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PETRA II. A Proton Injector for HERA

J.R.M.Maidment

RAL Chilton, England.

DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY HAMBURG

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1 Introduction

In this note we describe the results of detailed studies concerning the modifications to the PETRA lattice to ensure it will accumulate, accelerate and deliver protons to the HERA main ring. In Section 2 we detail the design of a bypass to prevent protons experiencing the high impedance electron RF cavities. Section 3 describes the proton linear optics whilst in Sections 4 and 5 we outline proton extraction and injection respectively.

It should be stressed that, where possible, use has been made of existing magnets or magnet designs and thus minimise the development of new hardware. As described in Section 3 compatability with the use of PETRA as an electron injector has also been ensured.

No re-evaluation of the choice of proton accelerating system has as yet been made. Throughout this work the RF parameters assumed are those given in the proposal[1].

2 The Proton Bypass

The transference of most of the existing 500 MHz accelerating structure from PETRA to HERA is foreseen. Sixteen 5-cell cavities, sufficient to reach 14 GeV, will remain and these may be grouped symmetrically around the centre of the South RF straight extending to ±23m. As the tunnel is 1 metre wider than that in the arcs and this increase is entirely on the outside of the ring it is logical to install a bypass on the outside of the existing beamline. The space on the inside is preserved for the passage of maintenance vehicles etc.

The proposed bypass is shown in Figure 1. The arrangement of quadrupoles in the electron line differs slightly from the present geometry, the reason for this is given in Section 4. Three extra bending magnets per half-straight are used, identical to normal PETRA dipoles and series powered. The last electron bender (between Q9N and Q8N) is repositioned so the return yoke is on the inside and is switched off for proton operation.

The precise geometry is summarised in Table 1. Longitudinal displacements (S) are measured along the electron line from the symmetry point; transverse displacements (X) are positive outwards and the given coordinates refer to the centre of each element.

Element	Position S(m)	Beam Displacement X(mm)
BP1	57.000	0.0
Q9N	53.140	108
B	49.044	224
Q8N	45.600	414
BP2	40.600	694
BP3	33.400	896

Table I. Bypass Element Geometry

The quadrupole Q9N may have to be split on the horizontal symmetry plane to allow the beam to pass between its poles. It is not powered for proton operation thus avoiding non-linear field gradients. Q8N is shown dotted since a preliminary investigation indicates it may not be needed for the electron optics. All bypass quadrupoles are identical in design to those of PETRA.

The final displacement of 896 mm is ample to avoid the electron quads and cavities and does not consume the full one metre notionally available. Installation of this bypass may nevertheless need services, bus bars etc. to be re-routed. The machine circumference for protons is some 38 mm greater than that for electrons and the effect of this is discussed in Section 4.

3 Proton Linear Optics

Saturation effects in the dipoles limit the peak proton momentum to 40 Gev/c. Quadrupole field gradients are similarly limited to 16 T/m and the maximum phase advance per normal cell is 34°. The average dispersion in the dipoles is then Dx=2 m and, depending on the precise matching into the straights this leads to gamma transition (γ_t)=12.5. Rather than cross transition with the slow acceleration rate imposed by the PETRA dipole power supply (dP/dt=1.6 GeV/c/s) we seek an optic in which γ_t is below the injection energy (P=7.5 GeV/c, γ=8.06). This implies still weaker focussing in the arcs, an average dispersion around 10m and phase advance per cell of some 17°.

There is no requirement for low beta at the interaction points, in particular we have assumed that the mini-beta quadrupoles are removed thus freeing a power supply circuit. No attempt is made to reduce the dispersion in the short straight section for to do so would increase the peak value in the arcs if γ_t is to be kept constant.

In going from the arcs into the long RF-straight we do require small dispersion. Prior to extraction bunch rotation is performed and high dispersion in this region would impose extra aperture needs on ejection elements. Most of the quadrupoles in the bypass are connected in series with their electron counterparts. Three additional independent circuits ensure matching of the derivatives of dispersion and beta functions.

At present PETRA uses 22 independent quadrupole circuits. The proton optic requires 24 such circuits but includes 21 of the present quad families. This ensures that the change-over from electron to proton injector is made by resetting power supply currents only, no polarity changes or circuit reconfigurations are needed. Two additional dipole circuits are also needed.

Figure 2 is a plot of the proton optic envelope functions from the WWP to the centre of the RF-straight while Figure 3 is the corresponding plot from the WWP to bypass centre. Some of the lattice parameters are detailed in Table II.

	Horizontal	Vertical
Working Point (Q)	8.73	9.20
Phase advance per cell (deg)	17	17
Max. beta in arcs (m)	58.6	58.6
Max. dispersion in arcs (m)	10.7	
Max. beta in straights (m)	144.0	94.5
Max. dispersion in straights (m)	18.1	
Chromaticity (P.dQ/dP)	-14.8	-10.2
Gamma Transition	6.265	
Circumference (m)	2304.038	

Table II. Proton Optics Parameters

4 Proton Extraction

Protons are extracted from the North RF-straight towards the inside of the ring and are transported to HERA via a beamline with horizontal and vertical bends. To avoid the HERA West hall the horizontal bending section, of around 90m radius, starts around 34m upstream of the long straight centre.

Figure 4 is a sketch of the North extraction region, it can be seen that the beam must clear the inside input edge of Q6N. To achieve this Q6N is displaced downstream from its present position by 2.0m; Q5N is also displaced by 1.0m. To preserve symmetry for electron optics these changes are made on both sides of all 4 long straights.

The extraction system consists of a full aperture fast ferrite kicker (PK) downstream of Q0B, two septum magnets (PPS, PS) between Q8N and Q7N and an extraction magnet (EM) after Q7N. The transverse displacement of PPS must be enough to provide aperture for both circulating electrons and protons. Initial calculations indicate that the electron optic is the determining influence requiring a displacement of about 20mm. The maximum PPS displacement is set by the need to eject the beam through the normal aperture of Q7N which is defocussing and aids in bending the protons. The maximum displacement is approx 42mm.

After acceleration to 40 GeV/c the proton RF frequency is changed by $df/f=1.67.10^{-5}$. This steers the beam to compensate for the additional circumference introduced by the bypass. The equivalent momentum deviation is $dP/P=-6.5.10^{-4}$. which corresponds to a transverse displacement of some -7mm in the arcs, -11mm at the WWP and -0.2mm at PPS. The RF volts are increased to compress the bunch to fit into the HERA acceptance. We assume a DC beam bump will be used to bring the proton beam up to the PPS inside face parallel to the ideal orbit. The fast kicker provides a displacement of 12mm at PPS to switch the proton beam into its aperture whence it extracted via PS and EM.

Table III gives details of the ejection element parameters and the resultant proton beam displacement. At the upstream end of Q6N, 32.55m from the symmetry point the proton beam is displaced inwards by 435mm emerging at an angle of -67mrad.

Element	Length(m)	Field(T)	Angle(mr)	S (m)	X(m)
PK	0.480	0.186	0.67	60.010	-
PPS(2.5)mm	1.50	0.5	5.6	43.830	-47
PS(5mm)	1.50	1.0	11.2	41.200	-63
EM	4.00	1.5	45.0	36.750	-155
Q6N I/P	-	-	-	32.550	-435

Table III. Extraction Element Geometry

5 Proton Injection

Protons are injected via the positron transfer line from DESY. Ideally they can be placed on the equilibrium orbit using a kicker downstream of the septum, displaced by 90 degrees in betatron phase. However the positions of the present two downstream kickers are adequate for although the phase shift to the first kicker is only about 19 degrees, the reduction in beta demagnifies septum displacements by a factor of 2. The first kicker puts the beam on axis at the second kicker which compensates the residual angle.

The septum field is adjusted to place the input beam parallel to the closed orbit (displacement=-70mm). The first kicker gives an angle of 0.22mrad and the second -2.3mrad. For 480mm long magnets this corresponds, at 7.5 GeV/c, to fields of 0.01T and -0.12T respectively. The rise and fall times required depend on the chosen method of filling PETRA which is currently under review.

One difficulty remains the beamwidth in the septum magnet. Since both the value of dispersion and beta are high the matched beam is ±24mm wide and exceeds the present septum aperture. One solution is a new magnet; another is to devise a specific injection optic which gives a smaller beam while preserving longitudinal acceptance.

6 Conclusions

The studies reported here have revealed no insurmountable problems. Further optics optimisation is possible since there is a great deal of flexibility provided by the PETRA quadrupole configuration. In particular further work on proton injection and on conflicts, if any, with electron extraction should be undertaken.

We are unable at present to specify rise and fall times of kickers since the necessary work is not complete. It is proposed to study the influence of filling method, RF system and optics on possible instability thresholds. This will then lead to the required specification.

7 Acknowledgements

I am grateful for many fruitful discussions with G Hemmie, K Steffen, G A Voss and B Wiik at DESY. Programming assistance at RAL was freely given by C R Prior and Janet Trotman.

8 References

1.) HERA A Proposal etc. DESY HERA 81/10 July 1981

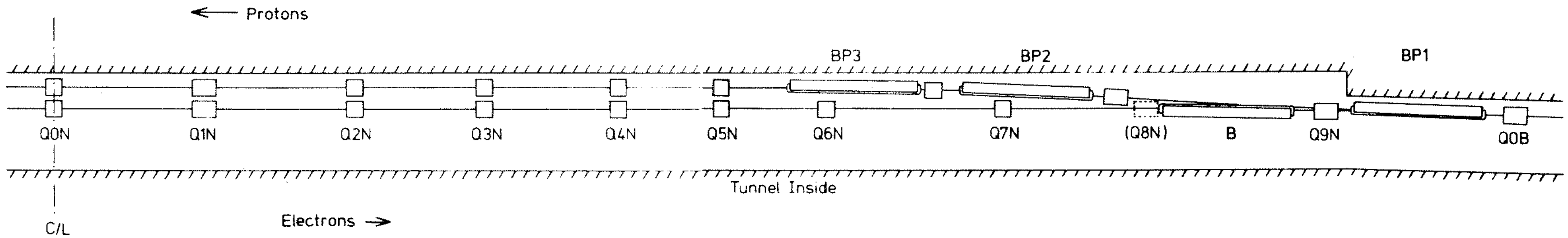


FIG.1 PROTON BYPASS IN H.F. SOUTH

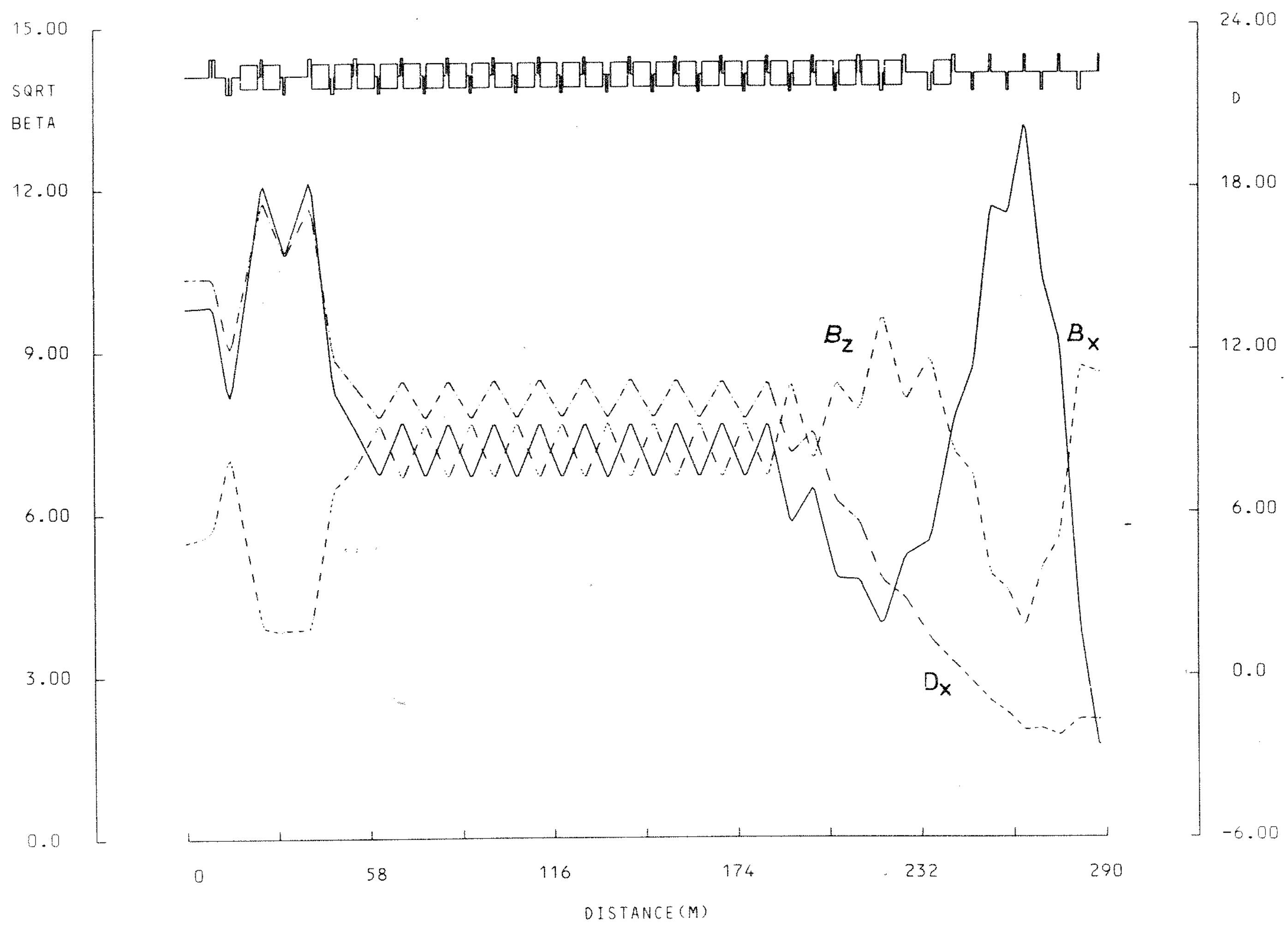
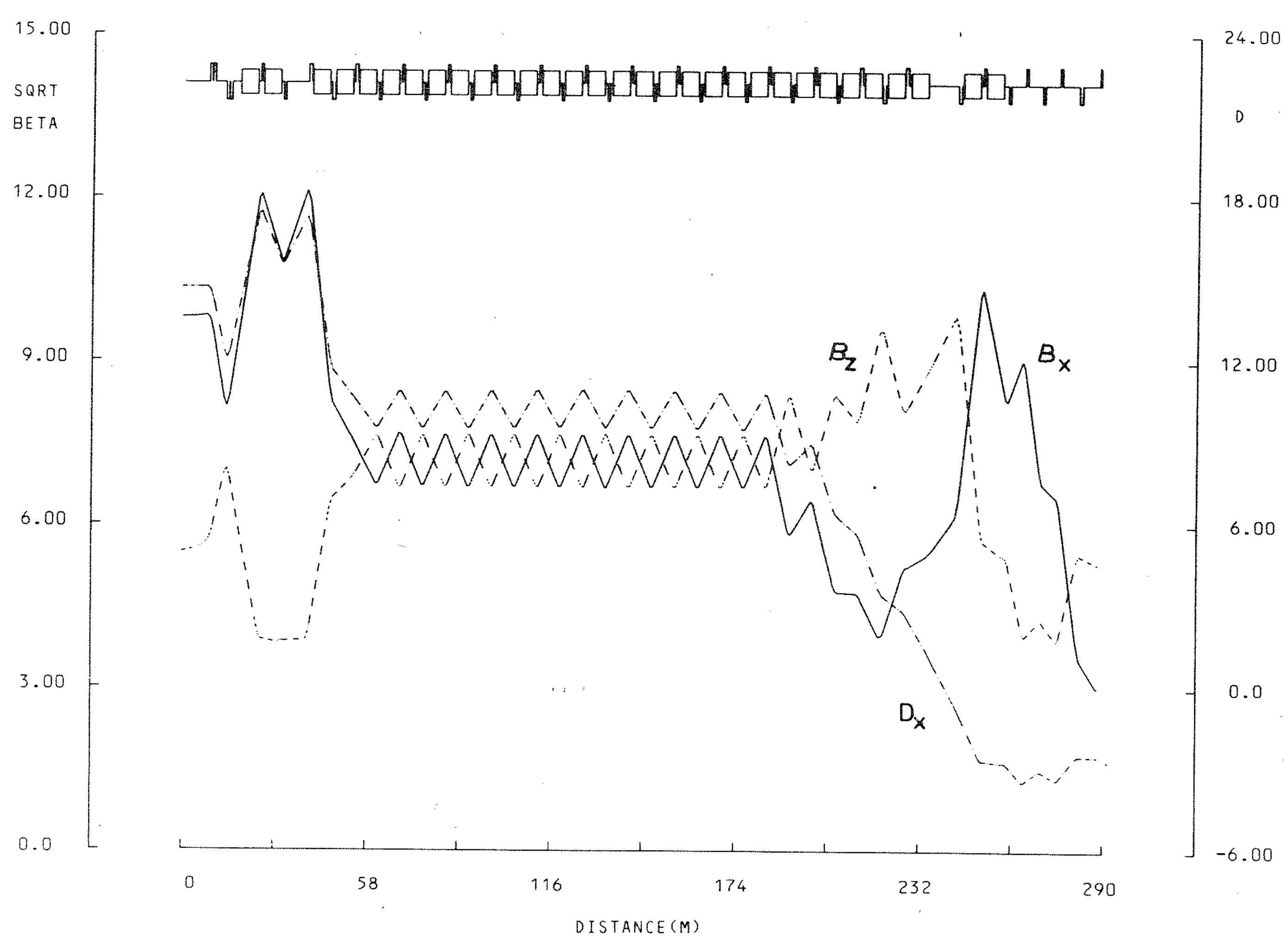


FIG. 2 Envelope Functions WWP-RF Straight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B_z
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DISTANCE(M)

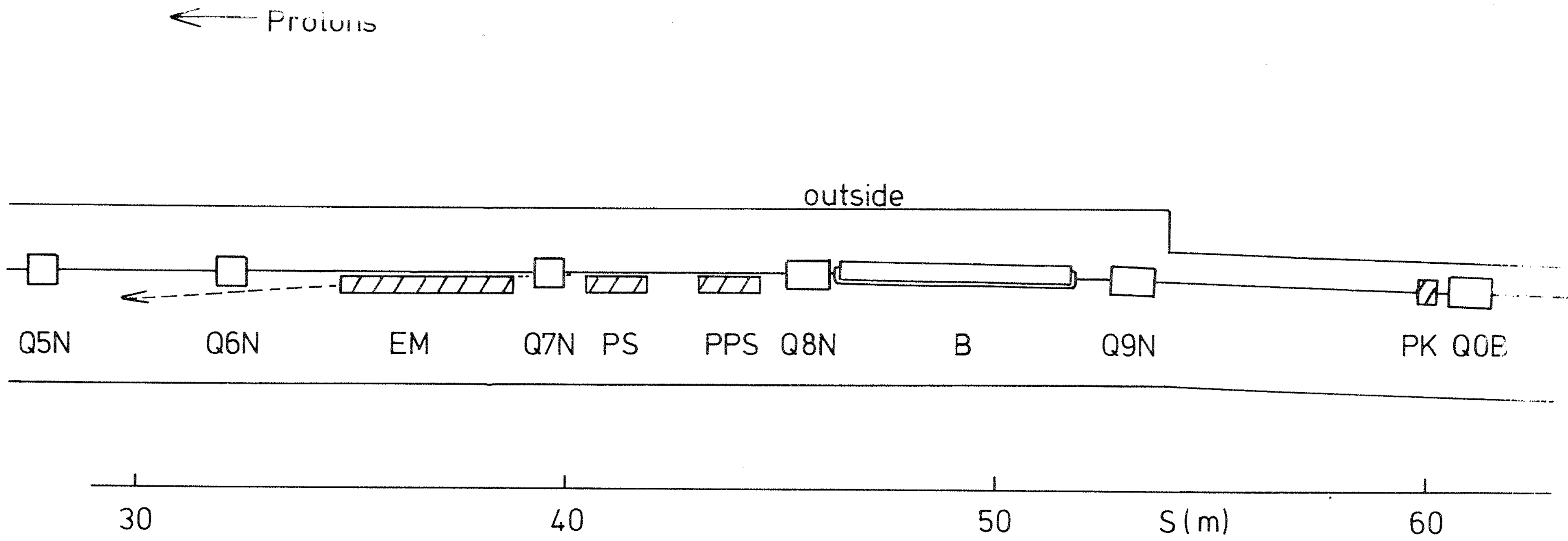

FIG. 4 Proton Extraction (North)