IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

PRESENT-DAY STATUS OF THE SYNCHROPHASOTRON AS A NUCLEAR ACCELERATOR

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Introduction

In recent years the Dubna Synchrophasotron has been operating as an accelerator of light nuclei. Since 1970 it has been used to accelerate deuterons and helium (in the $z/A \approx 1/2$ mode). After the development of the electron beam method of deep atomic ionization the Synchrophasotron can accelerate light nuclei, including neon. At present the accelerator has been adapted to a new region of research, viz., that of relativistic nuclear physics /1/, where physisists are attracted by energies of 3.5 GeV/u and higher.

Most of the experiments performed with the Synchrophasotron pertain to particle energies of about 4 GeV/u, but some have been carried out at 4.2 GeV/u.

The experience gained during operation of the accelerator for almost 25 years has shown a rather high reliability of its essential units. The main magnet winding (made of copper and operating at a peak current density of 5 A/mm^2) had no failures. Routine inspections confirmed the reliability of the winding.

The main current aggregates have also operated without failures although several years after running some flaws were found in several poles of the generators. Consequently the construction of the poles was modified and an additional aggregate was installed.

The vacuum chamber showed a rather good longevity though it demands attentive maintenance and repairs. The seals between the stainless steel elements of the inner part of the chamber have not been replaced since assemblege. They are made of standard vacuum rubber and have lost some of their flexibility under the action of the vacuum and radiation; possibly they will have to be replaced in the coming years.

After a period of operation of the accelerator the magnetic field correction system was considerably modified and a device for pulsation damping in the flat-top current of the magnet was put into operation /2/.

In 1974 a new injector was installed to accelerate protons and nuclei with energies of 20 MeV/u and 5 MeV/u, respectively.

In the last 5 years the pulse intensity has been increased from $2\cdot10^{11}$ to $4\cdot10^{12}$ for protons, from $5\cdot10^{10}$ to $4\cdot10^{11}$ for deutrons, from 10^8 to $5\cdot10^{10}$ for helium and from $3\cdot10^4$ to $4\cdot10^6$ for carbon. This increase was attained mainly by increasing the linac current and by introducing improvements in the system of energy modulation of the injected beam and magnetic field correction /3/. However, particle losses at the initial stage of acceleration are significant. This shortcoming is connected with distortions of the magnetic field /4/ arising as a result of deformations of the magnet ring foundation which turned out to be insufficiently rigid /5/. Adjustment of the magnet (weight 36 ktons) without disassembling the vacuum chamber is practically impossible, and the pole face correction system allows one to solve this problem only in part.

Injection

To obtain beams of relativistic ions it seems attractive to employ an electron beam ion source (EBIS) yielding ions with a high degree of ionization. Sources of such a type permit one to get output synchrotron ion intensities sufficient for carrying out many various experiments. In addition to a substantial decrease of the injector dimensions,

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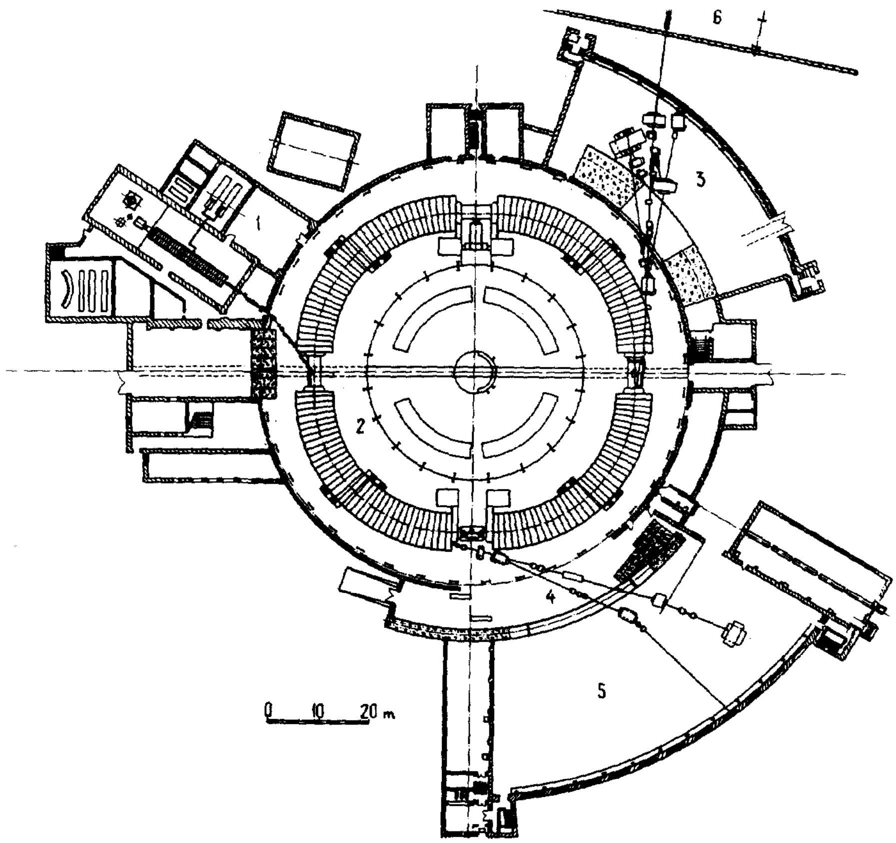

Layout of the Synchrophasotron

1 - Linac LU-20

2 - Ring

3,4 - Extracted beams

5,6 - Experimental halls

the conditions for ion production in such an ionizer would completely correspond to the operation characteristics of synchrotrons, since the time required for multicharged ion production is of the order of several seconds and considerably exceeds the extraction time ($\sim 10^{-5}$s). For the Synchrophasotron the time between cycles ($\approx$ 9 s) is sufficient to produce such multicharged ions as Xe^{52+} at the available electron density in the experimental ionizer KRION-2 /6/.

To generate He^{2+} in the duaplasmatron source, a mixture of helium and hydrogen (in the ratio of 100 to 1) is used as the working gas. This concentration of hydrogen is sufficient to restore the oxidic layer of the cathode during its operation. Therefore the lifetime of the cathode is significantly increased. Moreover, the presence of hydrogen makes it possible to have a high ($\approx$ 250 V) arc voltage across the gap and stable discharge initiation. This essentially increases the yield of He^{2+} from the source. Under such conditions the helium beam current at the exit of the linac rises by a factor of 3 and is 1.2 mA.

For acceleration of nuclei the Alvarez linac is operating in the $2\beta\lambda$ mode. To use the full voltage of the preinjector (which is a high voltage pulse transformer), the particles are injected into the 5-th cell of the linac cavity. In order to avoid any action of the r.f. field on the beam in the first four gaps, the latter are separated from the remaining part of the cavity by a solid copper wall. During the acceleration of nuclei no r.f. power is supplied to the first module.

Data on the injector are presented in detail in several publications, for example, in /7/.

Extraction

The Synchrophasotron beam extraction system based on the $Q_x = 2/3$ betatron resonance has two channels of ejected beams. The first one with an efficiency of above 90% and 500 ms duration is intended for counter and wire chamber experiments. The second channel having an extraction duration of about 600 μs is mainly used for bubble chamber experiments. Beams of low (up to 300 MeV/u) and middle energies can be extracted in this direction; however the pulse duration does not exceed 100 ms and is limited by power dissipation in the beam transport elements. During a cycle it is possible to divide the accelerated beam into the two external channels and one of the internal target.

A feedback system has been developed to ensure constancy of the external beam current in the course of extraction. The current in the gradient winding is modified by functional conversion of the signal obtained as the difference between the signal from the extracted beam monitor and a reference voltage. A very small part ($< 10^{-3}$) of the circulating beam can be "split off" by means of this system. Low-frequency ripples in the extracted beam current are also suppressed by this system.

The research program using external nuclei beams has been extended after putting into operation a new experimental 6000 m^2 hall. Experimental work has begun and at present new physics equipment is being installed in the hall and adjustment of the beam transport channels is under way.

Monitoring and Control

The system is based on the EC1010 and VT1010B computers (VIDEOTON, Hungary) used for beam monitoring and control of accelerator operation. This system performs the following main functions.

- Measurement and presentation to the operator of some of the accelerator parameters (guide magnetic field, accelerating voltage frequency, beam intensity). Under low level intensities (10^2 - 10^7 particle/pulse) the circulating beams are monitored by means of ionization detectors placed in the vacuum chamber of the accelerator.

- Measurement and control of parameters of units of the slow beam extraction system: resonance windings, magnets and transport line lenses.

- Measurements and control of the space characteristics of the extracted beam (profiles, positions, sizes) in an intensity range of 10^6-10^{12} particles per pulse. Multiwire two-coordinate (30x30 wires) ionization chambers are used as beam detectors. At low intensities they operate in the proportional mode. The space parameters provide the initial information for calculation of the beam emittance and envelope of the extracted beam.

- Dialogue between the operator and computers to set and modify the system operation algorithm.

Graphic and alphabet-digital displays, TV-monitors, a plotter and a line-printer are used for presentation of the Synchrophasotron operation condition.

Development

Further increase of the beam intensity and the application of heavier nuclei in the Synchrophasotron are limited by losses due to the capture of electrons from atoms of the residual gas ($p=2\cdot10^{-4}$Pa). Work for improvement of the vacuum (up to 10^{-5}Pa) in the accelerator ring by means of cryopanels[6] is under way. A new linac involving an energy of 10 MeV/u and which permits ions with q/A=0.3 to be accelerated is being developed.

The development program includes the construction of a booster[8] with an uranium energy up to 300 MeV/u and to replace the Synchrophasotron to Nuclotron[9].

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