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# A PURPOSE BUILT STORAGE RING FOR SYNCHROTRON RADIATION RESEARCH

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## Summary

The Science Research Council has approved plans for building a 2 GeV electron storage ring at the Daresbury Laboratory specifically for producing beams of synchrotron radiation and so provide a continuing research facility when the electron synchrotron, NINA, is phased out. The initial objective will be to achieve the maximum current obtainable (0.37 A) using a single 250 kW, 500 MHz klystron to provide the RF power. This will produce high fluxes of photons down to 1 Å, initially along three beam lines feeding six experiments. User requirements have dominated the design considerations. Later developments proposed include the addition of a second klystron which will allow the beam current to be increased to 1 A and also provide excess power to supply the additional requirements when special superconducting 'wiggler' magnets are installed to extend the usable wavelength range down to 0.1 Å. The number of beam lines is expected to increase to about ten.

## Introduction

A paper was published in 1974[1] giving details of the proposal to build a 2 GeV electron storage ring at Daresbury for research using synchrotron radiation. This will provide a continuing facility, when the 5 GeV synchrotron, NINA, is phased out. The high energy physics programme on NINA is expected to cease at the end of 1977.

The design study has been completed and the Science Research Council have approved the project. The storage ring itself will be housed in the Inner Hall, at present surrounded by the NINA ring, and it will not be possible to proceed with the installation until this hall is cleared of the NINA RF and magnet power supply equipment. However, the booster synchrotron and linac, which form

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P. Clee and C.W. Trowbridge of the Rutherford Laboratory were responsible for the design of the wiggler magnet.

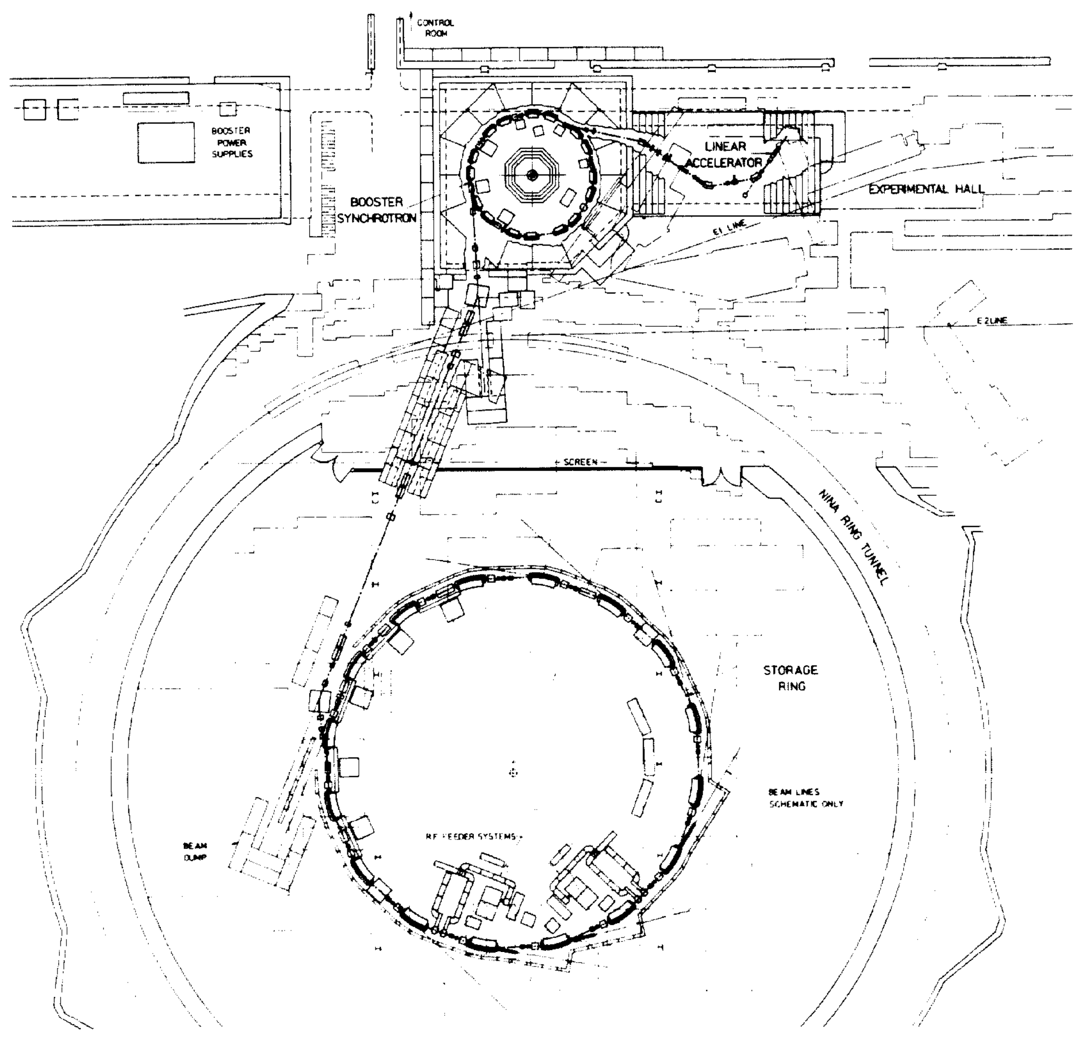


Fig. 1 Layout of Synchrotron Radiation Source.

the injector, will be housed at one end of the NINA Experimental Hall and can be installed in such a way that no interference will be caused to the high energy physics programme. Accordingly, it is planned to complete most of the construction of the injector before NINA closes. Fig. 1 gives the layout of the storage ring and injector, and Table 1 gives some of the main parameters.

Table 1

Main Parameters of Synchrotron Radiation Source

| | |
|---|---|
| Electron | 2 GeV |
| Radiation loss/orbit | 255 keV (without wigglers) |
| Flux of photons | $5 \times 10^{13}$/s/mrad at peak of spectrum per 0.1% bandwidth |
| Characteristic wavelength | 3.88 Å |
| Bending magnet flux | 1.2 T |
| Mean radius of ring | 15.28 m |
| $Q_v$, $Q_r$ | $\sim$ 3.25 |
| $\alpha$ | 0.145 |
| Number of periods | 8 |
| $Q_s$ | 0.06 |
| RF | 499.653 MHz |
| Harmonic no. | 160 |
| Peak RF voltage | 1.91 MV |
| Total shunt impedance | 29.3 MΩ |
| Number of cavities | 4 |
| Beam current | 1 A with 500 kW installed RF power |
| Injection energy | 600 MeV |
| Maximum injection rate | 10 Hz |

The initial objective will be to produce as high a current as possible at 2 GeV with a single RF power amplifier, a 500 MHz, 250 kW klystron as used at DESY. There will be three beam lines supplying six experiments. It is proposed later to add a second klystron in order to raise the beam intensity to 1 A with a sufficient margin of RF power to supply two 4.5 T three-pole wiggler magnets. The number of beam lines will be extended to about ten.

## Choice of Radio-Frequency

The design study has, in the main, confirmed the parameters given in ref. 1, the chief exception being the RF system parameters. A number of conflicting considerations made the choice of operating frequency difficult. This choice was in any case restricted by the availability commercially of high power RF amplifiers, but it seemed that suitable tubes could be obtained at 100 MHz, 200 MHz and 500 MHz. The possibility of using the RCA 2054 triode amplifier, at present used at NINA, at some frequency intermediate between 200 and 500 MHz was rejected on grounds of cost and technical complexity.

At the higher end of this range, owing to the high momentum compaction factor ($\alpha \sim 0.15$) of the ring, an overvoltage factor of 7.5 is needed to give an adequate quantum lifetime. To achieve the high voltage (1.91 MV) that this implies, requires a much higher shunt impedance than is stated in the earlier paper. This impedance can, however, easily be achieved using four copper cavities. The difficulties are firstly, that the higher impedance leads to a higher beam induced voltage when the full proposed beam current of 1 A is stored, and

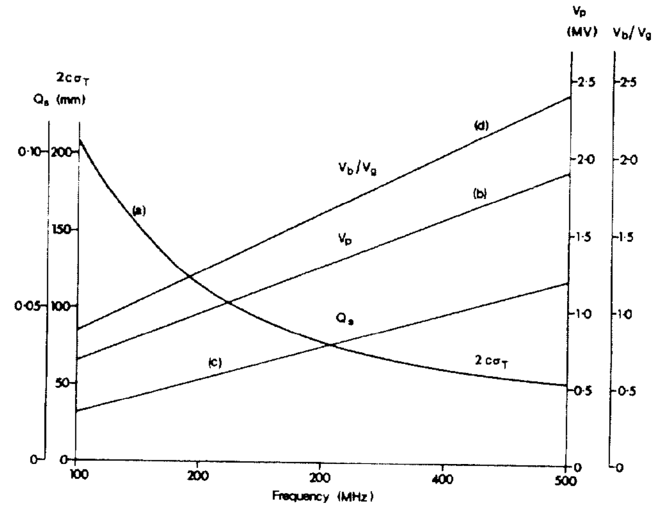


Fig. 2 Operating Parameters as a Function of Frequency
(a) Theoretical bunch length
(b) Peak transit time corrected voltage for > 100 h quantum lifetime
(c) Number of synchrotron oscillations per orbit
(d) Ratio of beam induced voltage to applied voltage

secondly that the higher voltage leads to a high value of $Q_s$ (0.06). On the other hand, the theoretical bunch length at 500 MHz is about right for those experimenters wishing to carry out measurements on the lifetime of excited states. As the frequency is lowered the bunch length increases as shown in fig. 2. In addition, due to the higher charge per bunch, anomalous bunch lengthening is more likely at the lower frequencies and this is sometimes accompanied by increased energy spread and reduced quantum lifetime. Fig. 2 also shows as a function of frequency the other factors just discussed, the required overvoltage, $Q_s$ and the ratio of beam induced voltage to generator voltage in a reactively compensated cavity. The high values of these parameters at 500 MHz may be restrictive, e.g. in the choice of working point, but are not regarded as preventing satisfactory operation.

The choice of 500 MHz was made partly because of the short bunch requirement, but also because it leads to an RF system, which is not only the most economical in terms of capital cost, but also leads to more flexibility of control. This is because in a waveguide feeder system high power phase shifters and variable coupling to the cavities can reasonably easily be achieved, whereas in the coaxial systems, mandatory at the lower frequencies, it is very much more difficult.

## The RF System

The approved programme allows for one 250 kW, 500 MHz klystron feeding four copper cavities located in two of the sixteen straight sections of the ring. The waveguide feeder system will be very similar to that used at DORIS, with power splitting and isolation provided by the use of magic-tee junctions. This arrangement will allow the necessary minimum of 1.9 MV to be created with a total cavity dissipation of 125 kW. Assuming 220 kW to be available at the cavities, this leaves 95 kW to supply the beam. With 255 keV radiation loss per turn at 2 GeV, a stored beam current of 0.37 A can be supported. The power input to each cavity is 55 kW which should easily be within the rating of an aperture window. A reduction of energy only to 1.95 GeV allows the stored beam to be increased to 0.5 A.

If the proposal to proceed to install a second klystron is implemented, then only a minor modification of the waveguide system would be needed to allow for the feeding of two cavities from each klystron. The windows would then have to pass 110 kW of RF power and it is hoped that tests will prove that this is practicable. The cavity dissipation, however, will to a first order remain unchanged at 125 kW since it is necessary to create the same cavity voltage. To support a 1 A beam

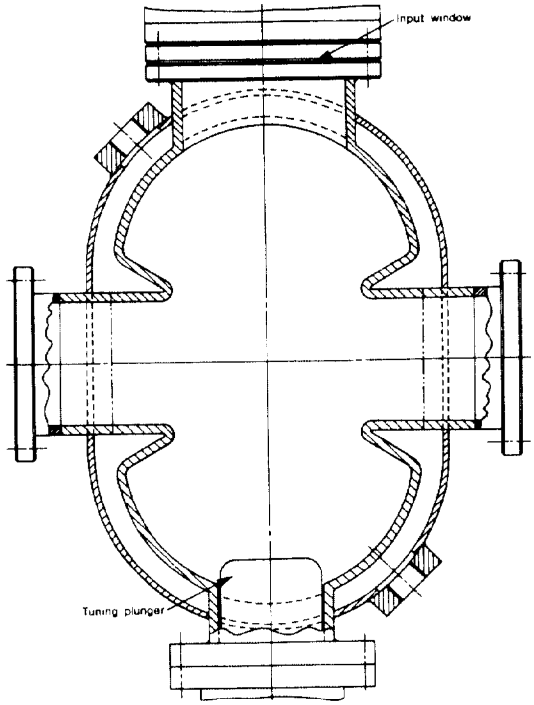


Fig. 3 Schematic diagram of RF Cavity.

at 2 GeV 255 kW of power is needed, giving a total requirement of 380 kW. This will leave at least 60 kW available to supply the increased requirements if two wiggler magnets are installed. Since the insertion of wiggler magnets increases the radiation loss per turn, the cavity voltage must be correspondingly increased and hence the cavity power dissipation is also greater. Cavities are therefore being designed with a cooling system capable of dealing with 40 kW of power dissipation in the walls.

The cavities will have the optimised shape shown in fig. 3 if the construction problems are solved. The re-entrant cavity not only increases the effective shunt impedance, but pushes up the frequencies of those higher order modes which are likely to cause instability problems. These problems have been encountered at DORIS[2] and have been tackled by a combination of Landau damping using an RF quadrupole and loading down of parasitic modes by means of a probe coupled to an all metal coaxial load. Provision will be made for similar measures to be adopted in the Daresbury ring. The insertion of a harmonic cavity to give $Q_s$ spreading is also under consideration.

## Multipole Magnets

The design of the lattice has centred on providing the maximum space availability for bringing out synchrotron radiation in beams with angles in the horizontal plane up to 40 mrad. The straight section lengths are all 3.82 m but about 1.75 m of this is required for an F or D quadrupole, a sextupole and a beam position sensing head. In some straights the remaining space is allocated to pairs of RF cavities, wiggler magnets in their cryostats, kicker magnets, etc. It is undesirable to have to provide space also for a multiplicity of correction magnets. It is also preferable when off axis injection is used that octupole fields should not be lumped at one or two points but be distributed round the

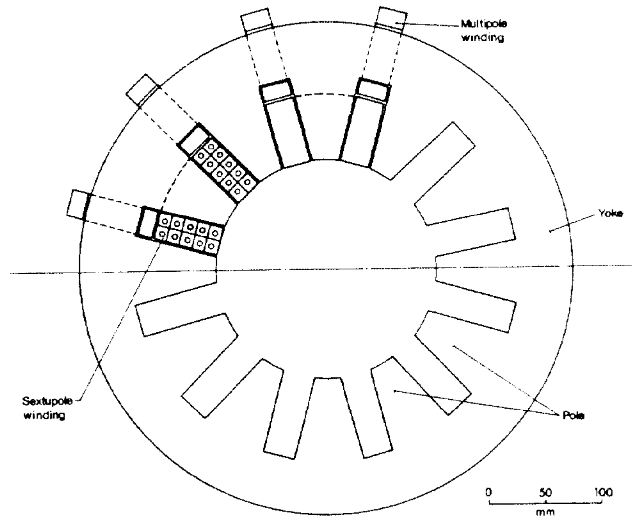


Fig. 4 Cross section of the Proposed Multipole Magnet.

ring. A design is being produced, therefore, for a multipole magnet which will provide the basic sextupole requirements for chromaticity control and also have the facility to produce any combination of correction field from dipole to decapole with any orientation and variation of amplitude round the ring. The proposed multivariable computer control system makes operation of this type of magnet feasible. A cross section of the magnet is shown in fig. 4.

## Wiggler Magnets

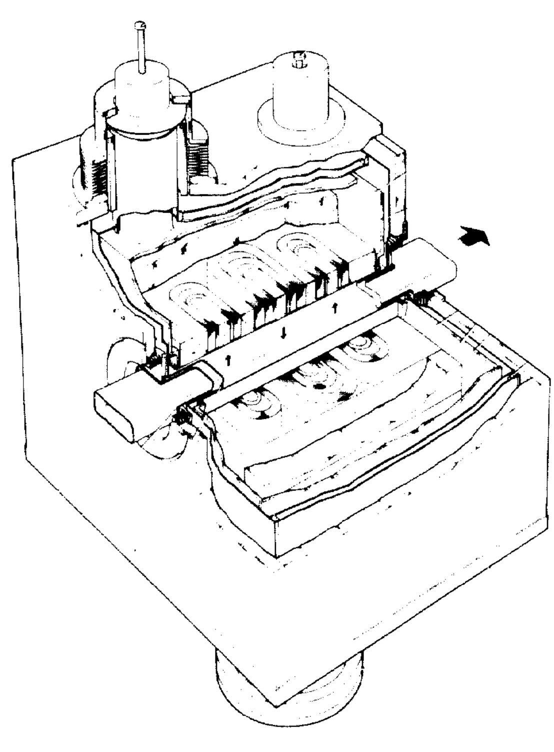

Fig. 5 Preliminary Design of a 4.5 T Wiggler Magnet.

As stated previously, in order to enhance the radiation in the 0.1 - 0.8 Å region a three-pole superconducting wiggler is proposed, the high field being produced only in the central region. A design giving a peak field of 4.5 T had been produced at the Rutherford Laboratory and is shown in fig. 5. The magnet consists of 3 pairs of race-track coils, the field in the centre pair being approximately twice that in the outer pairs. An iron yoke is used to give some field enhancement and to reduce stray fields outside the magnet.

The extra radiation per orbit produced by such a magnet is 19 keV so that, with 1 A beam current, an extra 19 kW is needed to supply the beam. However, it is also necessary to increase the cavity voltage, because of quantum lifetime considerations, and so the cavity losses are also increased. The total increase in RF power required when a wiggler is inserted is therefore 38 kW. The proposed installation of a second klystron would allow for two such wigglers, possibly with a modest reduction of the circulating beam current.

## Vacuum Requirements

The effective lifetime of the beam in the ring will probably be determined by vacuum conditions. An average pressure better than $10^{-9}$ torr is needed to obtain a lifetime of 8 h and this must be maintained whilst 255 kW of synchrotron radiation is being emitted, most of which will strike the special copper absorbers. Even with a total pumping speed in excess of $2 \times 10^4$ l/s it will be difficult to maintain a low enough pressure. In situ bake-out facilities will be incorporated and, if practicable, some means of cleaning by glow discharge. In addition ways of preparing and shaping the absorber surface and of coating it so as to reduce photo-electron production and desorption of molecules will be investigated.

## Single Bunch Operation

Single bunch operation of the storage ring is required by experimenters interested in measurement of lifetimes of excited states. The charge per bunch required in this mode of operation is the same as for normal operation, although clearly this could easily be pushed up to a higher value (limited by single bunch instabilities). The proposed mode of obtaining and stacking the single bunch is first to chop the 10 MeV beam from the linac at 2.22 MHz to provide a 25 ns train of bunches, followed by a 33.3 MHz chopper to limit the transmission to about 1 ns. This will form only one bunch in the booster for accelerator to 600 MeV.

The harmonic number of the storage ring is chosen to be 3n + 1, where n is the harmonic number of the booster. To decide when to transfer a waiting bunch in the booster into the correct RF bucket in the storage ring, a beam monitor in each ring will be used to produce a coincidence which will trigger the booster extraction system and the storage ring injection system so as to cause transfer within one booster period.

## Beam Lines

The facility will be entirely for synchrotron radiation experiments and this consideration has dominated the design philosophy to give a series of very high brightness sources with good positional stability with a lifetime in excess of eight hours.

The beam lines will fulfil the following requirements:

(a) acceptance of synchrotron radiation beams of 20 mrad and 40 mrad horizontal aperture,

(b) maximum shielding against high energy photons,

(c) protection against background radiation by the use of backward tangent extensions on the ring vacuum vessel,

(d) differential pumping to bridge possible differences in vacuum conditions in the ring and at the experiments.

## The Construction Programme

The planned programme of construction is based on the completion of the assembly of the linac and booster synchrotron by the end of 1977, the projected date for the termination of high energy physics on NINA. The NINA equipment will then be dismantled and removed. Assembly of the storage ring and its associated equipment is planned to be completed ready for commissioning in the spring of 1979.

## References

1. Daresbury Synchrotron Radiation Source Design Group. Proc. IXth Int. Conf. on High Energy Accelerators. 1974. (Stanford Linear Accelerator Centre, 1974, Conf. 740522) p.680.

2. DESY Storage Ring Group, Proc. IXth Int. Conf. on High Energy Accelerators, 1974, (Stanford Linear Accelerator Centre, 1974, Conf. 740522) p.43.