter but we were still trying to keep as much length as possible for antenna movements. Two of the PMIn pick ups had the problem that the antenna slid on the ceramic all the way to the support ring adapter. It was not possible to get a fixed fitting between ceramic and steel on one side. In the trial to keep the free hanging ceramic pin length as short as possible the critical adapters were individually shortened. We tried not to perform shock tests with the ceramic adapters, but one of the PMIn's fell from a height of nearly a meter to the linoleum floor, with major damage of the ceramics. All ceramic parts except the feedthroughs were then exchanged. The electrical connection of the PMIn gilded antenna ends is made by gilded springs to ensure good contact all the time. In a test no vacuum welding of the springs at 300°C and extremely clean vacuum conditions were found.

Prototypes of the big spring supports for the antennas were individually tested by moving them continuously back and forth. The first spring broke after more than 30000 and the second spring of the same adapter after more than 140000 movements. We performed no extra test on a prototype of the tiny spring support to the SMA feedthroughs for the PMH1. All antenna spring supports were visually inspected for good welds before they were finally welded together with the antennas inside the pipes.

The wave impedances between antenna and pipe of all pick ups were measured in the factory. It was found that the required distances h previously measured with much shorter models tended to be all overestimated. The adjustable antenna adapter for the PMZr had to be redesigned and the H1 pick ups now have a rather high wave impedance of about 53 Ω instead of 50 Ω. For the standard monitor PMAu and the electrically equivalent PMAO we could get excellent results for the wave impedance, namely (50.57 ± 0.74) Ω, all the values being between 48.5 Ω and 53.2 Ω. This is due to the relatively large series of 19 pick ups. The PMIn pick ups had a wave impedance of (49.1 ± 1.5) Ω in a range of 46.8 to 51.6 Ω without any possibility of adjusting when the parts had been built. The ZEUS pick up is adjusted to 0.5 Ω and constant impedance over the entire antenna. But this pick up has relatively large reflection coefficient ρ at the antenna support cable transition of up to 1.2 with a FWHM of 0.3 ns. At the readout frequency of 104MHz this should not be a problem.

Position Sensitivity

A good measure for the beam position is the ratio of the output voltages of two opposite antennas. For a wide range of values it is independent of bunch shape, selected measuring frequency and number of protons in the bunch. Of prime importance is the position sensitivity at the required orbit, which should coincide for all monitors except the ZEUS one with the centre of the pick up. In the ZEUS monitor the beam should pass at 10 mm's distance from the centre to allow extra space for synchrotron radiation without using more space of the detector acceptance than absolutely necessary. The sensitivity at the required orbit will be called monitor constant in this paper. It is necessary to know it in order to steer the beam quickly by an iterative process on the required orbit as well as to estimate the amount of orbit deviations.

The measurement of the position sensitivity was done by a special machine which moved a wire of 1 mm diameter inside the pick ups. The wire was only very roughly matched to the 50 Ω input cable impedance and was only roughly terminated in its own impedance. For the PMH1 and PMZr, which will be welded directly in the beampipe of the experiments, it was not even possible to solidly connect one end of the pick up with the measuring machine. The grounding was still

1) The prototype of the PMAu [1] in a stripped down antenna support version (just screwed) is used successfully in the proton bypass of PETRA II for the tune measurement and the radial loop.

sufficient, which was checked with the PMIn and PMAu pick ups. The centre of the pick up and the zero point of the measurement machine are aligned to better than a millimeter. The centre wire was excited with 104 MHz and the output voltage of the opposing plates was measured with a spectrum analyser.

A maximum of 97 equispaced points were measured between each pair of plates in the range ± 24 mm, or less if the monitor geometry did not allow for it. The sum of the output voltages should be nearly constant except for a very small quadratic contribution. This plot allowed a quick check for a grounding problem, a very common evil in this type of measurement. The measured voltage ratios were fitted in the central 10 mm of the monitor to a line, directly giving the monitor constant. Deviations of the entire measurements from this line helped to identify further problems on an individual measurement, i.e. bad grounding, bad cable connections, insufficient alignment and step motor tripping. The monitor constant measurements of the pick ups of a single type agreed very well, so we take the average values for the use in the ring (see table 2). As opposed to the monitors in the arcs all warm monitors were measured.

Table 2 Electrical Properties of the Pick Ups

Type	Monitor Constant [dB/mm]
PMAO, PMAu	0.673 ± 0.030
PMIn	0.898 ± 0.018
PMHl	0.70 ± 0.02
PMHr	0.35 ± 0.01
PMZr	0.39 ± 0.01

All pick ups are linear to better than 2.5 % in the central ± 10 mm region.

Determination of the Absolute Beam Position

The task of the orbit measurement is the most elaborate one. A precision of considerably better than 1 mm [2] relative to the next quadrupole group is required. This calls for a careful design and calibration of the pick ups as well as surveying the actual monitor position in the ring. The pick ups for orbit measurement PMAu and PMIn are all individually measured for their electrical centre relative to their mechanical centre in horizontal position (see fig. 2).

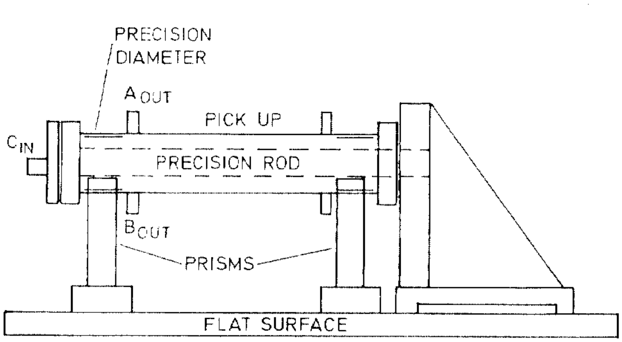

Fig. 2 Set up for measuring the electrical centre of PMAu and PMIn pick ups with a shorted precision rod

The mechanical centre of the pick ups is defined by a precise diameter on both ends of the pipe. We measured for the standard pick up PMAu 116.396 ... 116.527 mm and for the slender pick up PMIn 94.978 .. 95.000 mm. To get the electrical centre relative to the mechanical centre a steel rod of 43 mm diameter, and 32 mm diameter respectively, is centrally inserted into the pick up. The voltage ratio is measured both for the normal antenna position and in a position with the upper (lower) antenna down (up). Here one can deduce simultaneously the electrical monitor centre and the quality of the set up. Since the rods have to be so big in diameter as to prevent them from hanging too far down, for any offset position there are significant compensation currents on their surface. This means that they have a monitor constant different from the one of the beam. This constant was found by lifting the prisms and the rod standoff by one and also two 1 mm parallel plates. For the PMAu a value of (0.905 ± 0.02) dB/mm and for the PMIn a value of (2.96 ± 0.03) dB/mm was found. Using these numbers the accuracy of the setup was found to be better than 0.1 mm. The electrical centres are distributed in the following way:

	PMAu	PMIn
centre position	0.18 ± 0.48	0.10 mm ± 0.43 mm
with the range	- 7 ... 1.6	- 0.25 ... 0.32 mm.

This means an individual correction is necessary and to a sufficient accuracy possible. Taking the surveying accuracy, cable reflections and analogue electronics also into account, an r.m.s. accuracy of better than half of a millimeter seems to be feasible for a beam of sufficient intensity. The quality of the HERA r.m.s. orbit deviation measurement will then be determined by the cold pick ups in the arcs, which cannot be surveyed directly.

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