STATUS OF JULIC

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Abstract.- The isochronous cyclotron JULIC is a light ion variable energy accelerator operating between 22.5 and 45 MeV/A. Its bending limit corresponds to 180 Q^2/A MeV. JULIC is in regular operation since 1971, mainly used for nuclear physics experiments. About 10 % of the machine time is devoted to isotope production and applied topics. The spectrometer BIG KARL, in operation since two years, is now involved in 40 % of the nuclear physics experiments. The latest improvements concern the focussing channel in the extraction system, a microprocessor controlled emittance measuring device and a data logging system. The project ISIS for the external injection of heavier ions has been started.

1. Introduction.- After 10 years of regular operation this status report is used to describe the cyclotron facility JULIC as well as the major improvements which led to its present operational performance. Improvements and extensions in progress are also reported.

2. Cyclotron.- The isochronous cyclotron JULIC illustrated in figure 1 is a three sector compact machine[1)] with a bending limit of 180 Q^2/A MeV corresponding to a mean field $\bar{B}_{ex}$ = 1.3 T at the mean extraction radius $\bar{R}_{ex}$ = 1.4 m. This is achieved with only 50 kW power consumption of the main coils. This low power consumption coming from a low mean magnet gap is due to a special feature of JULIC: Three Dees[2)] are located in the three valleys. They are coupled in the machine center and represent at the same time the resonating system driven by a self excited generator on top of the magnet through a coaxial transmission line in the upper yoke bore insert (an internal Livingston ion source is located in a corresponding lower yoke bore insert). From this results the single mode of operation on the harmonic number h=3 and the frequency range of 21 to 30 MHz. Upper frequency limit and bending limit correspond for Q/A = 1/2. This illustrates that JULIC originally was conceived as a deuteron machine[1)] for energies between 45 and 90 MeV. Actually it was only during the construction of JULIC that modifications have been planned to accelerate other light ions[3)]. JULIC delivers p-, d-, $^3He^{2+}$ and α-beams[4)] variable in energy between 22.5 and 45 MeV/A.

2.1 Center region.- The original RF-center region suffered from the mechanical design allowing neither a reproducible movement of the Dee tips due to temperature changes of the 2.40 m long Dees nor an easy and clear adjustment procedure. Also there was no tool available to observe the adjustment state of the RF center region under working conditions. After all these problems had been tackled[5)] and additional water cooling had been applied to the Dee stems, the adjustment state of the RF-center remained within sufficiently small tolerances. A coherent radial beam amplitude $A_c \approx$ 3 mm which earlier had been observed and investigated with respect to external beam quality changes due to precessional mixing[6)] became sufficiently small ($\sim$1 mm) as well. Thus harmonic coils[7,8)] previously designed and put into operation have not been used extensively for beam centering. They might turn out to be valuable in connection with external beam injection.

Axial phase selection with slits on the first and fourth turn has been investigated successfully[8,9)]. The early phase slits have been replaced by remotely controlled flag slits in the SE- and N-Dee. Lately they have been used to produce a narrow beam for forward angle measurements with the spectrometer BIG KARL.

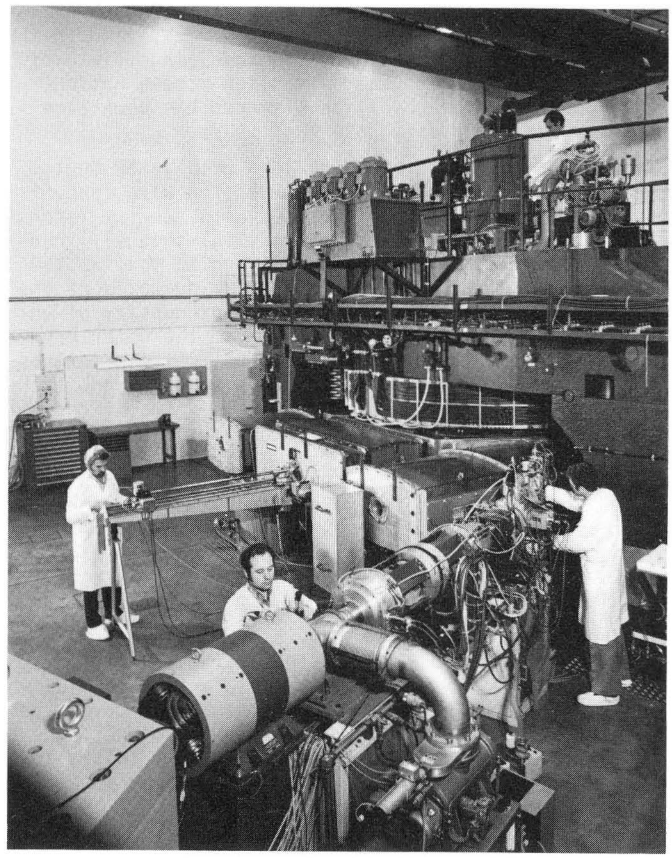

Fig. 1: View of the isochronous cyclotron JULIC.

A system for microscopic and macroscopic beam pulsing[10,11)] has been used extensively in nuclear spectroscopy experiments. It can either remove 2 out of 3 bursts from the beam or can deliver a macroscopic pulse with intensity fall times of about 1 µsec. Electrical axial beam deflection is performed by means of two plates covering 4 turns near the center in the NE-hill.

2.2 Acceleration.- The occurence of several short circuits led to the redesign and the construction of the indirectly cooled trim coil plates on the hills[12]. The original trim coil current parameter sets delivered by the cyclotron manufacturer led the beam to extraction radius but only in rare cases with optimum phase along the radius. A systematic mathematical[13,8] procedure for iterative beam phase optimization has been developed. It is based on the evaluation of the influence of the trim coil currents on the beam phase along the radius. After this procedure had been established in appropriate software on a PDP11/34 computer, the phase along radius improved considerably for the beams in use.

The quality of acceleration has been further improved by a better stabilisation of the main current power supply[14] and a much more reliable frequency control and regulation[15]. A step by step redesign and interchange of the other supplies and electronics especially those responsible for the RF-amplitude stability is in progress.

2.3 Extraction.- The multiturn extraction at JULIC[16] is performed with a 20^0 degree long septum deflector (120 kV/cm maximum electric field) in the south hill, a fully compensated screening channel installed in the SW-Dee and a focusing channel in the fringe field of the cyclotron magnet. The extraction scheme has not been changed but each of the elements has been carefully redesigned during the last years.

The deflector has been provided with a new septum made out of an upper and lower tungsten wire fence[12] the anti septum has been equipped with new insulators and a special oil cooling, which simultaneously insulates the high voltage leads. Mounted in the limited space inside the SW-Dee the compensating coils of the screening channels have a high current density of up to 65 A/mm^2. Electrolytic corrosion at the water manifolds and radiation damage of the polymeric materials led to the construction of this device using new techniques and materials[12]. Recently the focusing channel has been improved. Detailed field mapping was done and evaluated with a modified program SORTRM[17] to search for a reference trajectory giving minimum beam distortion. According to this evaluation graphite diaphragms have been inserted in the channel. To account for magnetic field form changes in the operating range of JULIC the channel has been provided with remote positioning.

Care has been taken to provide easy and quick dismanteling and replacement of the extraction elements and their parts, which was not satisfactory previously. Each of the above described measures improved the reliability of the extraction system and reduced the radiation load to the personnel remarkably increasing at the same time the delivered external beam intensities.

3. Beam lines.- The beam handling system (see fig. 2) has been layed out after emittance measurements of the external cyclotron beam had been performed[18]. It includes a double monochromater[19] in quadrupole-dipole-dipole-quadrupole configuration. The dipoles are 120^0 analysing magnets with large β-angles of 52^0. In the dispersive mode of operation the system gives an energy resolution of up to 1/10000 with a transmission of 2 %. When operated in single achromatic mode up to the full cyclotron beam intensity is available at the exit of the system. Thus a beam of high intensity can be delivered to all the target stations. The target stations B, F and E are especially used for high resolution experiments. Beam energy degraders are available at the achromatic outlet slit of the double monochromator and in the beam line to target station G. They allow the energy variation below the operation range of JULIC for nuclear spectroscopy experiments at the target stations A and G.

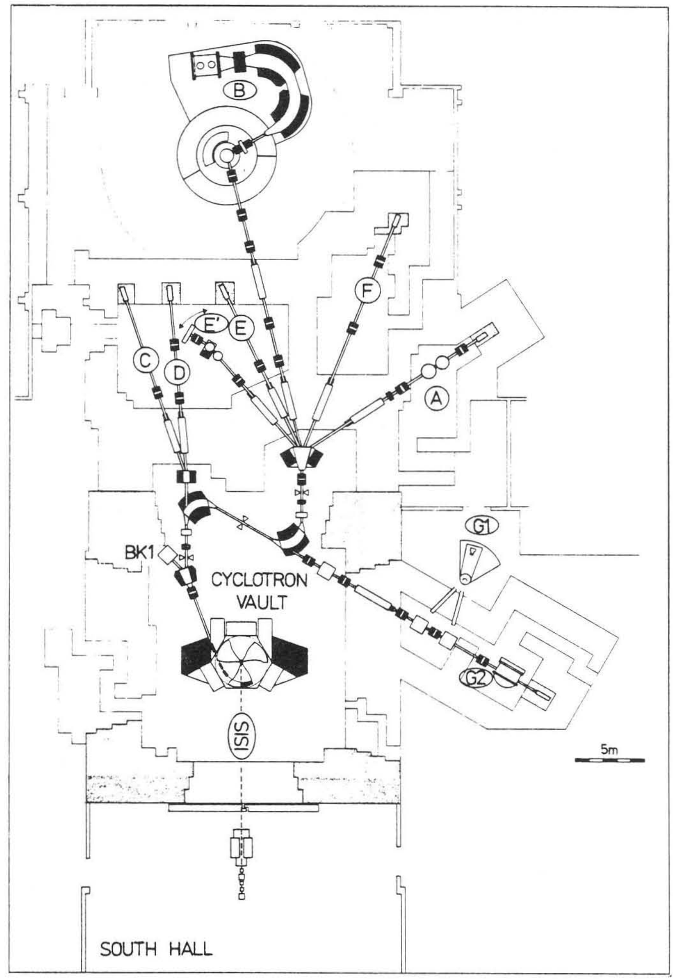

Fig. 2: Layout of the JULIC experimental area.

Target station A is mainly used for in-beam γ-ray spectroscopy. Devices for angular distribution, coincidence and multiplicity measurements as well as a sum spectrometer are available. At station B the spectrometer BIG KARL is located (see next chapter). At station C the BANDIT apparatus[20], a recoil collection and transport device is used for quick off line spectroscopy. At the target stations D and E 20 cm scattering chambers can be mounted, which are easy to use because the detector systems are mounted outside. A former little magnet spectrometer for tests and forward angle measurements at station E' has recently been dismantled. In the future this station will be used for in-beam conversion electron measurements by means of a superconducting solenoid. A large 100 cm diam. scattering chamber at station F has two independent turn tables and can be equipped with Si-surface-barrier detectors or with special home made Ge diodes for the measurement of high energy charged particles. The equipment at the target stations G1 and G2 is a bent crystal spectrometer for very high precision in-beam x- and γ-ray spectroscopy and an ironless orange type β-spectrometer. The target station BK1 and a remotely controlled internal target in the south of the cyclotron are especially suited for isotope production and related studies[21].

4. Magnet Spectrometer BIG KARL.- The high resolution magnet spectrometer BIG KARL[22,23,24] came into operation in 1979. Today it is used in about 40 % of the nuclear physics experiments. It consists of two quadrupole magnets followed by two dipoles and another quadrupole magnet, the latter allowing the variation of the dispersion from 0 to about 24 cm/(% momentum). Its maximum solid angle is 12.5 msr and its maximum resolution of $\Delta E/E \lesssim 1/10000$ is designed to match the performance of the double monochromator[19] in high dispersive mode operation. The dispersion matching of spectrometer and beam line[25] was found to be crucial for high resolution experiments where a resolution $\Delta E/E = 1/7000$ has been obtained for a solid angle of 3.5 msr. For larger solid angles further investigations of the H_t-correction coil settings[26] are necessary in order to eliminate higher order ion optical aberrations. Operating the double monochromator in a special low dispersive mode for experiments needing high beam intensity the resolution $\Delta E/E$ was well below 1/1000 at beam currents of up to 5 µA. A two dimensional multiwire proportional chamber[27] with an active area of 30x4 cm^2 is used to measure the horizontal and vertical position in the detecting plane. Its spatial resolution is better than 0.5 mm. A single wire detector of 100 cm length is under construction to cover the full detecting plane.

5. Diagnostics and computer control.- Beam diagnostic equipment for the cyclotron are movable internal targets situated in each of the valleys (Dees) as well as in the south hill. They can be equipped with differential finger and fluorescent heads. The beam phase along radius can be detected with a phase detection system[28] especially deviced to work in the presence of high RF-disturbances. Additionally the prompt γ-ray method using the SW-Dee target can be applied, but mainly it is used for the measurement of the phase width with a time resolution of typically 600 psec.

For the beam lines fluorescent screens, current measuring slits and beam stops are mainly used for diagnostics. The former emittance measuring device was not suited for computer control. A new microprocessor controlled device has been tested off line and is presently being installed during the yearly shut down time. Separately in x- and y-direction a slit at the exit of the cyclotron is followed by a wire grid (13 wires) mounted about 2.4 m apart before the first quadrupole. The mechanical components and the electronics have been manufactured according to our specifications by NTG Gellnhausen. The complete measuring cycle and data collection will be controlled by a microprocessor, while the data evaluation will be performed on a PDP11/34. After this PDP11/34 computer has been initialized 2 years ago, a data logging system has been installed and interfaced step by step, which scans the actual values of parameter settings of the cyclotron and the beam handling system. After some re-measurements of quadrupole strengths by means of the beam this system helped to improve the reproducibility of beam tuning especially also in the beam line to the spectrometer.

6. Operation.- Especially during the 6 to 7 weeks of shut down in the middle of every year a great deal more of improvements than can be reported here has been implemented to achieve and sustain a reliable cyclotron operation and to meet continuously diversifying demands. Figure 3 illustrates the operation record of JULIC during the past decade after the regular 21 8 hours shift per week operation had been started. Every two weeks 11 hours are used for maintenance and repair. With only minor variations during the years 20 % of the machine time have been used by our guests from German and foreign universities and other organizations, 10 % have been used by other institutes of the Kernforschungsanlage and 70 % have been used in house for nuclear reaction and spectroscopy experiments as well as beam and apparatus development (typically 6 %). 90 % of the machine time for research have been devoted to basic nuclear physics experiments and 10 % to isotope production and other applied topics.

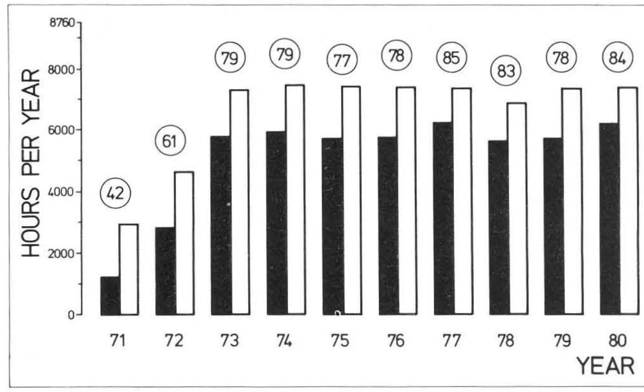

Fig. 3: Operating record of JULIC in the past decade. ■ cyclotron being operational □ scheduled operating time (84) portion of cyclotron being operational with respect to the scheduled operating time in %.

7. Outlook.- The project ISIS (Injektion schwerer Ionen nach EZR-Stripping) has been started, which mainly comprizes the development and construction of an ECR-ion source[29], a beam handling and axial injection system[30] and a modified center region[31] of the cyclotron. With ISIS the acceleration of heavier ions with Q/A>1/3 will become possible. ISIS will provide also more flexibility in producing high quality beams.

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