BONN CYCLOTRON PROGRESS REPORT

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Abstract

Recent operating performance is reported and several features of the accelerator design are described. The pulse suppression is achieved using a deflection system in the internal region. It allows the suppression of up to 11 microscopic beam bursts with a suppression of satellite peaks better than 10^{-4}. Also macroscopic pulsing has been made with the deflection system. An axial injection system including a buncher is under test. We are going to accelerate polarized protons and deuterons produced by an atomic beam ion source. An energy stabilization of the extracted beam is reached by a feedback signal derived from the monochromator system. A direct measurement of the energy spectrum of the analyzed beam has been performed in order to assure the assumed ion-optics.

Introduction

The Bonn Isochronous Cyclotron is a multi particle energy variable accelerator. In the normal mode of operation (3ω mode) the energy range lies between 7 and 15 MeV per nucleon. Since the 10th European Cyclotron Progress Meeting in Groningen [1] important improvements of the reliability and versatility have been achieved. The machine has been continously operated with the exception of a short shutdown where the old trim-coil system destroyed by corrosion has been replaced by a new system. By changing the coil arrangement, improving the cooling and increasing the maximum current of the power supplies, it is now possible to adjust an isochronous field in the total energy range of the machine.

Operating Performance

The distribution of operating hours during 1973/74 is shown in table 1. The breakdown of operating time according to the type of ion accelerated is shown in table 2. Nearly half of the time was used for the acceleration of alpha particles. In the normal mode of operation primary beam currents of less than 5 μA have been extracted. For experiments with semiconductor detectors an energy resolution between 1500 and 3000 has normally been adjusted with the monochromator system. The target beam currents ranged between 10 nA and 1 μA according the experimental requirements. A lot of experiments needed a high collimation of the beam and very low beam currents (0.1 to 1 nA). This requirement has easily been fulfilled with the remote controlled four slit collimator at the entrance of the beam handling system. High-resolution studies of sharp resonances have been performed with an energy resolution of 15000 at beam currents of 30 nA. Experiments with the split-pole magnetic spectrograph (Enge-type) have been performed using a mode where the dispersion of the double monochromator has been matched to the dispersion of the spectrograph. For high-current irradiations and neutron production beam currents between 10 and 20 μA have been extracted.

Table 1

1973/74 Time Distribution

operating for experiments	59.4%	
beam development	16.7%	
total operating time		76.1%
shutdowns, planned maintenance	8.7%	
unplanned maintenance	11.5%	
total maintenance		20.2%
shutdowns (Feiertage)	3.7%	

Table 2

1973/74 Particle Distribution

protons	16.3%
deuterons	23.8%
helium 3	11.9%
helium 4	48.0%
total	100%

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Beam Pulsing

The micropulse intervals lie between 33 and 50 nsec according the accelerator frequency range 20-30 MHz. A time resolution of the micropulses of less than 270 - 400 psec can be achieved by proper tuning the machine [1]. In order to increase the experimental possibilities a beam pulse suppressing system has been developed which covers a great range of time. Pulse intervals between 100 and 500 nsec are achieved with a radial deflector in the inner region. The deflector which covers 42° is matched to the third orbit. At the place of the deflector there exists a radial waist. The deflector is part of an oscillator which oscillates on a subharmonic of the cyclotron frequency. This arrangement exhibits by a very low power consumption (∿ 300 W). Up to 11 micropulses can be suppressed. The signal-to-noise ratio is better than 10000. The strong suppression of satellite peaks is due to the fact that the machine has a single-turn-extraction mode [2]. The long term stability of the arrangement has been successfully tested during experiments. The slow pulsing can also be realized with the deflector by applying rectangular pulses. It is also possible to switch the ion-source. An even greater versatility of the beam pulsing can be achieved by a combination of radial and axial pulsing which is under construction. A further beam pulse suppressing is in preparation at the axial injection line. The advantages of this system are the low deflection voltages and the simple accessibility.

Axial Injection

A beam transport system for the axial injection of polarized protons and deuterons has been developed and installed at the cyclotron [3]. The injection system consists of three einzellenses and four electrostatic quadrupole lenses. The beam comes 225 cm upwards through a hole in the lower yoke of the magnet to the cyclotron median plane. The beam is inflected with a hyperboloid inflector. For the axial injection of unpolarized ions a second entrance exists where at the moment a RF-ion-source mounted. Installation, tests and improvements of the injection system have been performed during the last months. A transmission of 60% has been achieved confirming previous measurements outside the cyclotron [3]. In order to increase the beam intensity a bunching system has been installed into the axial injection system. The first test measurements yielded an increase of the external cyclotron beam by a factor of 3. A factor of 5 seems to be possible. Details of the pulsing, injection and bunching facilities will be published elsewhere.

Ion-Sources

Together with the axial system an atomic-beam polarized ion-source has been installed [4]. The H- and D-atoms are produced by a 27 MHz discharge in a pyrex tube. The separation of the electron spin is achieved by a sextupole magnet with a length of 220 mm. In order to get a higher nuclear polarization a system of RF-transition is used. The succeeding ionization is achieved by electron impact. The test measurements yielded typical ion beam intensities of 2 μA for protons and 3 μA for deuterons at the exit of the source. About 1/3 of the total current lies within a phase space of 0.3 $\text{cm}\cdot\text{rad}\cdot\sqrt{\text{eV}}$. The phase space of the total beam has a value of 2.5 $\text{cm}\cdot\text{rad}\cdot\sqrt{\text{eV}}$ [4]. The tensor polarization P_{zz} of the deuteron beam has been tested via the $T(d,n)^4$He-reaction. The measurement yielded $P_{zz} = 0.79 \pm 0.02$. P_{zz} has been increased to 0.85 ± 0.02 by blocking the central region of the sextupole with a diameter of 3.5 mm [4].

First measurements of the polarized deuteron beam accelerated to an energy of 22 MeV yielded a degree of polarization of about 70%. The target beam currents were 15 nA at an energy resolution of 500 and 30 nA at an energy resolution of 200. It is expected that further developments will lead to essential improvements of these first results.

In order to get high α-beam-intensities with the internal injection an universal ion-source of the penning type is under construction [+]. Heavy ions up to the atomic mass 20 and a charge to mass ratio of e/m = 1/3 can be accelerated with the aid of this source.

Energy Stabilization

The instantaneous energy spread of the cyclotron beam lies in the order $\Delta E/E = 5\cdot10^{-4}$ to $1\cdot10^{-3}$ (fwhm) at beam currents below 5 μA. With the highly resolving mode of the double monochromator system [5] it is possible to filter a beam with an energy resolution up to 15000. The intensity of the filtered beam strongly depends on the proper tuning of the cyclotron as well as the time stability of the RF that means the amplitude and the frequency. The time stability of the magnetic field is high enough so that the energy stability of the extracted beam is practically not affected. The time averaged stability of the RF-frequency is also high enough (better than $1\cdot10^{-5}$) but

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short time instabilities cannot be compensated by the automatic regulation system due to the slow response of the mechanical tuning of the Dee system (up to approximately 2 Hz). A yet stronger problem is the time instability of the RF-amplitude which is caused by the thermal sensitivity of the capacitive measuring of the Dee-voltage. These instabilities lie in the order of 10^{-3}. Strong and rapid fluctuations of the analyzed beam current occur which are disadvantageous for most experiments as well as the operator.

In order to overcome these difficulties an electronic feedback system between the monochromator and the cyclotron has been developed [6]. Therewith the stability of the cyclotron beam is directly controlled by the monochromator system which has a time stability of better than $5 \cdot 10^{-6}$. The principle of this regulating system is very similar to the principle of the standard regulating systems of Van de Graaff accelerators. The beam is focused through a narrow entrance slit of the monochromator after the extraction out of the cyclotron. The intensity distribution at the analyzing slit directly corresponds to the energy spectrum of the primary cyclotron beam. A characteristic information of this distribution is the left-right asymmetry of the slit-jaw currents. The asymmetry signal which yields an optimum transmission through the analyzing slit depends on the tuning of the cyclotron. Due to the unique correlation between asymmetry signal and RF-amplitude it is possible to install a feedback circuit which regulates the asymmetry and therewith the RF-amplitude. Thereby the "hot spot" of the beam is precisely fixed between the jaws of the analyzing slit. The electronic fine adjustment of the RF-amplitude yields a stability of better than $1 \cdot 10^{-4}$. Energy instabilities which are caused by frequency (resp. magnetic field) instabilities in the order of $\pm 0.5 \cdot 10^{-4}$ are also well compensated. The regulation speed is high enough so that fluctuations in the order 50 Hz can easily be cancelled.

The result of the regulating system is an analyzed beam current constancy of better than 5%. Additionally the analyzed beam current is permanently kept to its maximum value, that means a real gain of integral beam intensity. A further advantage is the simplified operating and the instantaneous coming back after an RF-interruption. The regulating system can also be used in connection with an automatic energy variation of the beam.

Direct Measuring of the Analyzed Beam Resolution

In order to measure the width as well as the shape of the beam energy spectrum after a monochromator system a direct and rapid method has been developed. Details of this method will be published in a forthcoming paper [7]. An extremely high analyzing power of more than 50000 can be achieved with moderately dispersive magnetic systems by an extremely narrow ($\sim$ 10 μm) collimation with entrance- and analyzing slits. For the test measurements a split-pole spectrograph (Enge-tpye) has been used as magnetic system. In order to discriminate against slit-scattered particles a silicon detector with a good energy resolution is used as beam current meter behind the analyzing slit in the focal plane. A homogeneous scanning of the beam to be analyzed is achieved with steering units. It has been found that the high resolution mode of the antisymmetric double monochromator [5] yields an energy resolution of $E/\Delta E(\mathrm{fwhm}) = 14400 \pm 500$ with a triangular shape of the spectrum.

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