A TWIN BOOSTER INJECTOR FOR A LARGE PROTON SYNCHROTRON

by

R. Billinge

and

W. Schmoll

CERN

Geneva, Switzerland

1. Introduction

The injector proposed in the original CERN design study report was a fast cycling 8 GeV booster synchrotron of 100m average radius. A similar injector was proposed by the Berkeley group who more recently concluded that this type of injector was the most suitable of several types examined. From a technological point of view, such injectors appear to be feasible. In fact the most difficult part was considered to be the variable frequency r.f. system, and model studies have demonstrated that this presents no outstanding problems. There remain, however, two difficulties of a more fundamental nature. Firstly, the estimated space charge limit for the booster is somewhat marginal and secondly the maximum number of phase oscillations per revolution Q, is rather high. This requires an even distribution of r.f. around the circumference to avoid resonances and in addition, recent work has indicated the possibility of space charge induced satellite stop bands in machines with high Q when working close to their space charge limits.

Several ways have been examined of alleviating these difficulties, usually by increasing the linac energy or by inserting another circular pre-accelerator between the linac and the booster. The alternative proposed here is simply to decrease the booster radius, thus increasing the number of booster batches required for filling the main ring. Since the space charge limit in the booster is independent of its radius, this increases the total charge available for single-turn filling of the main ring. Furthermore, if the injection and ejection energies, the repetition rate and the r.f. bucket area (as determined by the linac energy spread) remain unchanged, the value of Q is reduced in proportion with the radius. Under the same conditions the r.f. voltage per turn and hence the number of accelerating cavities required, also scale with the radius. It follows from this that the booster radius should be made as small as possible compatible with a safe value for the peak magnetic field and adequate straight section length.

2. Basic Design

The design has been based on a FoFDOD lattice, with a magnetic field of 8 kilogauss at the peak energy of 8GeV. Considerations of injection and ejection, together with the space required for the r.f. cavities indicated the need for a long straight section length in excess of 4.5 meters. The choice of a long mid-D straight section instead of long mid-F was governed mainly by the need to minimize the circular aperture required in the mechanically tuned cavities and in addition the long mid-D lattice is preferable both for injection and ejection. A computer programme was used to study the variations in aperture requirements as functions of periodicty, straight section lengths and Q values et c., and it was concluded that the minimum average radius which satisfied all the requirements was 60m. The lattice proposed has 21 periods and since ejection will occupy three out of four consecutive long straight sections, this is the minimum periodicity which permits three-fold symmetry in the distribution of the 9 r.f. straight sections required. The main parameters are then as follows:

- Maximum kinetic energy: 8.0 GeV
- Injection energy: 200 MeV
- Average radius: 60 m
- Repetition frequency: 20 Hz
- Maximum field at equilibrium orbit: 9.0 KG
- Magnetic radius: 37 m

With these parameters, and for an r.f. bucket area of \(6 \times 10^{-5} \) rad, the peak value of Q is reduced to 0.12 and the overall space charge limit is almost twice that of the original booster.

Since it does not at the moment seem possible to increase the booster repetition rate substantially due to the increasing difficulty of the r.f. system, the filling time for the main ring would have to be increased in proportion to the inverse of the booster radius. Thus for a radius of 60m, a repetition rate of 20Hz and a main ring radius of 1200m the filling time becomes 0.95 seconds. However, this may be considered to be uncomfortably long in particular if it is considered very important to be able to run the machine below maximum energy with higher beam intensity than that obtainable at top energy. Twin rings may therefore be employed which would reduce the filling time to 0.45 seconds. Undoubtedly one of the most important advantages of twin booster rings would be the considerable increase in overall operational reliability of the entire accelerator complex. Indeed if one of the two rings were out of order, operation could continue with no other loss of performance than a doubling of the main ring filling time, which corresponds to a reduction in average intensity of only about 15% when running at peak energy.

It was initially suggested that the rings might be superimposed in the same tunnel and possibly share the same magnet and/or r.f. power supplies. However, to avoid excessive voltages to earth, the magnets would be divided into several groups as in the 'White circuit'. In this case separate chokes are required for the parallel circuits, which does not necessarily pass the same current. Consequently, these chokes cannot be replaced by machine magnets.

3. Further Considerations

It has already been indicated that twin rings could not be used as resonant circuits for one another. Also the superposition of the two rings, besides increasing the height of the tunnel required, also presents many difficult engineering problems associated with access and support of the machine components. Thus it seems that any savings which might result from making the machines interdependent would be small.

If the rings were housed in separate tunnels, it would then become possible to install and maintain or repair one ring while operating with only slightly reduced intensity with one booster. More detailed studies of the problems involved in sharing some facilities between the rings are needed before an estimate could be made of the possible savings which might result. However, it has been possible to estimate the increase in cost between two independent 60m radius rings and the original booster, simply by scaling the appropriate items. Although the total bending required is doubled, the magnet gap is reduced by 15% and the stored energy by 20%. The r.f. vacuum and tunnel costs have all been assumed to be proportional to the radius and the beam transport systems have been taken as common with the addition of an extra injection, ejection and two beam switches. With those assumptions, the cost of independent twin rings appears to be only 45% higher than that of the original booster.

4. Summary

For reasons associated with the overall space charge limit and to reduce the maximum number of phase oscillations per turn in the booster, it seems desirable to reduce the booster radius as much as possible, compatible with safe values for the peak magnetic field and the amount of straight section available. Although at the present time it does not seem possible to increase the booster repetition rate significantly, an increased filling time for the main ring can be avoided by having...
5. References

2) 200 BeV Accelerator Design Study, Lawrence Radiation Laboratory (1965).
4) W. Schnell, C. Zottler, Results on high-power models of mechanically tuned r.f. cavities for fast cycling booster-synchrotrons. Proc. VI Int. Conf. on high Energy Accelerators at Cambridge, Mass.

DISCUSSION (condensed and reworded)

J.M. Peterson (LRL): A small point regarding magnet lattice: You claim the FOOFDOOD is better for extraction and I would claim the opposite, that the FOOFDOOD with the long straight section between the F's, is superior in the sense of smaller kicker requirements, although I know your point, and Billing and Hardt have pointed out that one advantage of the FOOFDOOD is that it requires less aperture for the final extraction.

Billinge: We agree entirely about the FOOFDOOD structure being better from the fast kicker point of view except that the only disadvantage with the long mid-D straight section for the kickers is that the cross section of the kicker becomes almost square and then, for the same kicker impedance, one can simply make the kickers longer. By making the kickers longer, we can achieve the same impedance. In a lattice of this type, where we have adequate straight sections available, we can use two long straight sections full of kickers if necessary, without actually increasing the number of kickers. Then we think we can overcome the small disadvantage, from the kicker aspect, of reduced impedance.

G.K. Green (BNL): I wonder if a small element of unreality has crept into this through excessive linearization. I was noticing in the \( \beta \) function diagram the rather large peak in the vertical \( \beta \) function. Now, in these boosters, one may need to go rather nonlinear due to various space charge and instability requirements, and when one inserts nonlinearities, especially if one does it with concentrated sextupoles (after all, it is a little hard to file all the magnet poles in order to insert the desired second derivatives), then these \( \beta \) functions no longer look as pretty as these slides we have been seeing; the peaks go up here and down there and they move sideways; the situation really becomes quite complicated. I think the present tendency to linearize has rather oversimplified some of these considerations, such as where the kicker goes.

K.H. Reich (CERN): We are obviously aware of this and we know we have to watch the nonlinearities very carefully.

1) Before we fix the apertures, we want to know how good the elements will be.
2) We have chosen the triplets such that the end fields are relatively short; you may have noticed that the lenses are long, much longer than needed for gradients, and gradients are such that the field at the poles is only 3 kilogauss, just to get long lenses with small end fields. Also we are in contact with the ACO people who have had all these nonlinear effects and they have worked out the theory which is required to cope with it.

It is perfectly true that the non-linear theory we have so far, which usually uses the smooth approximation, cannot be directly applied. We are aware of that and are working on it. So far we think this design is all right. However, it must be watched.

Billinge: I think Dr. Green would agree that when comparing systems, one should at least start by comparing their linear properties.

P. Meads (Brobeck Assoc): One of the disadvantages of the FOOFDOOD or FOOFDOOD scheme is that, unless the good field region extends way over, at extraction, the beam comes out through several magnets in a region of very high sextupole and octupole component. I wonder if you have looked into this, if this is so in your case, and what you plan to do about it?

Billinge: First, I think I should explain the advantage we claim of having the beam come out in the middle of a long mid-D straight section. The envelope of required aperture in the magnet for normal acceleration is decreasing rather sharply at the entrance to a mid-D straight section. This implies that the ejected beam can be separating from the normal aperture requirement as it passes through the magnet preceding the long straight section. This enables one to begin the septum magnet very early in the straight section, in fact right at the beginning of it, and following that, have the beam completely out of the straight section, quite clear of the next magnet. Therefore, I think that in our case and for our parameters, this problem does not arise.