STATUS OF THE NEVIS SYNCHROCYCLOTRON *

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ABSTRACT

A general description of the various systems, i.e. the central region, the RF system, the extraction system, etc., of the Nevis Synchrocyclotron Conversion Project is presented. Recent progress is described and future plans are outlined.

I. INTRODUCTION

The Nevis Synchrocyclotron conversion is in the final stages of completion. In the conversion, we have retained the basic iron yoke and the main copper coils, but to increase the energy from 390 MeV to 560 MeV, we have added a 10 in. band of iron around the yoke and a set of auxilliary coils which now give us about 1 1/2 times as many ampere-turns as before. In order to allow room for an external proton beam, extra shielding and three secondary beam lines, which we did not have, we have doubled the size of the building.

II. General Description of the Machine and Components

The cyclotron is a three-fold symmetric machine with the vertical gap between the hills running from 3/4 in. near the center to 5 in. at the outer radii. Because of the close spacing at the center, it is necessary to have the iron sector on the RF side (south) at dee potential. As is shown in Figs. 1 and 2, this section is supported on five insulators; the ion source is inserted axially from the top and goes into the north valley at about 3/4 in. radius.

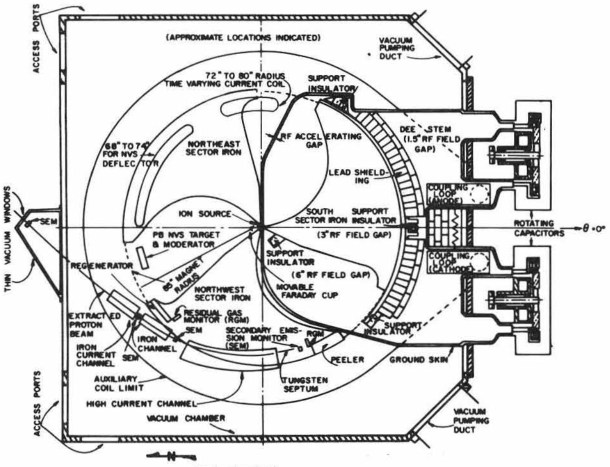

Fig. 1

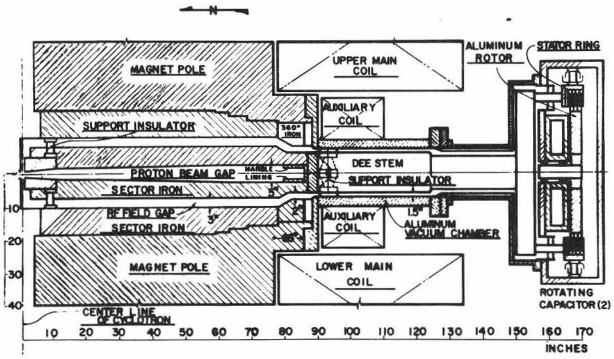

Fig. 2

The components of the extraction system, the time-varying bump, the peeler and regenerator and the current channel are at the larger radii. Upstream from the current channel, the last elements that the beam sees before leaving the chamber are the iron channel and the current-iron channel which focus the beam and steer it out of the chamber.

Just outside the chamber are two bending magnets (one vertical and one horizontal) and a triplet which focuses the beam onto two production targets where the secondary beams are produced (see Fig. 3). After the targets, the primary proton beam is refocused and bent into the beam stop. There will be facilities for isotope production both in the proton beam just before the beam stop and in the fast neutron beam behind the stop.

It is possible to use an internal target to provide neutrons for our 200 m neutron time of flight facility (NVS). In this mode, the beam is not parked but is deflected down by a 75 kV pulse into a cooled tungsten target in less than a single turn. The design is such that no changes have to be made inside the chamber to switch from one mode of operation to the other.

III. The Magnetic Field

The magnetic field of this machine is unique in that it is part way between that of a normal synchrocyclotron and an isochronous cyclotron. By having the field increase with radius, we are able to keep the RF frequency swing to 9 MHz (28 to 19 MHz) rather than the more usual 13 MHz for the ordinary machines of this size. In the early stages of the design,

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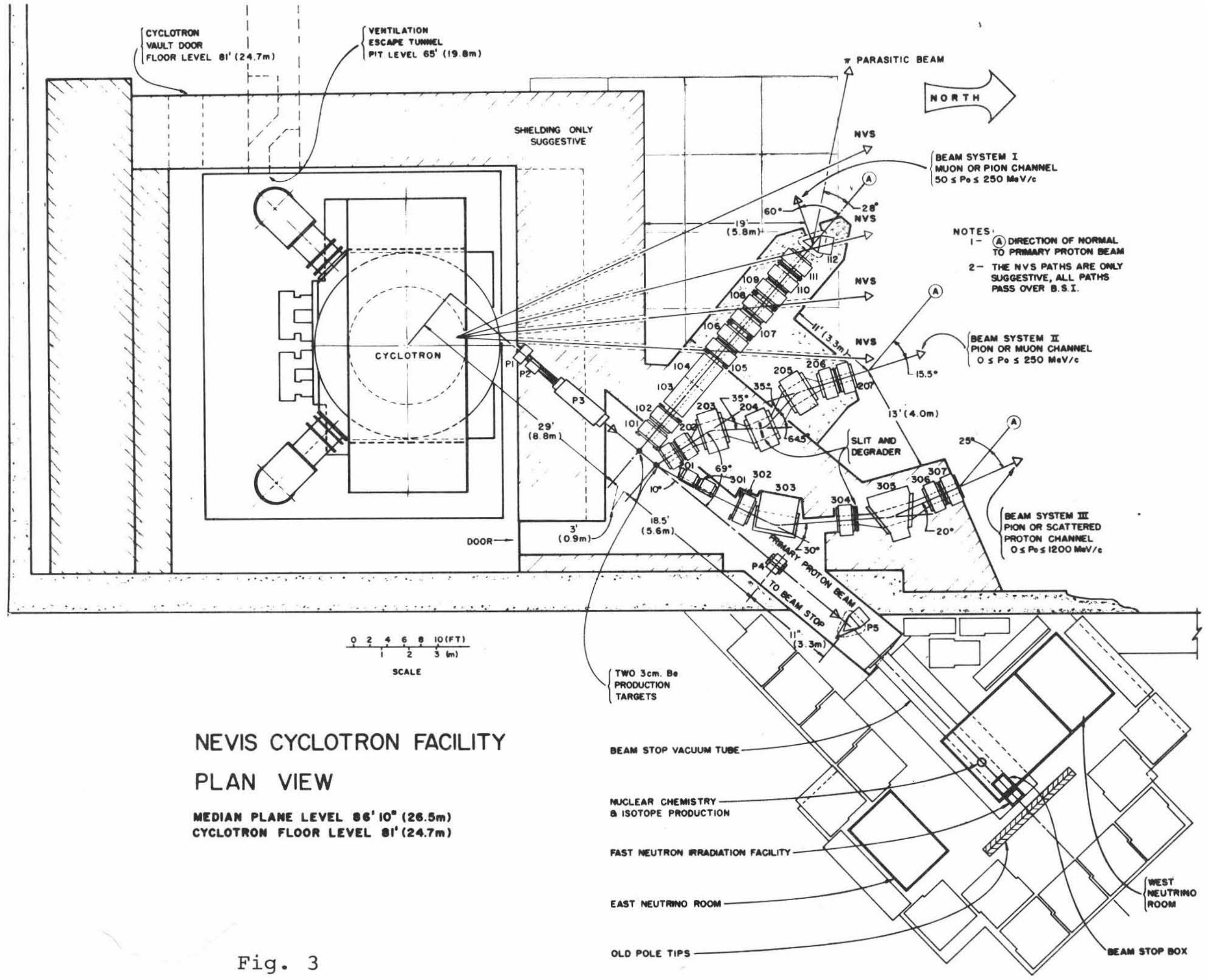

Fig. 3

it was hoped that we could have an isochronous machine, but it soon became obvious that we could not keep the beam focused out to the full radius. However, by having sector focusing with small vertical spacing in the center, we were able to reach a value of $\nu_z^2 \approx 0.026$ in the critical region below $r = 1.5$ in. As described below, this strong focusing allows a current of about 35 μA to be injected into phase stable orbits.

The azimuthally averaged magnetic field has a value of 18.1 kG at the center of the machine and rises monotonically to 20.1 at r = 80 in. Aside from the resonances, $\nu_r = 1$, $\nu_r = 2\nu_z$, the two resonances which could conceivably cause trouble are $2\nu_r + 3\nu_z = 3$ and $3\nu_r - \nu_z = 3$. These are excited by median plane asymmetries. The values ν_r and ν_z are such that they do not cross these resonances.

IV. Central Region

Figure 4 is a plan view of the central region. The Penning type ion source is inserted axially from the top and is fed by a freon cooled tri-axial set of conductors that supply the ground conductor, the +24 kV cathode potential and the +28 kV anode potential. These positive potentials could not be maintained d.c., but they are on only during the injection time (about 30 μsec) and after some conditioning, there is no problem with sparking. The grounded needle eye puller next to the ion source which provides a 28 kV kick to the ions, goes through the median plane as do the two pullers on the RF side of center. These elements provide extra vertical focusing on the first turn. The position of the ion source as well as the grounded and east RF electrode are all movable from the outside of the cyclotron.

Calculation of orbits for the central region have been done. The electric field was calculated using a three-dimensional relaxation calculation. The boundaries for the most part were on conductors where the potentials were known. The north and south boundaries were far enough inside the dee and dummy dee so we could assume that they were at the full potential of those structures. The potential between the dee and dummy dee on the boundary was calculated using a two-dimensional Schwartz transformation. The results of the calculation were not very sensitive to these boundary assumptions. Two sets of calculations were done: (1) assuming the dee and south shim, etc. at one potential (RF) and the rest at ground and (2) assuming the ion source was at one potential and everything else at ground. In the orbit tracing program, the fields from the first set of potentials were made proportional to $\cos(\omega_{rf}t)$ while the fields from the second set were "d.c.". The magnetic field used was measured directly in the cyclotron. A typical result of the calculations using these programs is shown in Fig. 4. It is interesting to note how strongly the fields of the hills and valleys affect the orbits even at small radii, indicating the strong vertical magnetic focusing in this region.

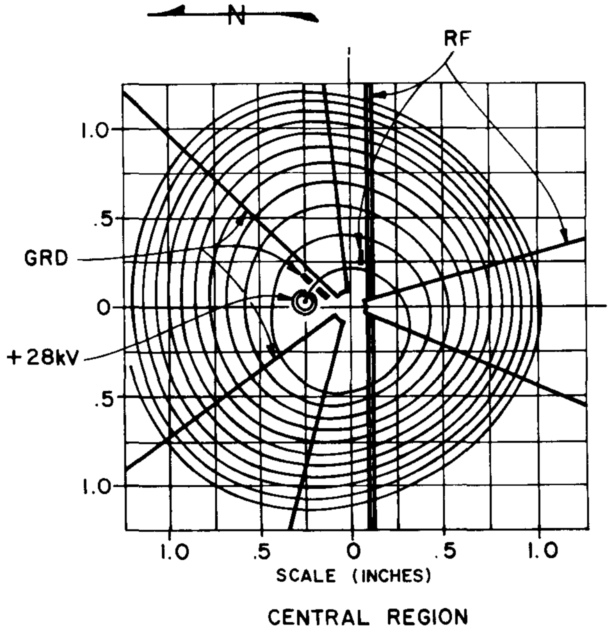

Fig. 4 Central region geometry with computer tracing of a typical orbit. Only the darkened elements (the ion source, the ground puller, the RF slits) go through the median plane. The positions of the ion source, the ground peeler and the east RF puller are externally adjustable.

These calculations show that with 30 kV on the dee and +28 kV on the ion source, we can accept particles from 40° to 90° RF phase (phase convention: RF maximum at 90°). These particles are followed to 1.5 MeV where they have radial oscillations from 6 mm to 12 mm. The positive voltage on the ion source has a strong effect on the first few turns, tending to give them a push to the north. This can be offset by a negative bias on the dee which of course helps prevent multipacting in the RF system.

The current that can be injected into phase stable orbits has been calculated using first order electric focusing proportional to $\sin(\varphi_{rf})$ and to $1/T$ (where T is the kinetic energy). If the current from the ion source is not a limiting factor, we should be able to get more than 35 μA out of the central region. We have actually measured the current at small radii and found that we get 12 μA scaled to a 300 Hz repetition rate (we were working at about 10 Hz to keep the radiation down). We plan improvements for the ion source which will be implemented in the near future which should bring the measured value close to the calculated one.

A representative sample of particles was traced from the central region to the parking orbit. These calculations included the effects of the cutback dee, and the imperfection harmonics in the magnetic field. They show that we should lose no more than 15% of the beam out of the phase bucket (this should improve with a properly timed RF voltage program as described below). The particles traced to the parking orbit have radial oscillations of about 0.5 in.

V. RF System

A paper relating to the RF system is being given in an accompanying report to this conference.[1)]

The structure of the RF resonator (shown in Figs. 1,2) is driven by a single grounded-grid triode (F7560 VN) whose plate voltage is supplied by a series modulator. The basic parameters of the system are: frequency range, 28 MHz to 19 MHz; RF on-time, ≈ 40%; RF on power consumption, 140 kW; maximum dee voltage > 30 kV; repetition rate, 300 Hz. The resonator is a half-wave system connected to the rotating capacitors in such a way that the rotors are almost at RF ground which avoids sparking at the bearings. Several parts of the system (the dee, the stators, and rotors) are d.c. biased (pulsed in the case of the dee) to help prevent multipacting and to provide a basis for a protection system which shuts the RF off for 700 msec after a spark has been detected minimizing possible damage. This allows us to condition the system at a higher voltage and much faster after the chamber has been open to air.

The voltage provided to the main oscillator can be controlled by a class D voltage regulator. This can be run in such a way that the voltage to the tube is maximum where the RF on the dee is minimum and vice-versa. It is also possible to program the voltage arbitrarily. This will be extremely useful since the energy spread can be reduced to about 0.5% by having the parking frequency the minimum frequency and slowly reducing the voltage over the last several thousand turns.

VI. The Extraction System

The beam is accelerated to full energy, parked at $\langle r \rangle \approx 77$ in., where it is held away from the extraction elements, the peeler (a weakening of the field) and regenerator (a strengthening of the field) by a negative magnetic bump produced by a coil near the east side of the chamber. By slowly changing the size of this bump from -75 G to +50 G, the beam is extracted slowly over the entire RF off-time; this should give a duty factor of > 50%. As the beam moves into the peeler and regenerator, it becomes radially unstable in such a way that its center moves exponentially toward the upstream (south) end of the current channel. The current channel is basically a thin sheet of current (the septum) and associated corrector coils which produce a field drop of 6 kG at radii larger than the septum and no change in field at smaller radii. The channel also provides a strong radial gradient (about 1 kG/in.) which just about balances the normal field falloff, thus preventing the beam from being radially defocused and vertically overfocused in this region. The iron-channel and iron-current are elements in the beam transport system which reduce both the main field and its gradient and provide steering out of the chamber.

Calculations using measured values of the main field and all other components of the extraction system show that we should lose only 24% of the beam on the current channel septum and probably less than 10% of the remainder due to vertical blowup in the extraction region, giving an overall efficiency of about 68%. These calculations show that a modification of the peeler could improve this efficiency. This is one of the projects that we will pursue before the machine becomes too radioactive to work inside the chamber.

The entire extraction process is well monitored and adjustable. The peeler, regenerator and the current channel can have both their upstream and downstream ends moved independently by about 1 in. The chamber does not have to be opened for these operations, but the field does have to be turned off. Two residual gas monitors (RGM) can detect the parked beam near the peeler and regenerator (see Fig.1). These RGM's are a series of 24 insulated copper strips evenly placed along various radii covering a radial spread of 6 in., and placed about 1.5 in. above the median plane. These strips are near ground potential. The same distance below the median plane is a solid copper plate with a potential of about -100 V. When the beam is parked between the plates, the residual gas is ionized providing electrons which are accelerated vertically along the field lines to the collecting strips. (The beam must be parked to provide enough signal to be useful.) The charge is detected by an integrator and displayed on a scope (see Fig. 5). This provides information about the radial spread and position of the parked beam which of course is a combination of its radial oscillations and the energy spread due to phase oscillations and the manner of turning off the RF. The beam can be detected at the entrances and exits of the various channels by the secondary emission monitors (SEM) indicated in Fig.1. These are similar to the RGM, but since the beam goes through these monitors only once, a thin slanted Al foil (0.0005 in.) is used to produce the electrons. Radial copper strips on the top and azimuthal copper strips on the bottom provide both vertical and radial information about the beam.

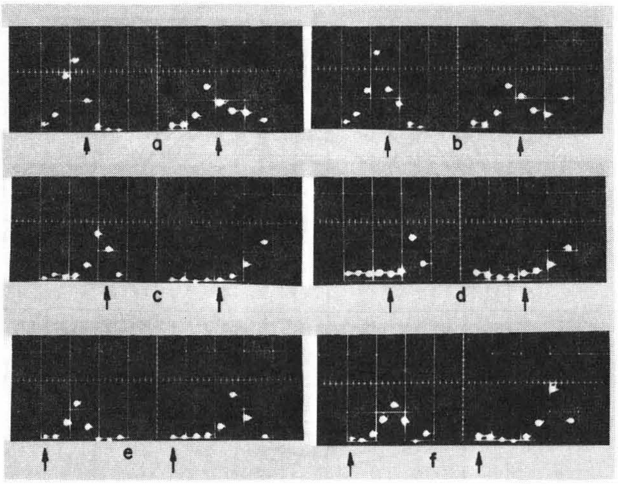

Fig. 5 Residual gas monitor (RGM) outputs. Each set of eight dots (left and right) represents the output of one of the RGM's in the chamber. The height of each dot is proportional to the beam current in a 1/2 in. radial section of the beam with larger radii to the right. (The resolution can be increased to 1/4 in. if desired.) The pictures all represent the parked beam that has been allowed to coast for 50-100 msec. The sequence of pictures (a) to (f) show what happens when the RF is turned off at lower and lower frequencies, i.e., larger and larger radii. The arrows all point to strips of the same radii.

VII. Secondary Beam Lines

A complete report on the secondary beam lines will be presented at this conference.[2)]

There will be three secondary beam lines at Nevis which can be used simultaneously (Fig. 3). I., a muon channel which can be easily changed to a high intensity pion channel by removing five of the quadrupoles in the channel and the final dipole; II., a good resolution (1% $\Delta P/P$) low momentum pion-muon channel with a 3 cm x 3 cm spot size. If more intensity is wanted at the sacrifice of momentum (10%), the fluxes can be increased by about a factor of 4. The spot size is unchanged. III., a high energy (P_π = 400 MeV/c) good resolution ($\Delta P/P$ = 0.55%) pion channel. The fluxes in this channel can be increased by a factor of 10 by opening the slits. Both the resolution and spot size will increase. This channel can also handle the full energy proton beam (P_p = 1180 MeV/c). The shielding is such that we would probably not want to have a flux of protons greater than about 10^9/sec.

All the present quadrupoles near the targets have hard anodized aluminum coils and stainless steel water connections with ceramic feedthroughs. The anodized wires are further insulated by strips and sheets of anodized aluminum foil which produces a coil which is very unlikely to be damaged by radiation.

VIII. Present Status and Future Plans

The first full energy beam was obtained in January of this year. As noted above, small radius ($\approx$ 15 in.) measurements indicate that we have about 12 μA (scaled to 300 Hz repetition rate) in phase stable orbits outside the central region. Our tests[3)] indicate that about 25% of the beam is lost between 15 in. and the parking radius ($\approx$ 77 in.). Most of the beam, probably 20% of the 25%, is lost from the phase bucket in a region where there is a dip in the RF voltage on the dee. There are several methods of correcting this condition in the RF, and we expect that when these are implemented, we will be able to bring 90% or more of the beam from the central region to the extraction radius. We have measured the vertical oscillations which are 0.25 in. FWHM and the radial extent of the parked beam which is 1.0 in. FWHM (see Fig. 5). All these studies were done with none of the extraction elements in place.

In February, March and April, we installed and tested in place all the various elements of the extraction system. Measurements were made of the fringe field of the 3000 A current channel and we found that we had to add some small iron shims on the large radius edge of the NW iron sector behind the current channel. The field was measured and these values were included in our extraction study programs.

We are presently engaged in extraction studies and tuneup. The first phase of these studies, which involves accelerating beam to full energy and parking it in the presence of the extraction elements is in progress. We have successfully accelerated the beam to nearly full energy, but find that it is hitting the bottom of the time varying bump coil. The calculated radial positions of the beam at various azimuths have been checked against measurements with the RGM's and with radially movable beam scanners. The agreement is excellent. Present studies are aimed at determining the details of the vertical position of the beam near the bump coil as a function of radius and as a function of extra current in the bottom coils of the main magnet. Upon completion of these studies, the bump coil will be reinstalled and we will begin the second phase of the extraction studies. In this phase, we will actually extract the beam and study the dependence of extraction efficiency on the positions of the various elements. The transition from extraction studies to experimental operation will take place during the coming autumn.

References

1) F. G. Tinta, these proceedings.
2) M.M. Holland, S.E. Metelits, these proceedings.
3) D.W. Storm et al, IEEE Trans. NS-22, #3, 1408 (1975).

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DISCUSSION

G. DUTTO: Did you give a figure about the average intensity that you have been using?

R.C. COHEN: Yes, we have actually measured 12 μA in the small radius region and I think we should be able to achieve our final goal of 20 μA.