IMPROVED PROTON INJECTION INTO HERA VIA PETRA OPTICS TRICKERY: ARE THE PROSPECTS REAL OR IMAGINARY?

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Abstract

Possibilities for optics changes in the PETRA ring for achieving improved proton injection into HERA are examined in this paper. By reducing the average dispersion, η at the PETRA top energy, 40 GeV, the bunch length for protons transferred into HERAp can be shortened without having to increase the PETRA RF-voltage. The number of protons captured in nearby HERA 208 MHz buckets is thereby reduced. With alternate PETRA extraction matching conditions, the effective aperture of the transfer line can also be increased. Finally new optics may be useful for mitigating anomalous emittance growth during the PETRA ramp. A range of options are examined in this paper in a search for improved PETRA/HERA performance.

1 INTRODUCTION

The longitudinal match for proton transfers from PETRA to HERA could be improved by lowering the average dispersion in PETRA at 40 GeV. At high beam current the present bunch rotation scheme is not perfect for particles in the tails of the longitudinal bunch distribution. These particles can end up trapped as satellites in nearby HERA RF-buckets, and are a source of trouble for the collider experiments, H1 and ZEUS, in terms of increased background and reduced good event efficiency to tape. If the average dispersion in the PETRA dipoles was to be reduced by a factor of two, then the PETRA bunch length would be reduced by the factor $2^{1/4}$ = 1.19.

By design the dispersion in PETRA is deliberately kept large (with peak dispersion 14.3 m, average 9.5 m) in order to be able to inject into PETRA slightly above transition. Thus during the PETRA ramp the machine never crosses transition and the same optics can be used throughout the cycle. The possibility does exist to reduce the average dispersion via an optics change made once one is far enough away from injection.

There are other reasons to consider alternate optics solutions in PETRA. There is an anomalous emittance blowup that happens during the PETRA ramp and it has been suggested that a possible culprit could be the relatively high peak η- and β-functions in the PETRA arc dipoles. There are large multipole fields (especially sextupole) due to eddy currents in the PETRA dipoles during the ramp and by reducing the beam size in these dipoles one might have a more linear and more well behaved machine.

A third reason for considering an optics change is to reduce β- and η-peaks in the transfer line to HERA. The transfer line acceptance is barely adequate and often several test/tuning injection shots are required to establish reasonable transfer efficiency into HERA. As we continue to push to higher injected beam currents, it is to be expected that the beam emittance will grow somewhat and that the transfer line can become a future injection bottleneck. Therefore an increase in effective transfer line acceptance, which might be easily achievable by reducing β peaks, would be quite welcome.

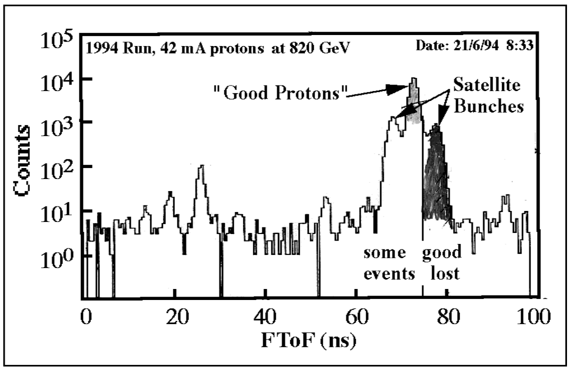

Figure 1: Timing spectrum with satellite bunches.

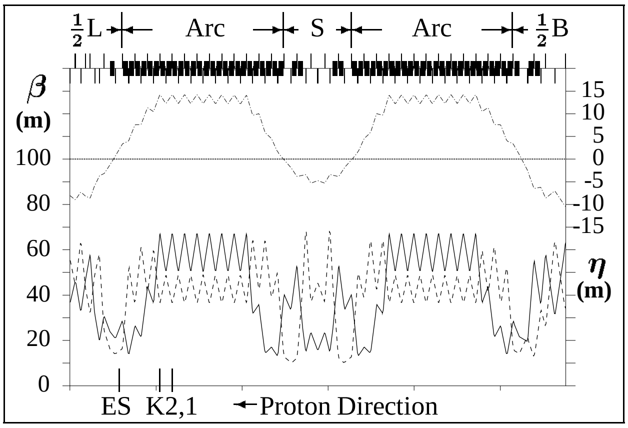

Figure 2: Original PETRA optics which is used from injection through flat-top (γ_t = 6.2). In this and subsequent figures horizontal-β (solid) and vertical-β (dash) are plotted in the bottom half using left hand scale and horizontal-η (dash-dot) is plotted in the upper half using right hand scale.

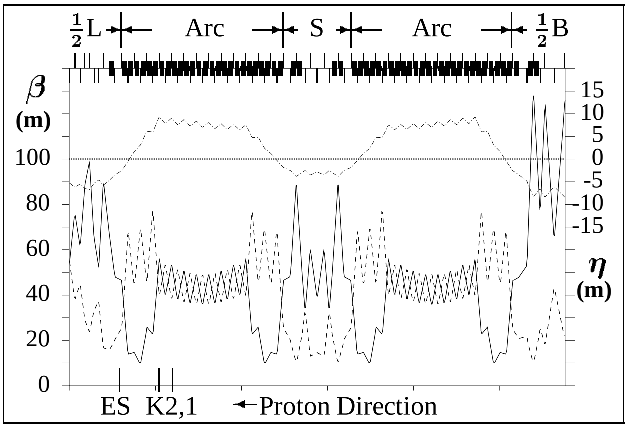

Figure 3: Symmetric FODO arc solution (γ_t = 8.8). Extraction kicker to septum phase advance is too large. Also note large horizontal-β peaks in bypass region.

2 PARAMETERS AND CONSTRAINTS

PETRA has near 8-fold symmetry with 8 arc sections separated by alternating combinations of long (L) and short (S) straight sections. In the south one of the long straight sections is modified so as to bypass (B) RF-cavities used during PETRA electron/positron operation. Proton extraction to HERA occurs via kickers (K1 and K2) and an extraction septum (ES) in the long straight section is shown in Fig. 2.

Maintaining the kicker to septum betatron phase difference is a very important constraint to any proposed optics change. Starting with a FODO solution, as shown in Fig. 3, in the middle of an arc we can match to the left and right to the long and short straight sections by assuming periodic boundary conditions. With stronger horizontal focusing in the arc sections, one is able quite naturally to reduce the horizontal β and η in the arc dipoles; however, this increased horizontal focusing leads to increased horizontal phase advance in the arcs and must be offset in the straight sections in order to keep the overall machine tune constant.

Keeping the tune constant is especially important for any optics change made during the ramp. An attractive scenario would be one that uses the old high dispersion optics for injection and then the changes optics during the ramp; however, we must be careful to keep the machine tune relatively constant or increased beam loss and emittance blowup due to resonance crossing is likely. Forcing a simple periodic FODO solution in the arcs and keeping the tune constant tends to increase in the magnitude of β peaks in the straight sections, but a moderate β-increase can be tolerated near the top energy 40 GeV, because of the adiabatically reduced beam emittance.

The more serious problem associated with a larger arc phase advance is the increased phase difference, departing dramatically from an ideal 90°, between the extraction kickers (K1 and K2) and the extraction septum (ES). The extraction kickers just fit into short slots in the north arc created by removing sextupole magnets at two locations. A purely hardware fix for such an unfortunate phase difference, i.e. swapping the kickers with sextupoles at another location, that is an odd multiple of 90°, is conceivable but not very desirable.

Thus one is led to seek optics solutions which use more of the freedom inherent in PETRA's 29 independently adjustable quadrupole circuits. Of course one does not have complete freedom. For example quadrupole polarity changing is too slow to be permitted during the ramp. Maximum quadrupole strengths are set by power supply and magnet design limits and in addition we have to identify quadrupoles, with favorable lattice function, for use by the tune control circuits (for fine tune control).

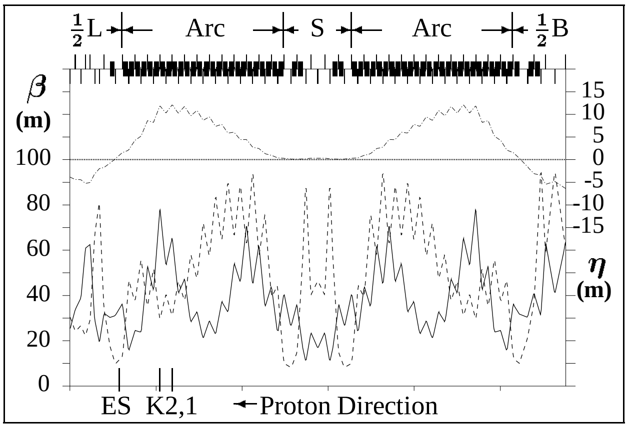

Figure 4: Compromise solution for: 11% bunch length reduction, 90° kicker-septum phase difference, same tune as injection, reduced transfer line β- and η-peaks and no polarity changes. γ_t = 7.9

A first step away from a symmetric periodic FODO solution occurs by introducing a small asymmetry between the ends of the arcs.. This asymmetry permits an increase of the horizontal-β in the quadrupoles which are located between the extraction kickers and the extraction septum. The extraction kicker and septum phase advances are then brought close to 90° phase difference.

Taking all the above constraints into account we are led to a compromise solution shown in Fig. 4. We see that it is no longer ever approximately periodic in its character; however, it achieves a 38% reduction in average dispersion in the dipoles (for 11% bunch length reduction). There are no polarity changes during the ramp, the tune is kept constant and the extraction kicker phase differences and β functions are even more favorable than for the original injection solution. It is however a true “compromise solution” in the sense that one could further reduce the average dispersion but at the cost of spoiling either the tune or the kicker phase advance.

A brief test of this compromise optics and the appropriately matched transfer line optics, was made during December 1995 machine studies. It was found possible to transfer beam into HERA with an encouragingly small longitudinal bunch spread of 1.6 ns FWHM; unfortunately these tests may only be taken as indicative and not conclusive because there was another PETRA machine experiment, involving an alternate bunch rotation scheme, which was done in parallel to this optics study. The true performance with new PETRA and transfer line optics should however become apparent during 1996 running.

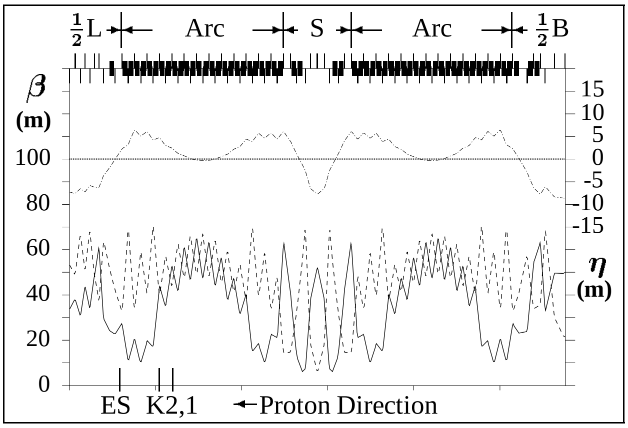

Figure 5: Reduced dispersion solution with peak-η = 6.4 m and ≈50% bunch length shortening (γ_t = 11.8).

Since a compromise solution is rarely exciting, one might consider what is possible by relaxing one or more of the above constraints and then pushing the optics to the limit. A first example is shown in Fig. 5 where the average dispersion decreases 4-fold. Here the horizontal tune increases while the vertical tune goes down for a final tune split of 5 units. These tunes are quite different from the current injection tunes and we would have to use an optics of this type also for injection; however, with a transition gamma (γ_t) of 11.8, PETRA would then have to cross transition. With the present slow PETRA ramp rate (to avoid eddy current troubles in PETRA dipoles) transition crossing might well be problematic.

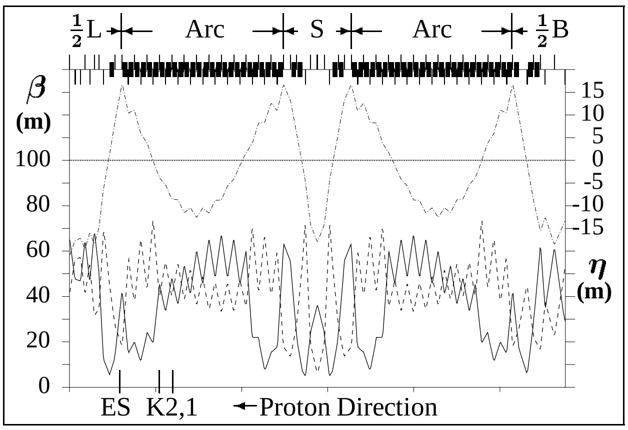

Figure 6: Imaginary-γ_t solution which avoids transition but has large 16 m peak dispersion (γ_t = 28.7i).

It would seem, at least on the surface, much better to avoid transition crossing altogether. This suggests another possible optic which achieves this goal as shown in Fig. 6. We note that it is possible to introduce enough negative dispersion in the dipoles at the center of the arcs so that the average dispersion in the dipoles, and thus the momentum compaction factor, becomes negative. In this case the γ_t is an imaginary number and particles in the ring never have to see transition. The cost of this imaginary gamma trick is the presence of 16 m η-peaks.

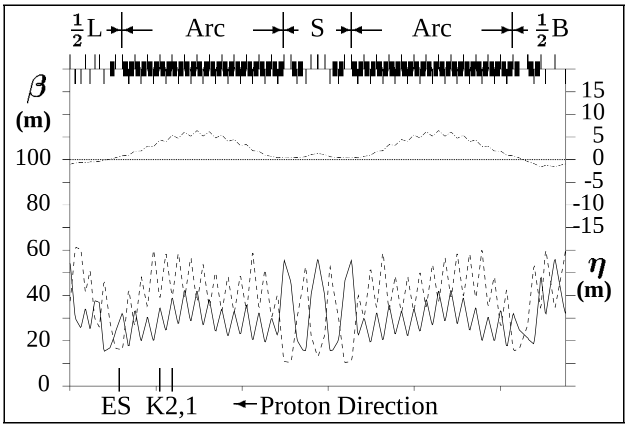

Figure 7: Solution with lowest average η and β but requires two additional arc power supplies and new current bus.

Rather than only lowering the average dispersion, we investigate how far one could lower the average β. An example of a dramatically lowered β solution is given in Fig 7. Unfortunately this solution is only possible by exceeding the main arc (QD and QF) quadrupole power supply voltage limits. That is to say without an investment in at least two additional arc quadrupole power supplies, the low β optics solution presented here can not be ramped beyond 32 GeV (40 GeV needed at top end for extraction).

3 CONCLUSIONS

The compromise solution shown in Fig. 4 is the optic that promises the greatest near-term tangible improvement in operation and can be implemented for 1996 running. For other solutions:

- Transition crossing could be checked theoretically, but a real system and hardware will be likely to involve a significant investment.
- Combinations of imaginary γ_t and/or low-β solutions are interesting to consider; however without investment in new power supplies, such solutions are not likely to be useful.
- Making an almost continuous series of optics transitions during the ramp, to avoid transition, could be considered; however, adding such operational complexity is not an obvious path to improving machine performance.