THE SIN RING CYCLOTRON PROJECT STATUS REPORT

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Presented by H. A. Willax

Abstract

A two stage isochronous accelerator for proton-beams of about 100 μA at more than 500 MeV is under construction at the Swiss Institute for Nuclear Research at Zurich. As previously described it ponsists of a sector focussed isochronous cyclotron for 70 MeV, acting as injector, and an isochronous ring cyclotron.

The **injector cyclotron** will also accelerate d, α, He_3, heavy ions as well as polarized d and p to variable energies. Those beams will be used separately. It will be constructed by Philips, Holland. The design goal for the **ring cyclotron** has been changed from 525 to 585 MeV. A prototype of the C-shaped sector magnets and of the RF-accelerating cavities have been tested successfully. Building construction work has started and installation ot the machine will begin in 1971.

1. Description of the SIN—Accelerator

As a device for the production of a high intensity beam of protons with an energy well above π-production threshold in 1962 we proposed a combination of an AVF-cyclotron (70 MeV) with a sector focussed ring cyclotron (500 Mev), both operating isochronous.

The reference desing which was used for development of the basic machine components has been described formerly [1, 2].

In 1967 the specification of the injector cyclotron were changed from a fixed energy to a multi-particle variable energy machine, whereas the ring device remainèd at fixed energy. The project finally obtained authorization last year and has now reached the phase of design and early building construction. In Fig. 1 the design layout of the machine is presented.

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1. 1 *The Injector Cyclotron*

The AVF—cyclotron of 2.45 m pole diameter and a single dee system has a variable magnetic field and continuously variable frequency within the range of 4.7 – 17 MHz, thus providing acceleration of various particle beams within the following energy ranges:

protons	10 — 75 MeV	(25 μA)
deuterons	10 — 65 MeV	(25 μA)
α-particles	20 — 135 MeV	(15 μA)
He_3-ions	15 — 160 MeV	(15 μA)
heavy ions	0.6 — 10 MeV/nucleon	(2 μA)

Axial injectiou is provided for polarized protons and deuterons. Those beams will be used for nuclear physics experiments in a separate area of the experimental hall. After passing a 110° analyzing magnet their energy resolution will be on the order of $\frac{\Delta E}{E}(FWHM) \approx 10^{-4}$.

As an injector for the high energy stage, this cyclotron will operate at an RF-frequency of 50 MHz which is the 3rd harmonic of the cyclotron revolution frequency. In this mode of operation it will deliver a 100 μA proton beam of 70 MeV, with an energy spread of less than 0.3% (FWHM) and amittances of less than 30 mm mrad. Special care will be taken in the optimization of the central region, the symmetry of the magnetic field (4 sectors) and the extraction system to guarantee a reliable beam of this high a quality.

The contract for building this machine has been given to Philips, Holland in fall 1968.

1. 2 *The Ring Cyclotron*

The 70 MeV proton beam is transmitted into ring device with basic characteristic features, which are advantageous for high intensity beams of intermediate energies:

— separated magnets with small gaps producing a low average field and rather strong axial focussing,

— a rather large energy per revolution, provided by separated RF-cavities for very high voltages.

In such a device conditions are pressented for a good control and **quantitative extraction** of c CW-beam of high quality.

The SIN ring cyclotron has 8 C-shaped magnets of ~18° azimuthal width. The pole gap decreases from 200 to 460 cm. 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 about 15—20.6 kG for a final energy of 585 MeV. Sets of low power pole face windings will provide the necessary field corrections. The stainless steel vacuum chamber is directly joined to the magnet poles by a flexible welding joint. There are different sections of the vacuum chamber containing probes, collimators, injection and extraction devices. 4 RF-cavites of 40 cm width in beam direction, 5.30 cm radial length and 330 cm hight, with an accelerating gap ot 15 cm provide voltages of at least 300—400 kV each at 50 MHz, which is the 6th harmonic of the particle revolution frequency in this machine. They are excited by individual 250 kW RF-power stages 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 90° bending magnet followed by a magnetic injection channel, and brought into equilibrium orbit by a correction channel. Since there is a complete separation of the orbits at injection radius, beam loss can be kept negligible.

With 1 to 1.5 MeV energy gain per revolution near extraction radius the radial gain is 4—6 mm, increasing to $\sim$8 mm at the extraction point due to the turnover of the magnetic field. Incoherent radial beam amplitudes will be on the order of 3—4 mm in this region. For an extraction device consisting of an electrostatic channel of 50 kV/cm with a 0.1 mm septum (130 mm long) a magnetic focussing element 45° downstream and an extraction septum-magnet 90° downstream, extraction rates above 90% have been computed.

The vacuum chamber is partly stainless steel, partly aluminium. The individual sections can be joined either with metal gaskets or inflatable bellows carrying radiation resistant elastomeres. Since oil contamination of the surfaces in the RF-cavities seem to limit the maximum voltage achievable, we propose a combination of turbo-molecular pumps, with titaniuna sublimators and ion-getter pumps, directly connected at the cavities.

2. Status of the Project

2.1 *Magnet Design*

After extensive studies on 2 megnet models 1:5 scale in connection with computations on beam stability, a prototype magnet full scale field was built [3].

After the first machining of the poles, which was done by Brown Bovery Company, Switzerland, the theoretical field has been achieved within $\pm 3\ _{0}/_{00}$ at nominal excitation. With this field configuration the final energy is 525 MeV (Fig. 2.).

Since there was still time to attempt a more ambitious program, it was decided early this year to try a pole gap machining for 585 MeV final energy. Simultaneously another set of 1:5 scal measurements was started for this final energy. The first results show the necessary field profile would be achievable. Using the same sector geometry for this higher end-energy, the beam has to pass twice the non-liner XZ-coupling resonance

$\nu_r = 2\nu_z$. However, with extensive numerical computations it has been shown by W. Joho that in our case there will be x-and z-amplitudes of a few cm necessary to lead to any distorting effects. Such amplitudes cannot be expected under normal operating conditions. The decision to go to an end-energy beyond 525 MeV will be final, after a few engineering aspects of beam injection and extraction are clarified towards the end of this year.

2.2 *RF-Design*

The development of the RF-cavities and the power stages went through the stages of 1:5 scale models, a full scale working model operating in vacuum and, finally, the prototype cavity excited by a home-built power stage delivering 80—100 kW at 50 MHz[2]. The first RF-power system for 250 kW is under construction at AEG—Telefunken, West Germany, and will be deliverd next spring.

The prototype cavity is a welded construction of 20 mm aluminium sheet with casted supports for mechanical rigidity. The inner surfaces are treated by rolling with polished steel rolls. By this method is was possible to reduce the RF-power loss to about 70% of the originally expected value. The Q value of this cavity turned out to be 32000.

With a combination of a 2000 m^3/h turbo-molecular pump and a titanium sublimator and an ion getter pump of total 10000 l/s effective pumpinp speed ot 10^{-6} torr we can reach vacua of 1×10^{-6} torr after a few hours of pumpdown. After a few weeks pumping the pressure came down to 6×10^{-8} torr.

The cavity has been baked out and was operating at about 400 kV. It was interesting to notice the X-ray level being down by a factor of 10 compared to the first working model of equivalent voltages.

A careful theoretical investigation of the problem of beam loading was carried out in cooperation with the Accelerator—Group of Karlstruhe (U. Schryber and C. Passow). It has been shown that there is no stability problem as long as the beam power per cavity does not exceed about 1/4 of the RF-power loss in the cavity. If a fast amplitude and phase regulating system can be applied, the beam power could be carried far beyond this limit.

2.3 *Mechanical Design*

The most serious design problem was considered to be the joint of the vacuum chamber with the spiralled magnet poles. The 60 cm thick pole itself is a part of the chamber wall and has to be tightly connected to the stainless steel chamber wall. This is done by means of a double-collar of thin stainless steel, one part welded to the pole, the other to the chamber wall.

The final weld connects the two collar-sheets all around the pole. This part can be cut and rewelded several times. A full scale prototype of such a section has been built and is presently tested.

The design of injection and extraction elements as well as beam probes and collimators has started.

2.4 *Control System*

It is planned to have a small digital computer (for instance a PDP 9) as an aid for operating the machine. In the first phase of operation it will be mainly used for automatic logging of data, in the second phase for parameter settings and limit control. In the third phase of operation it possibly could enter as an active element into a part of the control. function. The development of analog-digital converters goes along the lines of the CERN-developments.

2.5 *Buildings and Main Installations*

The laboratory will be built in Villigen, 35 km northwest of Zurich, close to the EIR at the river Aare. Fig. 4 shows the general layout. The main parts will be

2.5.1 the experimental hall 85×48 m^2 floor space and 18 m hight. A 60 ton crane, spanning the whole width will service the area from 12 m altitude. The hall contains the 2 accelerators in vaults at the north end. The shielding walls of the accelerator will be partly cas concrete, partlymovab le blocks. The roof shielding consists of removable concrete beams. The experimental area availableoutside the vaults is 2700 m^2.

2.5.2 the operations building joining the northeast part of the experimental hall. It contains control room, counting rooms, offices and workshops (a total of~2000 m^2 useful area).

2.5.3 the service building, joining the northwest part of the experimental hall. It contains the central heating system, cooling system, main power conversion system and a small workshop for special purposes (a total of 1500 m^2 useful area).

2.5.4 the laboratory building, situated about 70 m northwest of the main hall. It contains a total useful area for offices and laboratories of about 1800 m^2

Building construction work has started. In connection with design of the building the main power distributions and the cooling water circuits have been desingned. There is a total of 10 MW electric power and 6 MW cooling power available in the first phase of operation. This capacity can be expanded.

3. Schedules

The main buildings are scheduled for summer 1971. The injector cyclotron will be installed from summer 1971 to summer 1973. Its first beam is expected towards the end of 1973. The ring accelerator will be assembled during the years 1971—1973. The experimental program is in preparation and it is hoped that not much time will be lost from the startup of the machine to the delivery of beams.

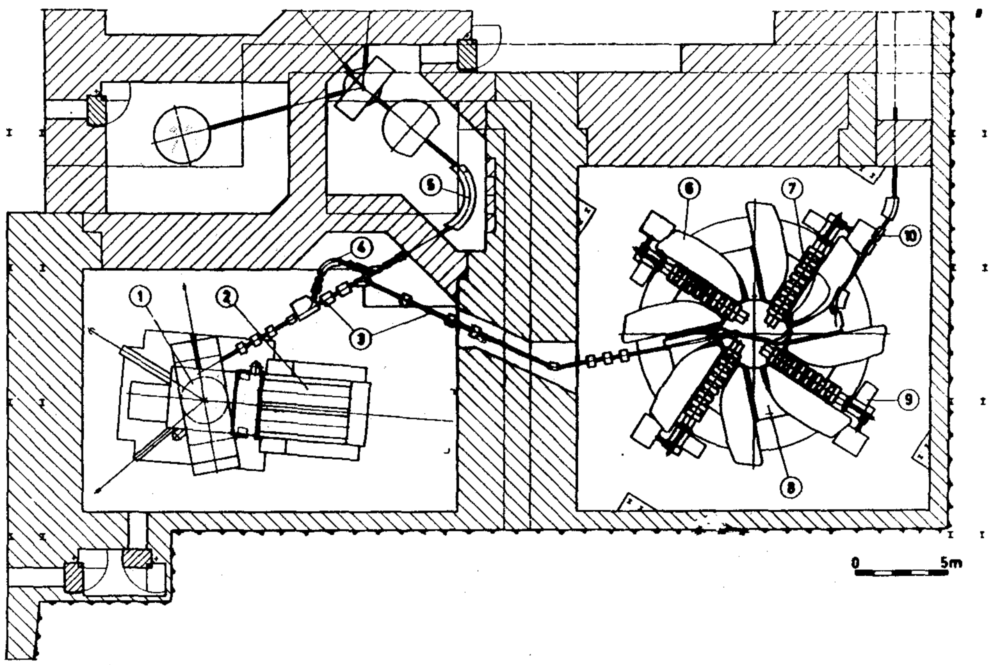

Fig. 1. Simplified assembly-drawing of the SIN-accelerator within the concrete shielding

1. Injector cyclotron, 2. RF-system for the injector cyclotron, 3. Beam-transport system to the ring cyclotron, 4. Beam-switch for simultaneous use of the 70 MeV beam for low energy experiments, 5. Low energy beam analyzing system, 6. Sector magnets of the ring cyclotron. 7. RF-cavities of the ring cyclotron, 8. "Free" section of the vacuum chamber, 9. Vacuum pumping system and RF-power stages, 10. Beam -transport system for the ejected protons.

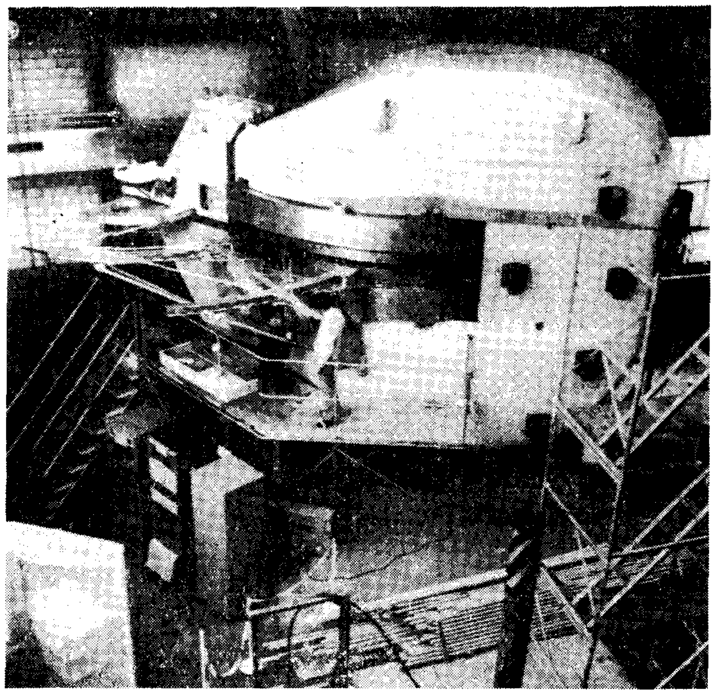

Fig. 2 Prototype of a sector magnet for the SIN ring cyclotron with automatic device for field measurements

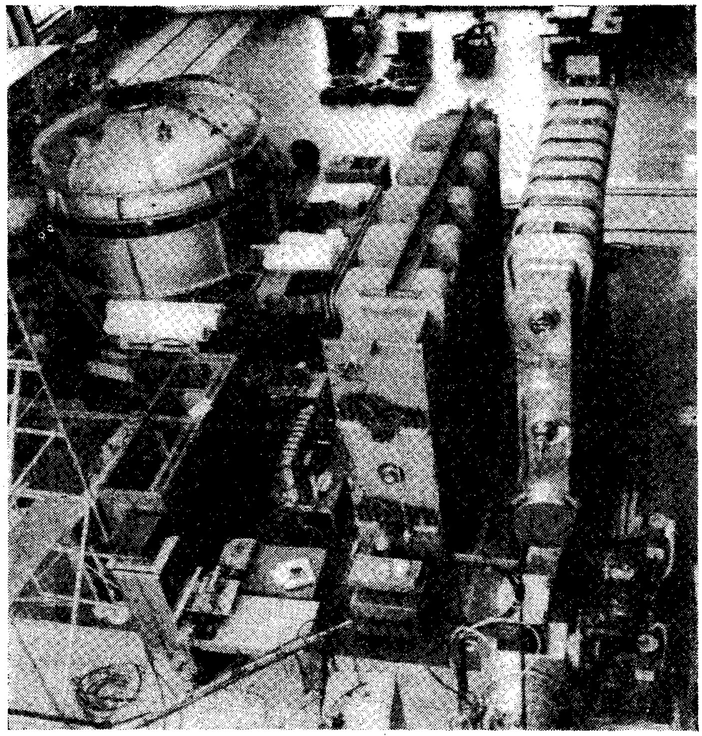

Fig. 3 The models and the prototype of a 50 MHz RF-cavity for the SIN ring cyclotron at the test stand

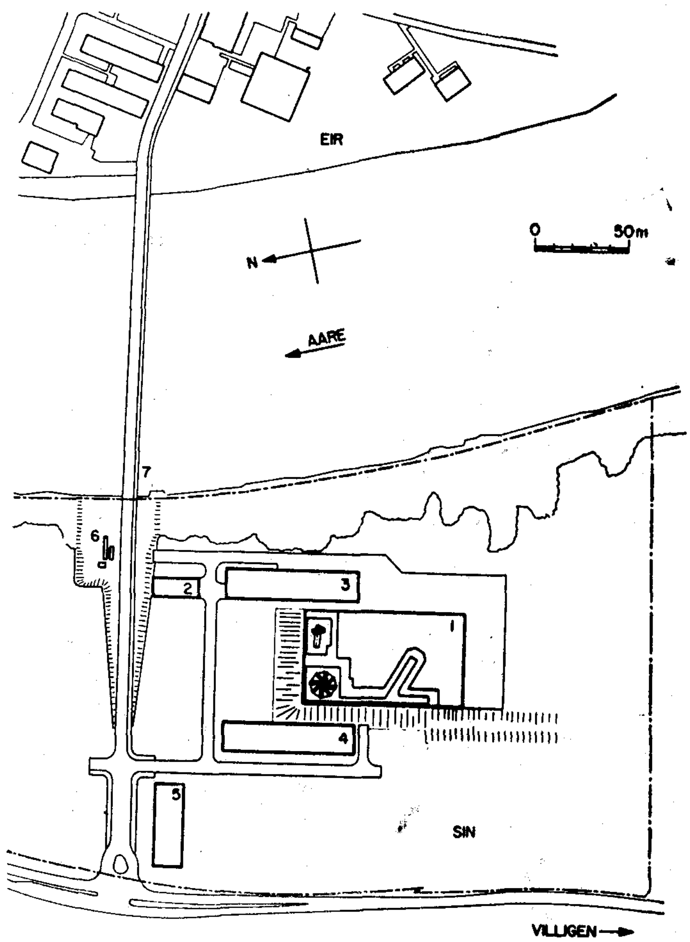

Fig. 4. The SIN laboratory at the site near Villigen

1. Main experimental hall, 2. Transformer station, 3. Control and operations building, 4. Building for electric and cooling water supplies, 5. Laboratory building, 6. Waste water purification, 7. Bridge connecting the SIN with the Swiss Federal Institute for Reactor Research (EIR)

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ДИСКУССИЯ

Замолодчиков: При каком вакууме Вы получили в разонаторе 400 кв.?

Willax: This was obtained at the vacuum 1×10^{-6} torr, but cavity could be evacuated up to 5×10^{-8} torr.

Оганесян: Какие тяжелые частицы Вы сможете ускорять на большом ускорителе?

Willax: We will not accelertte heavy particles at all in this machine.