INITIAL OPERATION OF THE ELECTRON SYNCHROTRON NINA

by

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Despite the usual troubles with suppliers failing to keep promised delivery dates, a beam was first accelerated in NINA on 2nd December, 1966, almost exactly three years after access had been obtained to the site. A note was circulated giving some details of this first start-up. The main parameters are given in Table 1.

Subsequently, the synchrotron has come into routine operation, and five experiments have been mounted; one of these is just about ready to start taking data. Some preliminary investigations have been made into the operation of the synchrotron, and these are reported here.

1. LINEAR ACCELERATOR

The specification called for at least 500 mA within 1% $\frac{\Delta p}{p}$ and 3π mm.mrad at 40 MeV. Out of a total beam current of 800 mA, measurements show that 460 mA comes within these limits, but the injector does not yet meet the specification as regards stability and pulse flatness.

2. INJECTION

Most of the operation has been with a lower current in the linac and an injection energy of about 45 MeV. There is an energy defining collimator slit in the injection path and this is normally set to give a total width of 1/2% $\frac{\Delta p}{p}$. Under these conditions, a current of about 200 mA is injected into the synchrotron, leading to a maximum high energy circulating current of 40 mA peak. When the width of the collimator slit is varied, although the injected current varies as would be expected, the accepted current flattens off above about 1/2% $\frac{\Delta p}{p}$, as shown in Fig. 1. Since the field at injection can be varied over a total of 1.6% before the accepted current falls off by a factor of 2, this apparently small momentum acceptance is not easily explained. Investigations are to be made into the operation of the momentum matching system.

The maximum effective horizontal aperture has been measured by finding the amplitude of low energy beam bump in either direction needed to lose the beam, using the pole-face dipole windings. This aperture is found to be fairly constant round the ring, at about 13 cm, which lines up with expectation.

The maximum vertical aperture, measured in a similar fashion using triplets of steering coils situated in the short straights, seems to be somewhat less than the expected 6 cm.

3. BETATRON OSCILLATION FREQUENCY

Measurements of the vertical and radial Q have been made at various parts of the cycle. Without correction, the vertical Q is relatively constant over the whole cycle (Fig. 2(a)). Under normal operating conditions ($\Delta Q = 0.36$ at injection) the radial Q is shown at (b). Subtracting the effect of the pole-face windings, the uncorrected Q is shown at (c). However, no appreciable current is accelerated without some correction, and the reason for this is not clear.

An interesting point is that another condition for acceptance can be found with a higher quadrupole correction - shown at (d), which apparently starts above the half integral value and passes through it. For high injected currents there is sometimes a step loss of beam when passing through this resonance, but nevertheless, the remaining current accelerated up to high energy is greater than in the case with less correction, and no step.

With the normal correction, the maximum beam current is about 25 mA, but with the higher correction, 40 mA has been observed.

At high energy $Q_r = 5.21$ and $Q_v = 5.26$.

4. R.F.

Due to parasitic oscillation troubles with the final amplifier triode, most of the operation so far has been with the driver stage feeding the cavities. This limited the peak power to about 80 KW. With this power, a circulating current of 30 mA peak, representing a mean current of nearly 1 μA, has been accelerated to 3 GeV, and a small current to 4.3 GeV. Recently, the parasitic oscillations in the final amplifier have been suppressed, and the synchrotron has been running with this in operation. A circulating current of 40 mA has been accelerated to 4 GeV and about 8 mA to 5 GeV.

The r.f. programme is generated from $\dot{B}$ and B^4 signals, so that the final energy of the synchrotron can be changed merely by changing the magnet current, and it is not necessary to touch the r.f. controls when changing maximum energy over the range 1 - 5 GeV.

When currents of the order of 40 mA are being accelerated, beam loading effects can be observed by the increase in the reflected power from the cavities. The cavities can be detuned and a frequency modulation programme applied to compensate, but the use of this has not so far resulted in an appreciable increase of accepted current.

5. TRANSMISSION LINE MODE

The resonant magnet system can support other modes, the principal one being that of the shorted transmission line formed by the magnet inductances and the stray capacitances. This has a fundamental frequency of about 550 c/s, and is excited by the pulse power supply and by the high energy beam bumps. It was intended to operate with the 3 ms pulse from the power supply occurring during the descending part of the magnet cycle. However, it was found that a greater current could be accelerated if the pulse occurred during the acceleration cycle. The time constant of the damping rate of the transmission line mode was found to be 16.5 ms, so there was significant amount remaining at injection when the pulse occurred about 5 ms beforehand on the descending part, even when the length of the pulse was adjusted to produce minimum 550 c/s component. The excitation was greater when the high energy beam bumps were applied for targetting and ejection. At first, no beam at all was accelerated for at least 2 cycles after a full amplitude beam bump.

The situation was improved by the addition of back-leg windings to the D magnets (beam bumps are applied to the F magnets only). These windings are interconnected in pairs with damping resistors, so there is no effect on the normal operation, but the transmission line mode induces currents in the resistors, so producing additional damping. This reduced the delay time constant to 5.2 ms and only the cycle after the beam bump is now affected. To improve the situation still further, back-leg windings are to be fitted to the F magnets and connected appropriately. These windings must be open circuited during the period of the beam bump, and suitable high speed relays are on order.

It seems that the remaining small amplitude of transmission-line mode induced by the power supply pulse is still responsible for a large part of the closed orbit distortions at injection. Fig. 3 shows the dipole corrections needed to obtain a central orbit compared with the closed orbit distortion calculated for a transmission-line mode current equal to 1% of the magnet current at injection.

6. TARGETTING AND EXTRACTED ELECTRON BEAM

Targets can be inserted in three of the vacuum chambers preceeding long straights. When beam bumps are applied at these points, photon beams with spill times up to 1.5 ms can be produced. Two targets can be engaged on the same cycle, and the beam shared in varying amounts.

For electron beam extraction, the regenerator current strip and the kicker magnet are situated in the same long straight. At least 50% of the circulating beam has been extracted, and measurements of the emittance of the extracted beam are proceeding. Preliminary results give an emittance of 0.65 cm.mrad in the horizontal plane, and 0.2 cm.mrad in the vertical plane for 95% of the beam.

The relatively large emittance, and the large vertical beam size (about 7 mm) at the exit window are unexpected, and the cause of this is being sought. The amplitude of the beam bump and regenerator currents are quite critical, which would not be expected from the theory, and so further investigation is required. The spill time for the extracted beam is about 0.5 ms at present, but it is hoped to increase this.

Fig. 4 shows an aerial view of the site, from which it can be seen that already the experimental area is being almost doubled in size and other building is in progress.

A positron converter and additional linac sections are on order, and it is hoped that injection of positrons into the synchrotron will start in Spring 1968.

DISCUSSION (condensed and reworded)

H. Winick (CEA): How do you deliver the beam to two internal targets?

Crowley-Milling: We have two adjacent targets and we put a little bit of beam on one target and the rest on the other at maximum energy. The beam bump circuits are sufficiently close in time to allow this.

James M. Paterson (CEA): How does the measured value of the admittance of external electron beam (2 mm/m rad) compare with the calculated one?

Crowley-Milling: It is considerably larger than we did expect. Not only the admittance in the vertical plane but also the size in vertical plane is larger than expected. Investigations are in progress to check this point.

Amman (Frascati): How do you measure ν values along the cycle?

Crowley-Milling: We excite the beam by RF coil and measure the increase in amplitude of the β oscillation. Whether the excitation is large or small over most of the cycle it seems to be the same.

V. Dzhelepov (JINR): What are the future plans, say for the energy of the machine or for any other facility e.g., polarized photon beams?

Crowley-Milling: Magnets can go up to 5.5 BeV but rf can accelerate only a small current to $\sim$5.4 BeV. We have no plans at present for polarized photon beams.

G.A. Voss (CEA): What is the width of the beam at low energy?

Crowley-Milling: If the momentum matching system is working all right then the beam should be 3 to 4 cm wide. We have not measured the beam width.

A.I. Alikhanian (Yerevan): What is the advantage of using NINA as the booster for the high energy machine?

Crowley-Milling: The emittance of beam at NINA is small at 3 GeV. Thus the magnet aperture required for the big ring is very small. Thus the big ring can be constructed by very small and cheaper magnets.

ELECTRON SYNCHROTRON NINA

PRINCIPAL PARAMETERS

Nominal Energy - 4 GeV

Bending radius in Magnets - 20.77 m

Mean radius of equilibrium orbit - 35.09 m

Magnet Lattice F $\overline{O}$ D O   Length of Magnet - 3.26 m

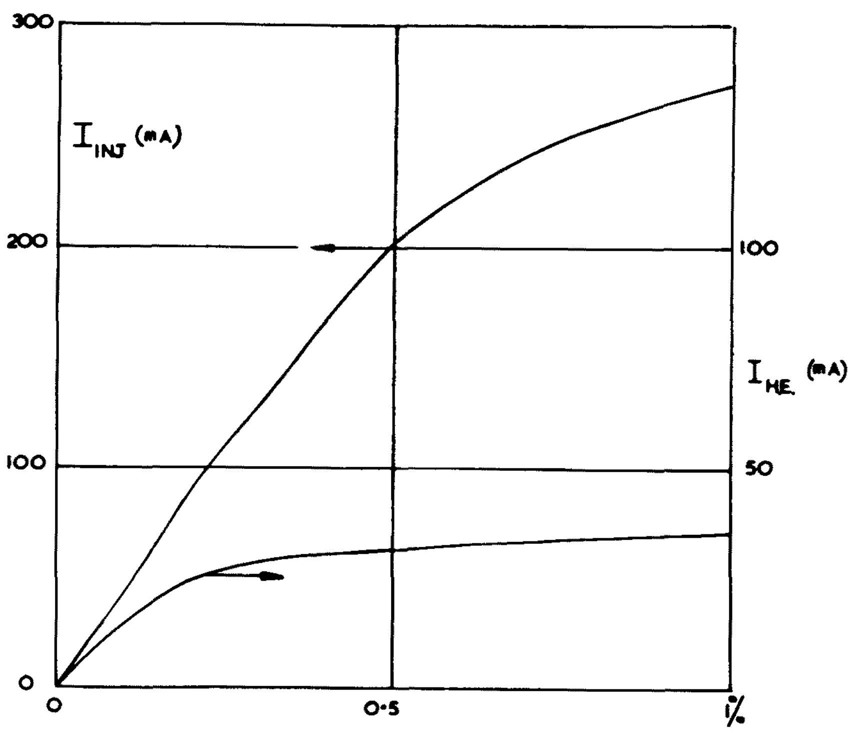
Length of straight sections - 3.5 m and 1 m alternately

Maximum Energy - 5.3 GeV at 8,500 gauss

Injection Energy - 40 MeV at 64.3 gauss

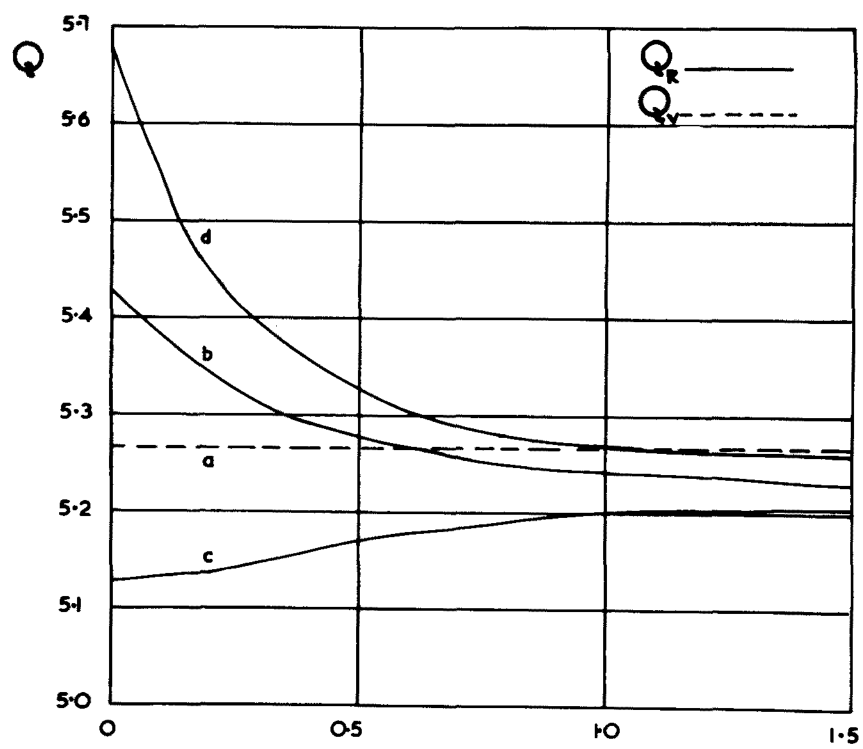
Nominal $Q_r = Q_v = 5.25$

Radio Frequency 408 Mc/s   480 kW peak   120 kW mean



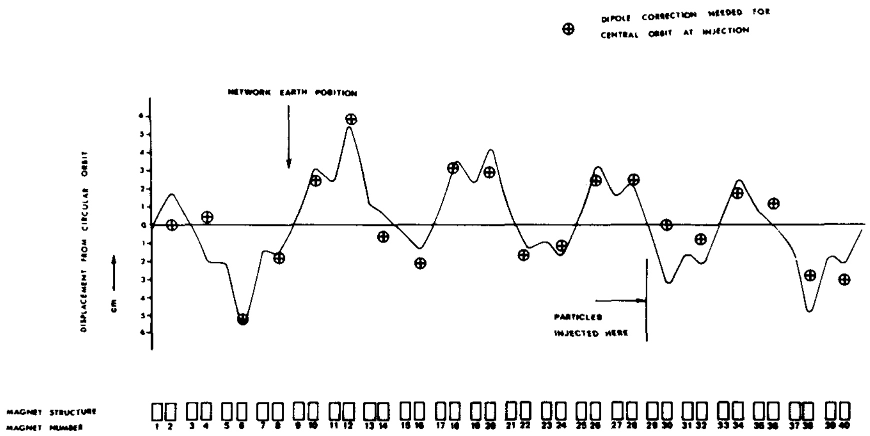
MOMENTUM DEFINING SLIT WIDTH

FIG. 1



TIME AFTER INJECTION (ms)

FIG. 2



CLOSED ORBIT DISTORTION PRODUCED BY DELAY LINE MODE

FIG. 3

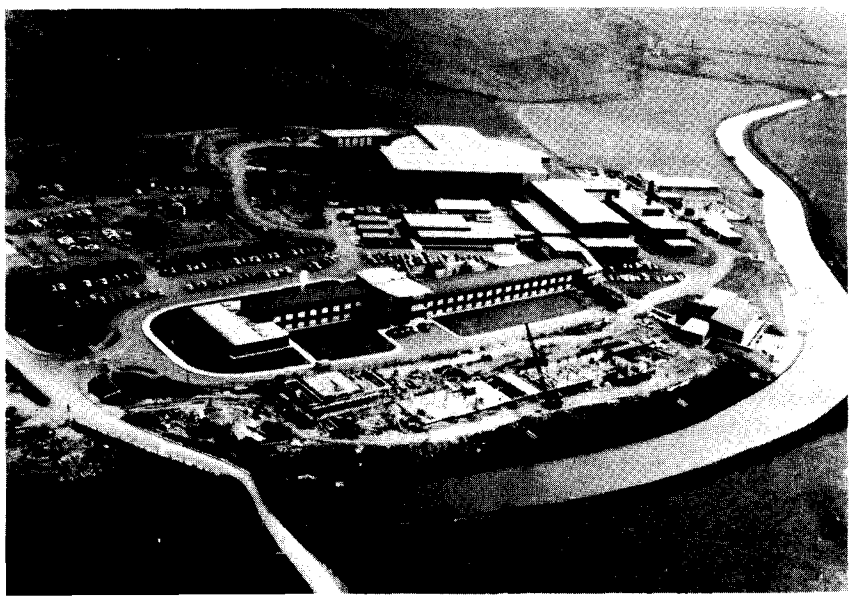


FIG. 4