

A PROPOSAL FOR A 15–20 GeV ELECTRON SYNCHROTRON

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1. Introduction

A proposal for a 15–20 GeV electron synchrotron as an addition to the existing synchrotron NINA has already been published^{1,2}. The main novelties of this proposal were the use of an electron synchrotron as injector, the small emittance and energy spread of the beam from this allowing the use of a very small aperture in the larger ring, and the concentration of the r. f. system into two travelling wave linacs. The main parameters are given in table 1, and the proposed layout, which would enable the existing experimental facilities to be used, is shown in figure 1. An alternative layout, which would involve fewer modifications to the existing machine, but would require the building of a new experimental area is shown in reference 2.

Since the publication of the proposal, some further investigation has been carried out, leading to observations which may be of more general interest in the design of medium and large accelerators.

2. Magnet Lattice and Correction System

Although the magnet lattice for the scheme has a superperiodicity of four, account must be taken of the large energy increment supplied by the two sections of linac, so that superperiod resonances of the order two must also be considered. Computations show that this should not cause appreciable difficulty, if the ring is filled reasonably uniformly round the perimeter, and the tolerances required are no tighter than have been achieved in existing installations. The magnets are supported on long beams, with the pivot point coming between two half magnets. Movement of the pivot point will move the magnet centred on that point, without appreciable movement of the adjacent magnets. This movement will be used to correct the closed orbit. The beam bump method of correction, in which three magnets are moved simultaneously at each step,

is favoured for this application. At first, these corrections will be under the control of the operator, but it is intended to give this job to the control computer, when some experience has been gained.

3. Magnet Construction

As the beam intensity increases, radiation damage becomes a dominant problem in the magnet design. Conventional magnet coil insulation will not withstand doses much over 10^{20} rads, so that either new methods of insulation must be developed, the loss of particles round the ring must be restricted, or the periodic replacement of coils or complete magnets must be scheduled. Proposals for the use of alumina concrete for coil insulation³ come in the first category, while the plans at NAL to avoid internal targets and aim for 99% extraction efficiency come in the second⁴.

In the case of the proposed synchrotron loss at injection should be small. The main loss at extraction occurs on the septum, and this would be in one of the very long straights sections, well clear of the main magnets. A beam dump would also be situated in a long straight section. Measurements in NINA show that, while the coil dose in some areas such as where injection or targetting is carried out, exceeds 10^{20} rads/year, the dose is down by a factor of 100 on this in the "quiet" sectors. Taking these precautions into account, conventional coils should have a reasonable expectation of life in the proposed synchrotron. Nevertheless, some investigation will be carried out to see how alumina concrete insulation could be applied to the magnets for a fast cycling machine.

Most of the existing electron synchrotrons use C-magnets with the coils divided into a number of sections, the thickness of each section being made small enough for the coil to be inserted through the magnet gap.

A similar arrangement would not be suitable for this synchrotron, where the magnet gap in the F magnets is only 22 mm, since the coils of this thickness and 4 m long would have inadequate mechanical strength. A new winding configuration has been developed which allows coils of double the gap thickness to be inserted from the end of the magnet, and sample coils are to be made to evaluate this. The scheme, shown in figure 2, has the disadvantage of increasing the coil overhang at one end, but this is not important in this particular case. The effect of the fringe field due to this is taken into account in the design of the end blocks.

The alternative method of construction is that used for the Cornell 10 GeV synchrotron, where the coils are "potted" directly into stacks of split H laminations, and an external vacuum envelope is used. Although this method of construction solves the problem of the vacuum chamber, and should provide the cheapest form of magnet, doubts are felt as to the life pumps must be used, as the gases evolved from the epoxy under radiation tend to poison the sputter ion type of pump.

4. Radio Frequency Power

The choice of the operating frequency for an accelerator is often determined by the availability of suitable power sources, the obvious example being the choice of radar frequencies for electron linacs, since the power and duty cycle demands are so similar. Only for the very largest accelerators is it economically desirable to have special tubes designed and manufactured for the project alone.

This limitation shows up particularly for medium or large electron synchrotrons, where the r. f. power needed to make up for the synchrotron radiation is the dominant factor. In the case of the proposed synchrotron, a peak power of 1.2 MW and an average power of 200 kW is needed even for the initial operating condition (1 μ A average at 15 GeV), going up to 12 MW peak and 2 MW average for the full 3 μ A at 20 GeV. Since the shunt impedance of a given structure varies as (frequency)^{1/2}, the higher the frequency, the lower the power required, and the cheaper the r. f. structure is likely to be. Calculations show that at 1224 MHz (3 times the NINA r. f.) a suitable structure could have an aperture large enough for the beam, and the "bucket" size would be sufficient. Although one manufacturer listed a klystron rated to give a mean power of 300 kW in this band, further investigation showed that the demand for tubes of this type was so small that it was uneconomic to maintain the expensive test facilities required, and future supplies could not be ensured.

At the next lower frequency suitable, 816 MHz, twice NINA r. f., the choice is wider, since this comes within the television transmitter band. In addition it is very close to the frequency chosen for the Los Alamos Meson facility (805 MHz), and this accelerator, using 45 klystrons, is large enough to warrant the design and manufacture of a special tube. Only small modifications would be required to this to make it suitable for use with the synchrotron. As a result of this, 816 MHz becomes the chosen frequency, although the actual tube type is still open.

5. R. F. Structure

In the proposal it was assumed that a travelling wave structure of the iris-loaded waveguide type would be used. Two sample sections of waveguide suitable for 1224 MHz operation have been obtained for both low and high power tests, to check for the incidence of multipacting, etc. Investigation of the π -mode standing wave structures as used at Los Alamos shows that this would also be suitable, and a shorter structure could be used. Evaluation of the relative merits of the two types of structure is proceeding.

For the increase in peak energy from 15 GeV to 20 GeV, either the r. f. power supply can be increased by a factor of 10, or the structure can be replaced by a superconducting system, the power supply

remaining unchanged. The first indication is that the cost of these alternatives would be about the same, but further investigation is necessary. Recent work at Stanford, reported at this conference, has shown that the necessary precision of control of the amplitude and phase of a superconducting r. f. structure can be achieved, but constructional problems still remain to be solved.

6. Magnet Power Supply

The proposal assumed the use of the "White" circuit, as used for most fast cycling synchrotrons. However, from investigations still proceeding, it would appear that pulser type circuits, in which thyristors are used to discharge capacitors through the magnet coils, may be preferable, if certain disadvantages can be overcome. The advantages are probably lower cost and the facility for providing flat top. The disadvantages normally include the high value of B at injection, and difficulties caused by jitter in the firing of the thyristors, but the new circuit, shown in figure 3, may be a way of overcoming at least the first of these disadvantages.

7. Vacuum Chamber

In a fast cycling accelerator, eddy currents limit the allowable conductivity of a vacuum chamber inside the magnet. The external vacuum enclosure used in the Cornell Synchrotron overcomes this difficulty, but reservations about this method of construction have already been expressed.

Present electron synchrotrons mostly use ceramic chambers, but these are relatively expensive, and the minimum wall thickness obtainable would take up a relatively large proportion of the magnet gap on the proposed machine. Methods of construction under investigation include sprayed ceramic onto a very thin wall stainless steel former, corrugated stainless steel foil, and a fabricated chamber, similar to that proposed for the booster synchrotron for the 300 GeV Accelerator.

It was intended to use sorption pumps for the initial evacuation of the system, with sputter-ion pumps for the high vacuum. However, it has been found that some types of sputter-ion pumps evolve large quantities of hydrogen when starting up, even when new, and this may require a change to turbo-molecular pumps for the initial evacuation.

8. Transfer from NINA

The ratio between the orbit perimeters of the proposed synchrotron and NINA is 6 to 1, and the cycle repetition ratio of the two must be the same, if the maximum mean current capability is to be retained.

Transfer of the beam from NINA to the booster in a single NINA orbit time would result in excessive transient disturbance of the r. f. system, since the orbit time and fill time of the r. f. structure are comparable, and a poor duty factor. Therefore the charge has to be spread more evenly round the ring. This requires six turn ejection from NINA. To split each bunch into 6 equal parts, and eject these on successive turns, would be difficult and lead to excessive loss on the septum required. The proposed scheme³ would use 68 MHz vertical magnetic fields to separate successive bunches in each batch of six in the radial direction, so that the application of an additional "staircase" pulse would result in the ejection of one bunch in every six on the first turn, the second out of every six on the second turn, and so on. This would give a bunch repetition frequency of 68 MHz in the new ring, compared with 408 MHz in NINA, and the same charge would be spread out over six times the perimeter. A prototype r. f. deflector is being designed and a magnet and pulser for the staircase pulse are under construction.

This system of r. f. beam bumps can also be used for the sharing of the beam in a synchrotron between two targets. If the deflecting r. f. is half the synchrotron r. f., alternate bunches can be deflected onto each target.

9. Controls

Work is proceeding on the design of a simple multiplex system for alarm, measurement and control signals. This system will normally operate in conjunction with a control computer, but is being designed so that the continuous interrogation of interlock and alarm signals is independent of the operation of the computer. Normal operation of the equipment will be through the computer, using CRT displays and "Joystick" controls.

10. Status of the Project

A detailed design and engineering study has been authorized by the Science Research Council, and this is due for completion by September, 1970. If authorization to proceed with the construction is obtained shortly after this, initial operation at 15 GeV would be possible by the end of 1974.

REFERENCES

1. Proceedings of the 6th International Conference on High Energy Accelerators 1967. p. A-76.
2. Preliminary Design Study for a 15-20 GeV Electron Synchrotron: "NINA Booster" Report DNPL/R2.
3. The manufacture of Synchrotron and Transport Magnets as an Integral Prestressed concrete Structure. R. H. E. L. Report to be issued.
4. National Accelerator Laboratory. Design Report July 1968.

TABLE I

1. Orbit Parameters

Orbit circumference	1323.00 m
Orbital period	4.41 μ s
Number of betatron oscillations per turn	17.75
Mean orbit compaction factor	4.65×10^{-3}

a) Magnet periods

Magnet arrangement	52 periods of	$\frac{\bar{O}}{2}$	$\frac{F}{2}$	$\frac{O}{2}$	$\frac{D}{2}$	$\frac{\bar{O}}{2}$	$\frac{D}{2}$	$\frac{F}{2}$	$\frac{\bar{O}}{2}$
Mean radius									146.900 m
Bending radius in magnets									120.0028 m
Magnetic field on equilibrium orbit (20 GeV)									0.556 T
Length of half magnet									3.6250 m
Length of \bar{O} straight section									1.2350 m
Length of \bar{O} straight section									0.400 m
Field index	approximately								516
Maximum value of β function									27.24 m
Maximum value of closed orbit function									1.29 m

b) Normal long straight sections

Arrangement	4 periods of	$\frac{0}{2}$	Q_D	$\bar{0}$	Q_F	$\frac{0}{2}$
Length of section						100 m
Length of quadrupoles						1.0 m
Length of \bar{O} straight section						22.0 m
Length of \bar{O} straight section						1.0 m
Phase shift						360°
Maximum gradient in quadrupole (20 GeV)						15.4 T/m
Maximum value of horizontal β function						70.0 m
Maximum value of vertical β function						78.5 m
Maximum value of closed orbit function						1.87 m

2. Magnet Parameters (assuming C-magnet)

		F	D
Number of half magnets		104	104
Aperture required	Horizontal	50	33.6 mm
	Vertical	18	25 mm

3. Radio Frequency

Maximum radiation loss per turn (without damping system)	118 MeV
Radiation loss per turn (15 GeV)	38 MeV
Frequency	816 MHz
Harmonic number	3600
Number of r. f. stations	2
Length of accelerating structure per station	80 m
Total attenuation in each structure	0.9 neper
Peak r. f. power required per station (15 GeV 1 μ A)	560 kW
Mean r. f. power required per station (15 GeV 1 μ A)	95 kW

4. Transfer

Energy at transfer	3 GeV
Field in Booster at transfer	0.0834 T

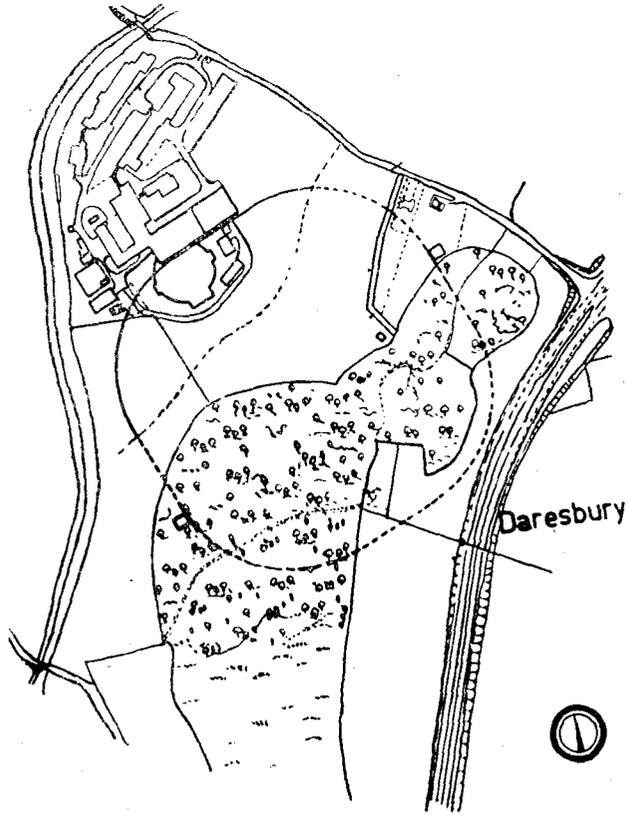


Fig. 1.

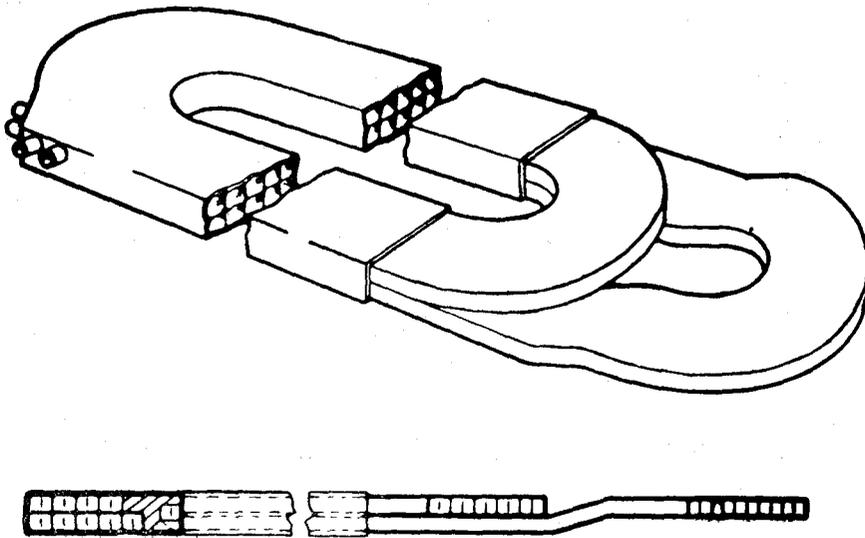


Fig. 2.

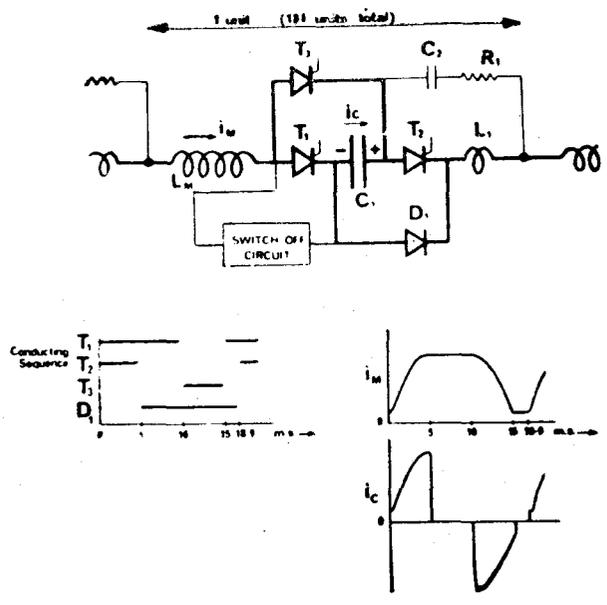


Fig. 3.

ДИСКУССИЯ

Комар: Имеются ли в настоящее время опытные участки камеры с напыленной керамикой?

Saxon: At present we have no model vacuum chambers but these are to be made. We already have equipment for spraying ceramic at the Laboratory.