STATUS REPORT ON THE SIN RING CYCLOTRON

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ABSTRACT

For the production of intensive meson beams, a ring cyclotron for a 100 μA proton beam at 590 MeV is presently being constructed at the Swiss Institute for Nuclear Research (SIN) near Villigen, in the northern part of Switzerland. The pre-acceleration of the beam to 72 MeV will be accomplished by an AVF-cyclotron, which can also be used for acceleration of d, He and heavy ions to variable energies. The status of the development and construction of the ring cyclotron is described.

BRIEF DESCRIPTION OF THE ACCELERATOR

The main design purpose[1] of the accelerator is the production of large fluxes of π- and μ-mesons by means of a proton beam of 590 MeV of the order of 100 μA intensity. The accelerator is a two stage combination of an AVF-cyclotron (72 MeV) and a ring cyclotron (590 MeV) with separated magnets, both machines operating isochronously at 50 MHz[2].

THE INJECTOR CYCLOTRON

The AVF-cyclotron with 2.5 m pole diameter, 4 spiral sectors and a single dee acceleration system has a variable magnetic field and continuously variable frequency within the range of 4.7 to 17 MHz, thus providing acceleration of various particle beams to a range of energies.

Axial injection is provided for polarized protons and deuterons. These beams will be used about 25 % of the time for low energy nuclear physics experiments in a separate area of the experimental hall. After passing a 110° analyzing magnet, their energy resolution will be of the order of $\Delta E/E$ (FWHM) $\approx 10^{-4}$.

As an injector for the high energy stage, this cyclotron will operate at an R.F. frequency of 50 MHz which is the 3rd harmonic of the cyclotron revolution frequency. In this mode of operation, it is designed to deliver a 100 μA proton beam of 72 MeV, with an energy spread of less than 0.3 % (FWHM) and emittances of less than 30 mm mrad. Special care will be taken in the optimization of the central region, the symmetry of the magnetic field and the extraction system to guarantee a reliable beam of this high quality. The contract for building this machine was given to Philips Holland in Fall 1968.

THE RING CYCLOTRON

The ring cyclotron has 8 C-magnets of ~ 18° azimuthal width. The pole gap decreases from 9 to 5 cm over the radial range from 200 to 460 cm. The sectors are spiralled since pure flutter-focussing would not be sufficient for the energies under consideration. For reasons of easier and efficient machining, the pole contours were chosen to be circular arcs, providing a spiral angle of ~ 32°. The pole field increases radially from 15 to 20.8 kG for a final energy of 590 MeV with a main excitation of 148000 amp-turns. 18 sets of 400 amp-turn pole face windings in each second magnet provide the necessary field corrections In the other magnets, only injection and extraction radii will be controlled by trim coils.

The stainless steel vacuum chamber sections are directly joined to the magnet poles by flexible welded joints. The other sections of the vacuum chamber, built of aluminum, contain probes, collimators, injection and extraction devices. The individual sections can be joined either with metal gaskets or inflatable bellows carrying radiation resistant elastomers as gaskets. Since oil contamination of the surfaces in the R.F. cavities seems to limit the maximum voltage achievable, we are using a combination of turbo-molecular pumps and titanium sublimators directly built onto the R.F. cavities.

4 R.F. cavities of 40 cm width in the beam direction, 530 cm radial length and 330 cm height, with an accelerating gap of 15 cm each provide a voltage greater than 500 kV at 50 MHz, which is the 6th harmonic of the particle revolution frequency in this machine. They are excited by individual 250 kW R.F. power amplifiers, jointly driven by a highly stabilized master oscillator. Voltage and phase control are provided in the circuits.

The beam is injected in the mid-plane through a combination of bending magnets followed by a magnetic injection channel, and brought onto the equilibrium orbit by means of an electrostatic correction channel. Since

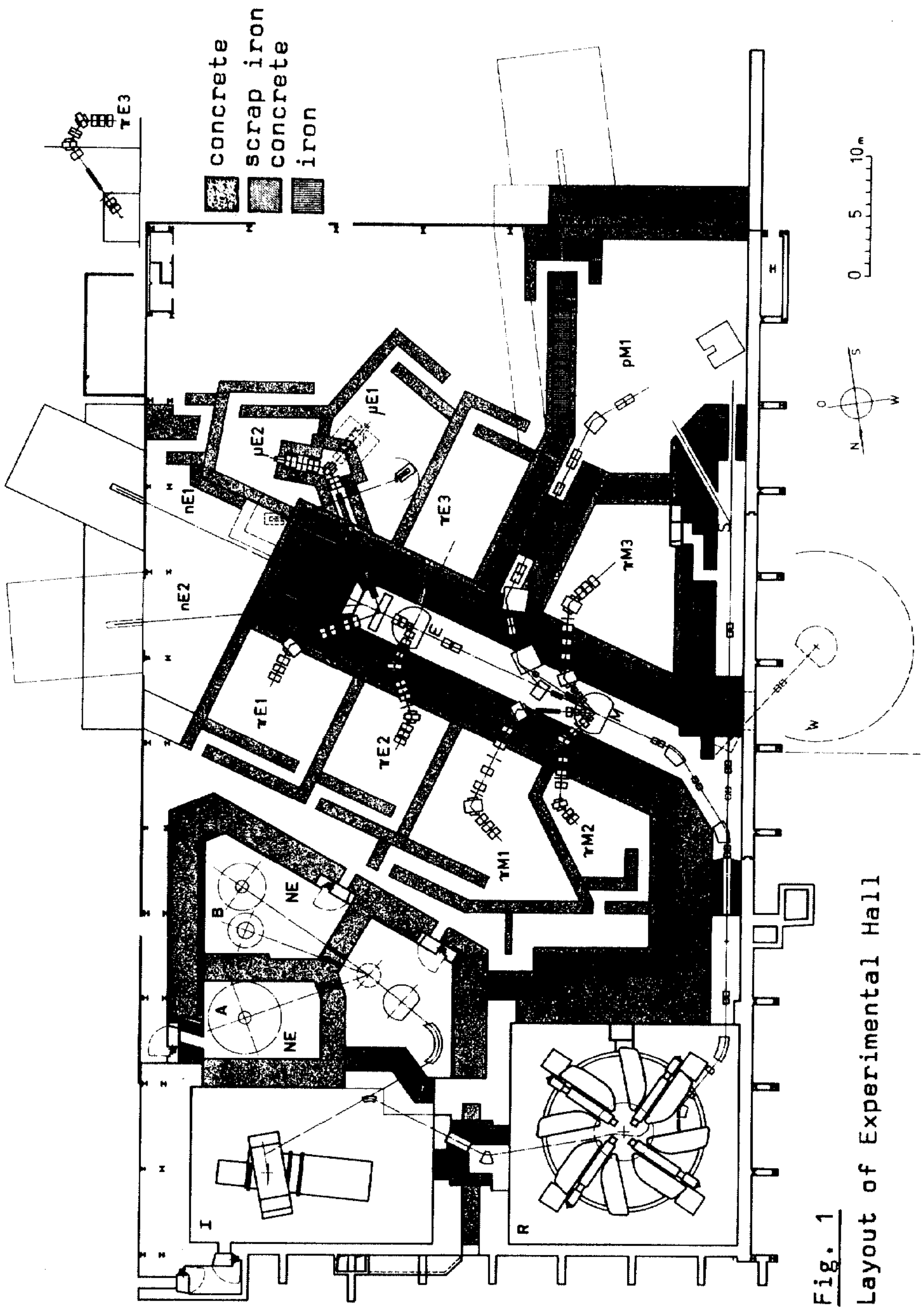

Fig. 1
Layout of Experimental Hall

there is complete separation of the orbits at injection radius, beam loss can be kept negligible.

With about 1.5 MeV energy gain per revolution the radial gain is 6 mm near extraction radius, increasing to ~ 8 mm at the extraction point due to the turnover of the magnetic field gradient. Incoherent radial beam amplitudes will be of the order of 3 to 4 mm in this region. For the extraction system consisting of an electrostatic channel of 50 kV/cm with a very thin septum (120 cm long) a magnetic focussing element 45^{0} downstream and an extraction septum magnet 90^{0} downstream, extraction rates above 90 % have been computed[3].

EXPERIMENTAL BEAMS

The secondary beams will be produced essentially on external targets. A layout of the experimental areas[4], as planned for the early operational phase is shown in fig.1. The denotations in this figure have the following meaning: I injector cyclotron, R ring cyclotron, NE A and NE B target areas for beams from the injector cyclotron, M thin, E thick meson production target, S targets for special purposes.

Pion beams:

πE1	beam of high resolution and high energy, high intensity
πE2	low energy beam of high intensity (stopped pions)
πE3	beam for biological and medical research
πM1	high resolution, high energy beam
πM2	high resolution, low energy beam
πM3	intermediate resolution, high energy beam

Muon beams:
μE1 and μE2

Nucleon beams:

pM1	polarized protons
nE1	unpolarized neutrons
nE2	polarized neutrons

In table I the main parameters for pion beams as computed under the assumption of 100 μA protons of 590 MeV are summarized.

It is planned to build a muon channel with a 50 kG superconducting solenoid of 15 cm inner diameter and 8 m length[5]. The muon beams expected are typically 10^{8} μ/sec (50 MeV) at an experimental target area of 70 cm^{2}. All the shielding walls needed in the experimental hall consist of movable elements.

Table I

π-beams

Target	Beam	Θ_{prod}	Range of Energy (MeV)	$\Delta p/p$	Intensity (sec^{-1})	Remarks
Cu 2 cm	πE_1	0°	50 - 350	$\pm$ 0.13 %	π^+ $7 \cdot 10^9$ π^- $9 \cdot 10^8$	at 225 MeV $\Delta p/p = \pm 5$ % $\Omega = 40$ msr; $\ell = 15$ m
	πE_2	90°	50 - 70	$\pm$ 1,0 %	π^+ $1 \cdot 10^9$ π^- $3 \cdot 10^8$	at 50 MeV $\Delta p/p = \pm 5$ % $\Omega = 60$ msr; $\ell = 10$ m
	πE_3	90°	50 - 80	$\pm$ 1,1 %	π^- $2 \cdot 10^8$	at 60 MeV $\Delta p/p = \pm 5$ % $\Omega = 30$ msr; $\ell = 12$ m
Be 0.5 cm	πM_1	22.5°	50 - 350	$\pm$ 0.04 %	π^+ $5 \cdot 10^7$ π^- $6 \cdot 10^6$	at 300 MeV $\Delta p/p = \pm 2$ % $\Omega = 13$ msr; $\ell = 20$ m
	πM_2	67.5°	50 - 100	$\pm$ 0.4 %	π^+ $2 \cdot 10^8$ π^- $3 \cdot 10^7$	at 100 MeV $\Delta p/p = \pm 5$ % $\Omega = 50$ msr; $\ell = 9$ m
	πM_3	22.5°	50 - 350	$\pm$ 0.12 %	π^+ $7 \cdot 10^7$ π^- $8 \cdot 10^6$	at 300 MeV $\Delta p/p = \pm 5$ % $\Omega = 6$ msr; $\ell = 15$ m

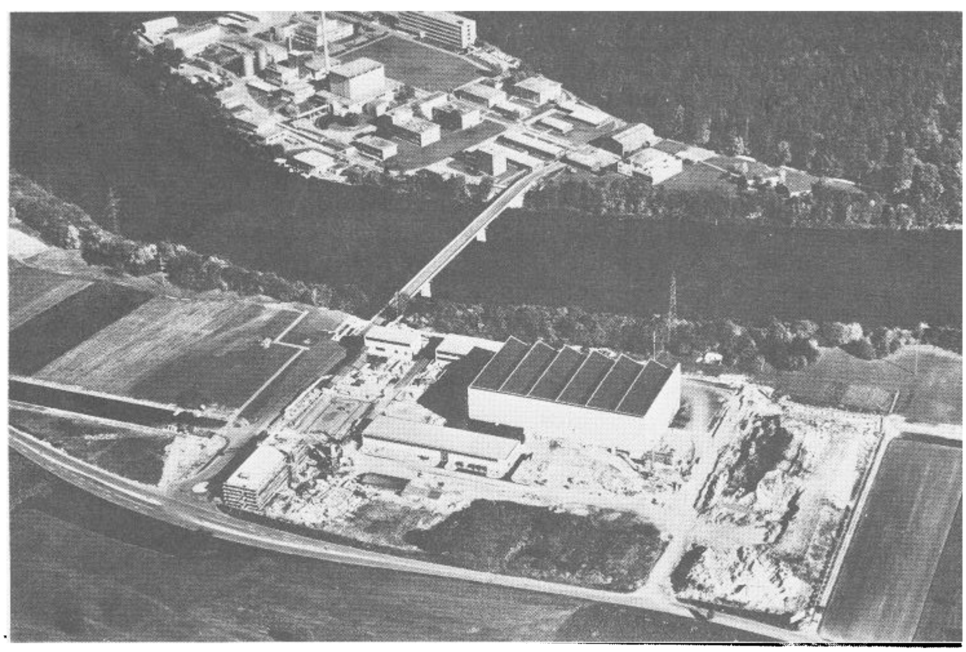

Fig. 2 SIN site near Villigen on the river Aare. In the background the Swiss Federal Institute for Reactor Research (EIR)

STATUS OF THE PROJECT

The building construction program has been completed according to the schedule as worked out in 1968. Fig. 2 shows the situation of October 1971. In addition to the plans of 1968 an assembly hall of 14 x 36 m with 2 floors of office space on both sides is now under construction.

The assembly of both accelerators started according to schedule in Summer 1971. The injector cyclotron magnet has been set up at Villigen and after measurements of the iron field (optimized for 72 MeV protons) the trim coil assembly was mounted. Measurements at different excitations are presently being carried out. No corrections of the pole configuration were necessary. Magnetic shields had to be mounted underneath the magnet yoke for protection of the low energy injection beam lines. The stray field within the axial injection channel is compensated by special coils.

The vacuum tank and the R.F. system (fig. 3) have been assembled at Philips, Eindhoven. First tests of the variable frequency system were carried out successfully. The 50 MHz resonance system is now being completed (a specially designed removable shorting bar, mounted within the dee-tank). The 50 MHz power amplifier system, similar to the system SIN used for the cavities, is installed at Eindhoven and has delivered full power to a dummy load.

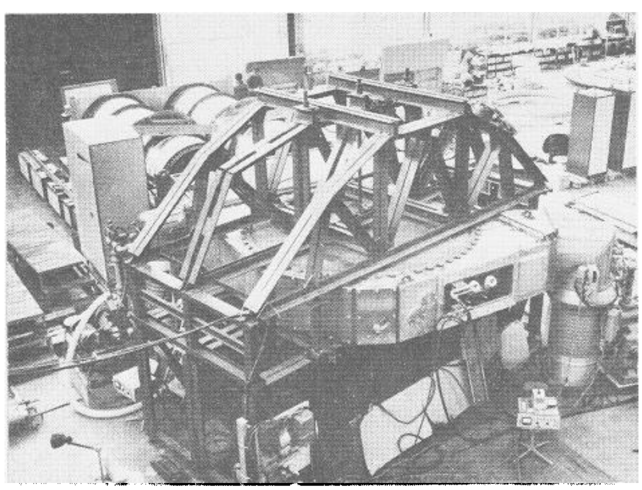

Fig. 3

Vacuum chamber and R.F. system of injector cyclotron being assembled at the Philips test site Eindhoven, Holland (courtesy Philips)

Extensive studies of the center region properties, including the design problems of the axial injection system, were carried out at the Philips Research Lab by N. Hazewindus and J.van Nieuwland[6] of Geldrop. The results are quite encouraging, indicating that large beam currents can also be expected from the internal source in the 3rd harmonic mode. The beam extraction system is now being designed.

All components of the 72 MeV and low energy beam transport lines have been ordered and are under construction.

The ring cyclotron assembly at Villigen started in Summer 1971 with the first sector magnets beeing set up and measured on the ring foundation. At present, the first measurements of field superposition effects of neighbouring magnets are being carried through (fig. 4).

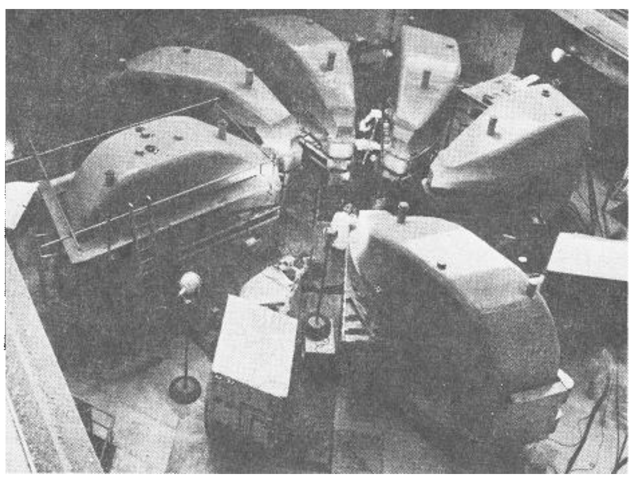

Fig. 4

Sector magnets of the ring cyclotron being set up and measured at the Villigen site. 6 of 8 magnets are complete, only the lower yoke parts of the remaining two are in place.

In the 4 magnets measured up to now, the original deviations from the "isochronous field" configuration were all within

$$\left| \frac{\Delta B}{B} \right| < 1.5 \cdot 10^{-3}.$$

To correct the iron field as well as possible we use shims mounted at the pole edges as shown in fig. 5. By this method it is possible to correct the deviations from isochronism to

$$\left| \frac{\Delta B}{B} \right| < 2 \cdot 10^{-4}$$

after two iterations (fig. 6).

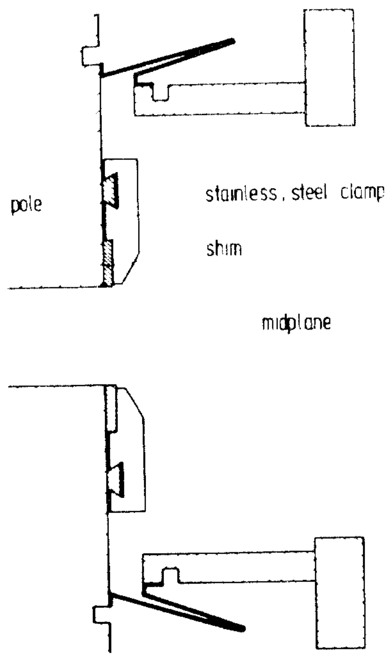

Fig. 5

Shims fastened on the pole edges of the sector magnets (schematic)

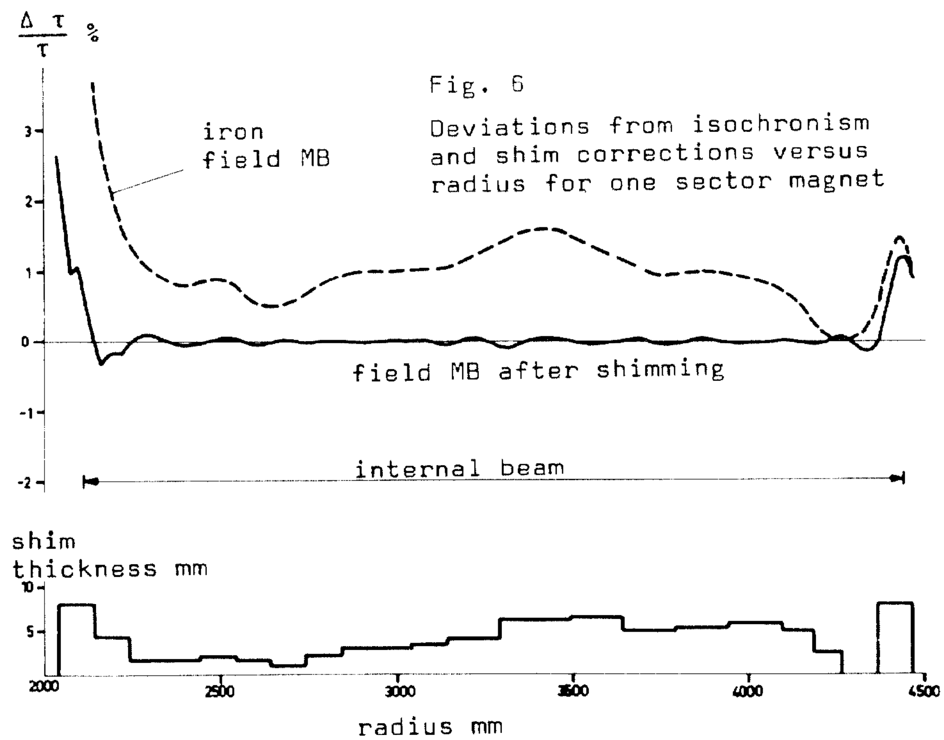

Fig. 6

Deviations from isochronism and shim corrections versus radius for one sector magnet

In consequence to these results the complete set of 18 pairs of trim coils per magnet (2 x 200 amp-turns per pair) will only be mounted in 4 magnets. In the 4 remaining magnets the coils no. 6 to 14 (see fig. 7), which are mainly for the control of isochronism, can be left out.

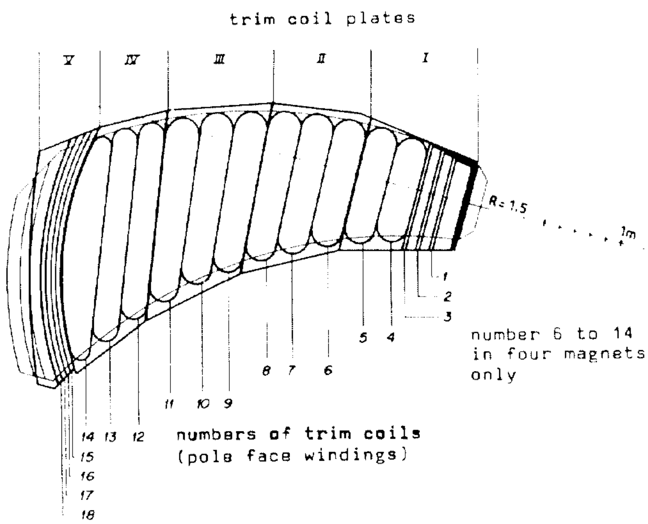

Fig. 7

Pole face windings of sector magnets for correction of isochronism and field assymmetries

The pole face windings, designed with indirect cooling, are mounted in aluminum sandwich plates. The anodized aluminum plates carry the cooling channels on the side facing the pole-gap. The plates can be mounted on and removed from the poles without taking the magnets apart. They are fastened only at the pole edges. In the prototype, the original conductors were anodized aluminum strips of 0.5 x 5 mm cross section (current density max. 6 A/mm^2). These conductors had to be replaced by glass fibre insulated copper strips of 0.8 x 5 mm cross section (current density 7 A/mm^2) since heat transfer problems arose in vacuum. No organic material is used for insulating or fastening the coils. The trim coil assemblies are now in fabrication and will be mounted after the magnets are set up on the ring.

All stainless steel vacuum chamber sections have been fabricated. Fig. 8 shows the assembling of one section with the magnet poles. The stainless steel collars providing the vacuum seal between pole edge and chamber wall presented no problems. The assemblies are carefully tested before being mounted on the ring. 2 of the 4 aluminum chamber sections have been delivered and were leak tested successfully.

Fig. 8

Magnet poles being fitted to vacuum chamber section

All the high vacuum pumping combinations have been assembled and are presently being tested (fig. 9).

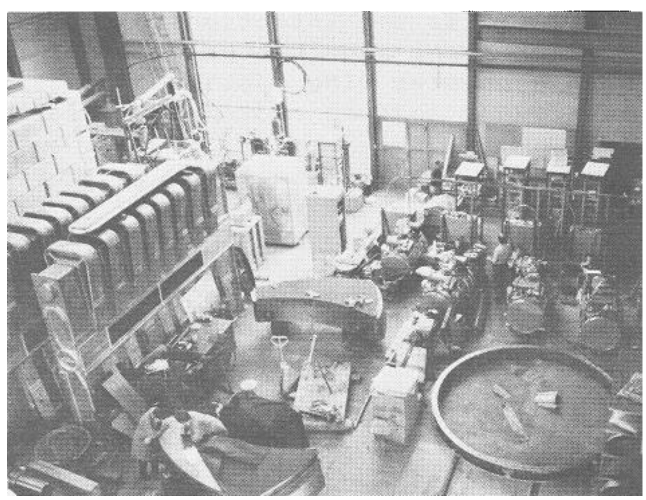

Fig. 9

SIN test site at Zürich-Oerlikon. From left to right: Shielding wall of R.F. cavity with power amplifier in the background; 2 cavities prepared for testing; the last pair of magnet poles (preparation of assembly). 4 vacuum pumping systems being tested.

The 4 R.F. systems are tested successively at the SIN test site in Zürich-Oerlikon (fig. 9), before assembly at Villigen. Encouraging results were obtained with the prototype combination of a 250 kW power amplifier system and the first cavity, as described by P. Lanz[7]. The peak voltage achieved, as well as voltage and phase stability were better by a factor of ~ 2 with respect to the original design goal of 350 kV $\Delta V/V$ 1 ‰, $\Delta\phi \sim 3^{\circ}$. Those results justified an increased effort to further develop the machine for single turn extraction, and, perhaps an increased beam intensity. At present, a 150 MHz cavity with its corresponding phase stabilization system for "flat topped acceleration" is in development, with the aim to incorporate it into the ring by 1976.

More detailed investigations on beam extraction were carried out by M. Olivo[8]. Monte Carlo calculations on extraction efficiency and heat absorption lead to the conclusion that e.g. molybdenum foils with thicknesses $d < 0.05$ mm would be more advantageous as a septum than tungsten wire strips. Molybdenum foils of thicknesses smaller than 0.05 mm were successfully tested under realistic geometric and high voltage conditions. In our case, it seems possible to use foil thicknesses down to 0.015 mm where the "deflection efficiency" exceeds 95 % with a maximum temperature of $\sim 800^{\circ}$ C at the leading septum edge.

Diagnostic elements, such as beam positioning probes and phase probes, have been developed and built as prototypes[9].

It is the intention to perform extensive testing of all important accelerator internal elements this Fall, when a quarter ring section consisting of 3 magnets, 1 R.F. cavity and 1 "free section" should be operable together.

By this time also a number of standard components of the digital control system, as described by L. Besse[10] are available to be tested under operation conditions. Presently, the IBM 1800 process control computer with its peripheral equipment (including an IBM 1810-A2 disk storage) is being interfaced with the data transmission system ROAD (Rapid Operation and Acquisition Dataway). The required software for reliable transmission will also be available for these tests.

The schedule for the assembly of the accelerator still follows the one set up in Fall 1968. First tests of the ring cyclotron with beam are expected towards the end of 1973.

REFERENCES

1. J.P. Blaser, ETH-Bulletin, 28, 8, (1971)

2. H.A. Willax, Fifth Internat. Cyclotron Conference (Butterworths, London 1970) p.58

3. G. Tripard, W. Joho, Nucl.Inst.Meth. 79, 293 (1970)

4. H.J. Gerber, SIN Annual Report 1971, p. 128

5. C. Petitjean, G. Vécsey, IEEE Trans.Nucl.Sci., NS-18/3, 723 (1971)

6. N. Hazewindus, J.v.Nieuwland, private communication

7. P. Lanz, this conference, H7.

8. M. Olivo, SIN Annual Report 1971, p.63

9. U. Schryber, R. Reimann, A. Paulin SIN Annual Report 1971, p.60

10. L.J. Besse, this conference, N4.

DISCUSSION

MILLER: At what radii do the $\nu_r = 1$ resonances occur in the injector cyclotron?

WILLAX: At about 18 cm.

MILLER: I noticed there is an almost continuous array of harmonic coils. Are those really necessary?

WILLAX: Philips is very careful about putting everything into the machine which makes it able to control the first harmonic at the places where they think it important. It is especially important at this radius where ν_r is going through 1. It can be shifted slightly, depending, but not very much, on the centre cone they really put in, and they have not decided yet. They even think of having no centre cone in the injector.