HIGH ENERGY BOOSTER FOR AN ELECTRON SYNCHROTRON

by

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1. INTRODUCTION

The success of the SLAC accelerator and the new Cornell 10 GeV synchrotron have led us to examine the possibility of using NINA as an injector to a synchrotron in the energy range 15/20 GeV. In addition to electron and photon physics, one can expect from such an accelerator useful fluxes of secondary particles up to and even beyond 10 GeV/c with a good duty cycle.

Our proposal is to build a large ring (200 m mean radius) intersecting NINA on line parallel with the present experimental area (Fig.1). Not only would this mean that we could use the present Experimental Hall for experiments with the large accelerator, but the particular topology of the Daresbury site would mean that the civil engineering for the large ring would be simple and relatively cheap.

2. GENERAL PHYSICAL LAYOUT

The requirement to be able to use the present Experimental Hall with the new accelerator restricts the maximum radius of the portion upstream from the Hall to about 150m, due to the proximity of the Bridgewater Canal.

To allow for a maximum energy of 20 GeV, a bending radius of at least 120 m is required, to keep the radiation loss within a reasonable limit. For optimum design, up to a third of the perimeter of a large electron synchrotron may be needed for r.f. structure. Some additional straight length is also required for injection and extraction. The layout shown in Fig. 1, of four quadrants, of mean radius 150 m, separated by four straights, each 100 m long, meets these requirements. It is possible to match such long straights into the magnet lattice if each straight is arranged to have 2π phase shift and unity transfer matrix. The radiation loss per turn at maximum energy for this layout would be 37 MeV at 15 GeV, rising to 117 MeV at 20 GeV. The beam height would be about 2ft. 6ins. above that of NINA, to allow photon beams to pass over the NINA magnets.

One possible magnet lattice, which has been chosen for initial consideration, is shown in Fig. 2. This is basically a FODO structure having 13 magnet periods per quadrant, but a short straight is added in the centre of each magnet, to make the magnets of more reasonable length, and facilitate the use of a remote alignment system. The overall Q is 17.65 and other details are given in Fig. 2.

3. MAGNET APERTURE

The radial width of the circulating beam in NINA has been measured to be 5 mm near a point of maximum amplitude, at 3 GeV, compared with a theoretical figure of about 3 mm. The height has not yet been measured, but it is unlikely to exceed the theoretical 1.6 mm by very much. For a single turn ejection, it should be possible to transfer the beam to the larger ring without appreciable increase in emittance. For the lattice studied, the function β_{max} would be 24 m and the closed orbit function 1.35 m, compared with 17 m and 2.1 m respectively for NINA. Thus the beam injected into the large ring would have maximum amplitudes little different from those in NINA. In the long straights, β_{max} rises to 75 m, but the closed orbit function remains below 1.1 m, resulting in a maximum horizontal amplitude of about 12 mm. Since, with this magnet lattice and an isomagnetic equilibrium orbit, radiation causes anti-damping of the horizontal betatron oscillations which more than offsets the initial adiabatic damping with increase of energy, the maximum amplitude in the quadrants rises to 13 mm at 15 GeV and 55 mm at 20 GeV. By using different equilibrium orbit fields in the F and D magnets, the lattice can be designed to have equal damping in the radial and axial planes, but this results in an increase of the synchrotron radiation by about 8%. For 15 GeV maximum, the anti-damping could be tolerated, and it could even be of some advantage in extracting the electron beam. However, as the ultimate aim is 20 GeV, the system must have some damping. The use of an isomagnetic orbit with a "Robinson" damping magnet is also being considered.

With damping, the beam size is likely to be sufficiently small for the aperture requirements to be mainly determined by the orbit distortions caused by misalignments and field variations. Approximate calculations show that for a maximum closed orbit distortion of 1 cm, it would be necessary to keep the rms error in magnet position to less than 0.1 mm. These, and other conditions, lead to a maximum aperture requirement of the order of 5 cm horizontally by 2.5 cm vertically. Although this aperture may seem small, the recent operation of the Cornell synchrotron with a maximum aperture of 7 x 3.8 cm and an injection energy of only 150 MeV, without the use of the remote alignment jacks, shows that it may even be on the generous side.

4. MAGNETS

A choice has to be made between the conventional C-magnet with a separate vacuum chamber and the H-magnet with a vacuum enclosure as used at Cornell. The thin corrugated stainless steel vacuum chamber developed for the French electron synchrotron proposal makes the C-magnet economically competitive with the H-magnet, and it has other advantages.

Despite the larger orbit diameter, the magnet for the proposed booster would have a total weight no greater than that of NINA, and the stored energy would be less than half, so the power supply would be relatively cheap.

5. INJECTION

The simplest method of transfer would be to eject the whole beam in one turn from NINA and inject it into the big ring. Since the orbit time of the latter is 4.41 μs, compared with 0.73 μs for NINA, this would result in a poor duty cycle factor for experiments. It would be better to use multiturn ejection from NINA to fill the big ring more uniformly. To avoid the loss of current inevitable with schemes using septum magnets to divide up the beam, it may be better to use an r.f. kicker system in which every sixth bunch is ejected on the first turn, and the rest of the bunches ejected sequentially on subsequent turns, so that the big ring will be filled uniformly with bunches spaced six times as far apart as in NINA. Fig. 3 shows the injection path and possible gamma and electron beams.

6. RADIO FREQUENCY AND ACCELERATING STRUCTURE

The frequency to be used for acceleration must be equal to that used in NINA or a harmonic of it, if loss is to be avoided on the transfer.

For most efficient use of the r.f. power, a travelling-wave structure is best, and, since the shunt impedance varies as $f^{\frac{1}{2}}$, a high frequency is indicated. Also the size of the structure is inversely proportional to the frequency, so the cost is likely to be lower for a higher frequency. Possible frequencies are 816 Mc/s and 1224 Mc/s.

The layout proposed would have 4 long straights each approximately 100 m long. There would be four pairs of quadrupoles in each straight, but leaving a total free length of about 80 m per straight. Cases have been worked out for the isomagnetic case for total structure lengths of 160 m and 320m and beam loadings of 1 and 3 μA mean, for a frequency of 1224 Mc/s, and these are summarised in the table, from which it can be seen that a peak power of just over 1 MW would be sufficient for initial operation at 15 GeV, for a total structure length of 160 m.

7. BUILDING AND CIVIL ENGINEERING

The civil engineering and building required for the booster are simple and relatively cheap. Fig. 1 shows that the greater part of the booster perimeter would be in the sandstone escarpment to the south of NINA. This is fortunate in that the costs of tunnelling in rock in the last few years have gone down remarkably with the advent of very efficient boring machines[1].

Fig. 4 shows a cross section of the site showing the position of the proposed ring. The only other buildings required would be light structures at existing ground level to house the r.f. power supplies.

8. SECONDARY PARTICLE PRODUCTION

The recently-published experiment work[2-4] on the secondary particle production at SLAC with primary electron beams of 16 and 18 GeV has confirmed predictions based on measurements at lower energies.

Taking these figures, the fluxes which might be available in a typical beam transport system from the booster, in a channel of 10% momentum acceptance with a solid angle at 5.5 GeV/c of 0.25 mstead, falling as the square of the momentum, have been calculated and are shown in Fig. 5.

9. ESTIMATE OF COST

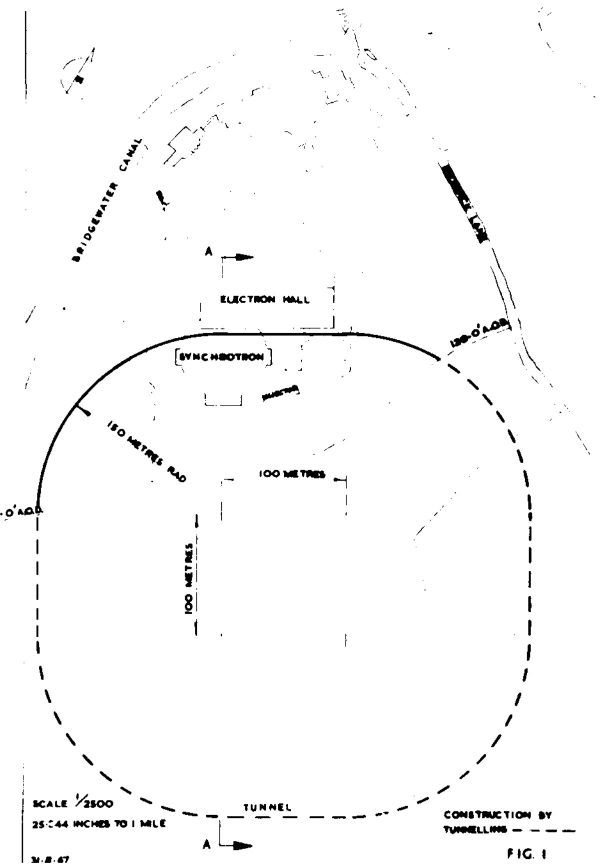
An estimate of the cost of the initial stage of the booster has been made using the actual costs of NINA as a basis. This is summarised as below:-

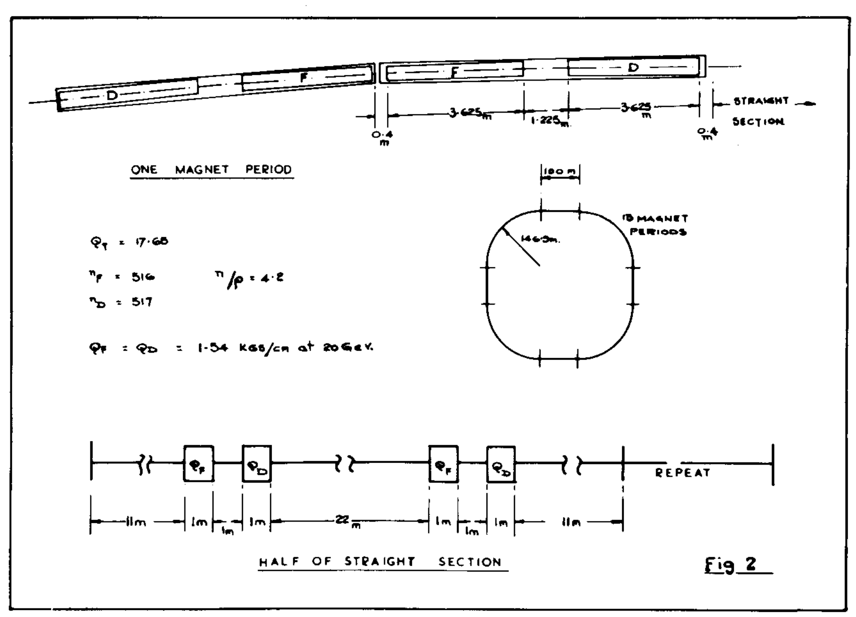
	k£
Magnet	770
Magnet Power Supply	345
Radio Frequency	460
Vacuum	210
Controls	150
Injection	140
Buildings	885
Other	200
	k£3,160

On the whole we feel that the figures given above are not unduly optimistic. Although the costing is based very largely on what we know of NINA there are a number of technical problems which have to be investigated which may well result in cheaper solutions.

TABLE

Final Energy	GeV	15		20	
Radiation loss/turn	MeV	37		117	
Mean current extracted from NINA	μA	1	3	1	3
Circulating current	mA	5	15	5	15
Optimum αL	neper	0.7	0.45	0.9	0.75
Peak r.f. power L ≈ 160 m	MW	1.1	1.85	8.3	10.4
L = 320 m	MW	0.72	1.45	4.8	7.0
Mean r.f. power (approximate) L = 160 m	MW	0.3	0.5	1.7	1.8
L = 320 m	MW	0.2	0.5	0.9	1.2





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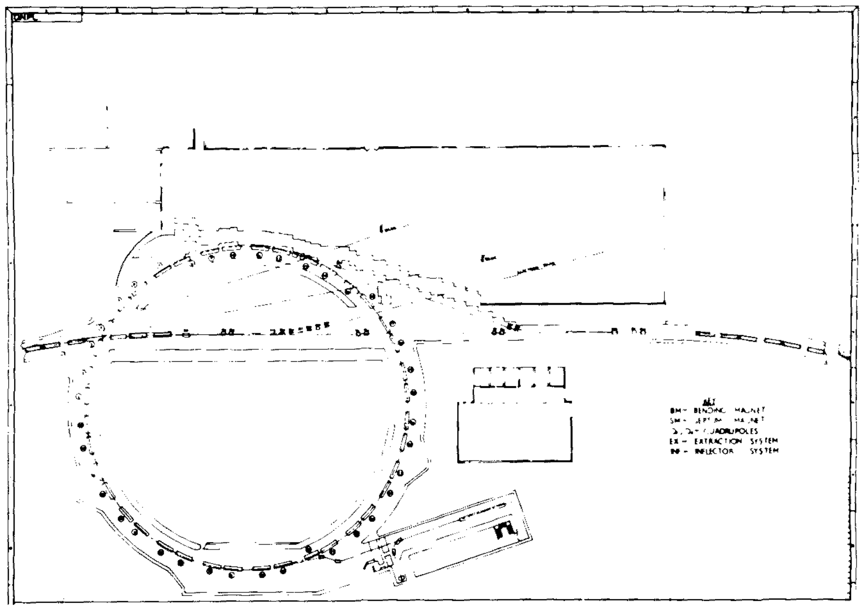
2. A. Barna et al. - Phys. Rev. Letters 18 360 (1967)

3. A. Boyarski et al. - Phys. Rev. Letters 18 363 (1967)

4. S.M. Flatte et al. - Phys. Rev. Letters 18 366 (1967)


KEY
BM – BENDING MAGNET
EX – EXTRACTION SYSTEM

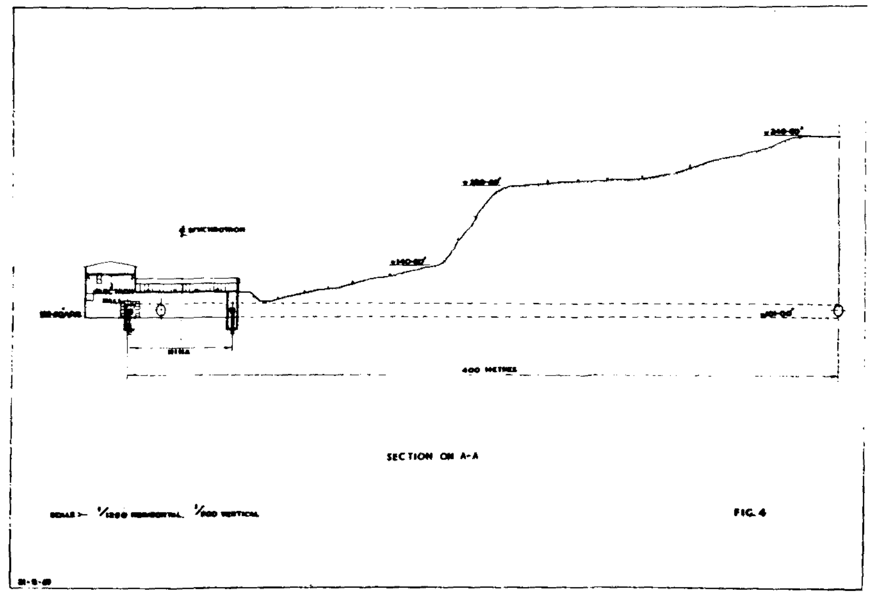

400 METRES
SECTION ON A-A

FIG. 4

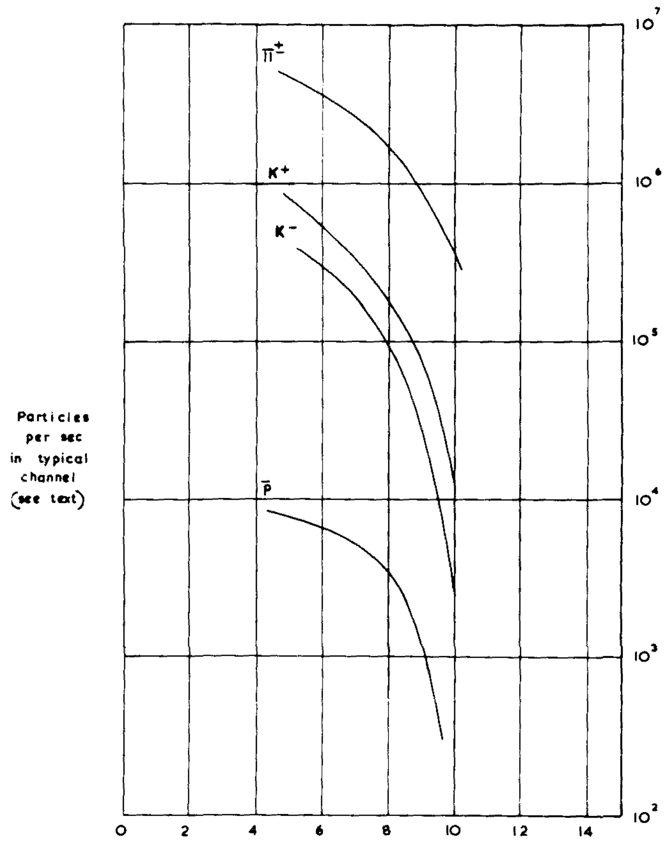

Particles
per sec
in typical
channel
(see text)
$\pi^{\pm}$
K^{+}
K^{-}
$\bar{p}$
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
0
2
4
6
8
10
12
14
GeV/c

FIG 5