INITIAL OPERATION OF THE RECONSTRUCTED UPPSALA SYNCHROCYCLOTRON

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Abstract.The 185 MeV Gustaf Werner synchrocyclotron has been converted to a variable energy, multi-particle, sector focussed cyclotron and is now in operation with external beam. At present the cyclotron operates in a constant frequency, isochronous mode in which protons can be accelerated to a maximum of 110 MeV while heavier ions can reach 200 Q^2/A MeV. The first extracted beam was obtained at the end of May 1987 and the first nuclear physics experiments with protons and alpha-particles were made in November 1987. With the presently installed internal PIG ion source and central region, first and second harmonic acceleration can be used. Internal alpha beams of 100 microampere and pulsed proton beams with peak intensity of more than one milliampere can be produced with the internal source. So far the extracted beam has been limited to 10 micro-ampere. The operation of the cyclotron in a frequency modulated mode is foreseen to start in the second half of 1988.

Introduction

The Gustaf Werner synchrocyclotron has been reconstructed from a classical synchrocyclotron with cylindrical poles to a sector focussed cyclotron which can be operated both in a constant frequency, isochronous mode and in a frequency modulated, synchrocyclotron mode[1],[2]. The cyclotron is one of three accelerators at the recently established swedish accelerator centre called the The Svedberg Laboratory(TSL)[3].

The synchrocyclotron was shut down in 1977 when funds were available to start the reconstruction programme for the cyclotron and to build the new experimental areas. The programme for the cyclotron comprised a complete rebuilding of all parts: the installation of a three sector pole geometry and trim coils, a new vacuum chamber, a new central region with a PIG ion source, an extraction system with electrostatic and magnetic channels and an rf-system capable of operating at fixed frequency with a high Q-value on the resonators and with modulated frequency with up to 10 % bandwidth.

After model measurements on a 1:4 scale model and field shimming on the full scale magnet the field measuring programme was finished in the spring 1985 when the final field maps were made. Power tests with the first rf-system started in June 1984 with the dee in an airfilled test chamber. The installation of the new vacuum chamber and the rf liners started in July 1985. In December 1985 high-vacuum pumping began and in January 1986 the first rf-system was installed in the vacuum chamber and rf power tests with vacuum started. After the installation and testing of the ion source and the rf control system the first internal beam was accelerated on November 6, 1986. By the completion of the extraction system the beam could be extracted for the first time on May 29, 1987.

Cyclotron characteristics

Fig. 1 shows the basic characteristics of the beams for the rf frequency range 24-12 MHz, harmonics 1 to 4. The number of acceleration turns, required to reach the full energy, is around 2400 when accelerating on rf harmonic 1 and around 600 when accelerating on rf harmonic 2.

Operating results

After the first successful extraction, a test period of about two months was used to tune the beam and to optimize the extraction process. A $^4He^{2+}$ beam of 110 MeV accelerated on harmonic 2 and a proton beam of 72 MeV accelerated on harmonic 1 were used. The measured optimum transmission through the electrostatic channel was found to be over 80 % in both modes and the total extraction efficiency about 65 %. After installation of a pair of slits on the first and second turn on the harmonic 1 orbit at the centre of the cyclotron the transmission through the electrostatic deflector increased to close to 100% (No detectable beam losses measured with internal beam probes, remaining uncertainty due to secondary electrons) and the total extraction efficiency increased to over 80 %.

For tuning the cyclotron to a new particle energy, precalculated trimcoil settings are used. These are calculated using field data measured at five field levels. Linear interpolation between the fields is used. As a consequence very small trimming in the settings was required for field levels close to the measured ones, while somewhat more trimming was required for interpolated fields to get a proper phase behaviour. It is foreseen to use a higher order interpolation in the future to improve on this point.

The beam emittance has been measured at the exit of the cyclotron by means of a movable slit and a multiwire probe and found to be 9π mm-mrad full width in both planes on rf harmonic 1. The energy spread was measured on a 50 MeV proton beam by means of a solid state detector.With correct tuning of the cyclotron the measured Δ W/W is 2.10^{-3} FWHM. A slight mistuning of the cyclotron can cause an increase of this value, for example if parts of two precessional cycles are extracted simultaneously. The table 1 presents a list of all particles end energies tested so far and available on targets. To obtain new intermediate energies in general only a few hours are required for finding the correct setting of the rf-system and to optimize the extraction process.

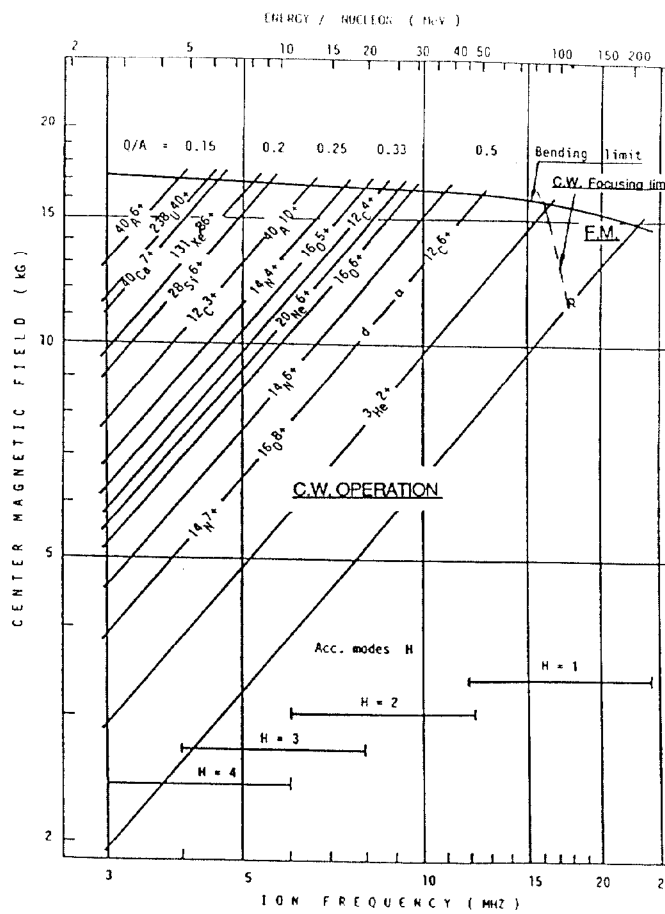

Fig. 1. Energy per nucleon, centre magnetic field and ion frequencies for some ions.

Table 1

Ion	Energy(MeV)	Current (max. extr.)
p+	50, 60,72,100,105	10 μA
$^4He^{2+}$	50, 68,75,113, 120, 185	2 eμA
$^{12}C^{4+}$	155	200 enA

Internal $^4He^{2+}$ currents of 100 eμA have been accelerated, limitation in radius beeing the beam power on the measuring probes. With the ion source operating in a pulsed mode, peak currents of 700 μA have been extracted.

Planned external sources

An external heavy-ion source of ECR type is under construction for the cyclotron. The source is of similar construction as the room temperature ECR source at the superconducting cyclotron at NSCL, East Lansing, USA. In addition there is planned an external source for polarizes protons and deuterons. The source is specified to deliver beams with up to 20 keV energy with intensities up to 50 μA within an emittance of 55 mm mrad[MeV]$^{1/2}$ and with polarization higher than 75% of the theoretical values.

Both sources will be placed in a separate room adjacent to the cyclotron vault with a common beam transport system including the vertical injection line to the center of the cyclotron. The construction of the ECR is carried out in Jyväskylä, Finland and the source will be delivered to Uppsala by mid 1989. The polarized source is beeing purchased commercially and the delivery and installation are expected during 1990.

Experimental facilities

Fig. 2 shows a view of the entire experimental area to be used for cyclotron experiments. A specification of the beam lines connected to separate experimental halls is given in Table 2. Each beam line contains scanners and/or viewers to be used for beam diagnostics and Faraday cups which can be inserted at strategic positions along the beam lines to enable beam blocking and control of beam intensity.

Heavy radiation shielding between the halls permits access to halls adjacent to beam holding areas.

Table 2

Beam line	Area	Activity
A	Crypt	Irradiation Facilities
B	Marble Room Blue Hall	Neutron Production, Switchyard Spectrometer Physics
C	Beam corridor	Beam Transport, Bio-Medical Experiments
D	Blue Hall	Spectrometer Physics
E	Beam Dump	Irradiation Facility
F	Beam corridor, Gamma Cave, CELSIUS Hall	Injection Line for CELSIUS
G	Bio-Medical Hall	Bio-Medical Experiments
H	Bio-Medical Hall	Bio-Medical Experiments
I	Gamma Cave	Heavy-Ion Experiments
K	Gamma Cave	Heavy-Ion Experiments
L	Gamma Cave	Heavy-Ion Experiments

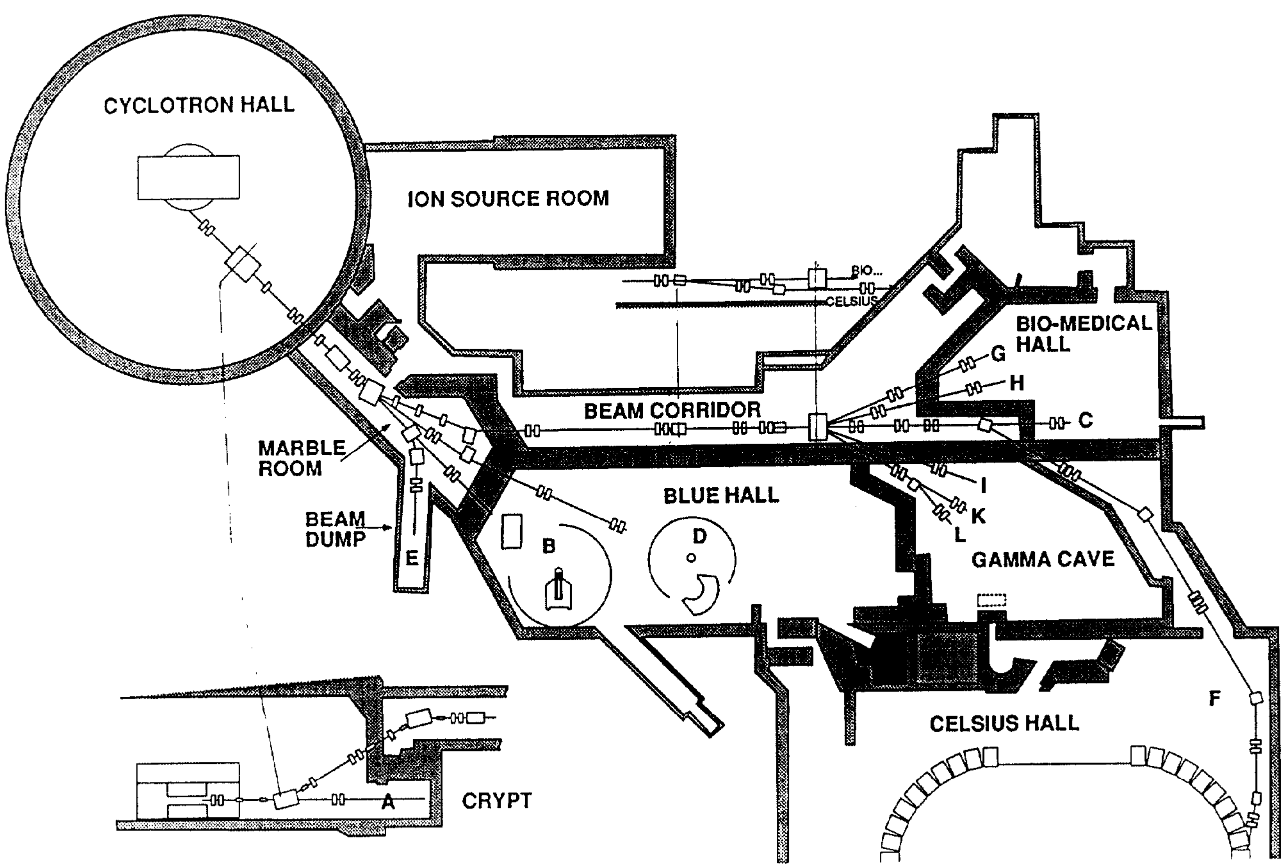

Fig. 2. View of the experimental areas

Monoenergetic neutron beam facility.

The monoenergetic neutron-beam facility is designed to operate in the neutron energy range 50-200 MeV. It uses the $^7Li(p,n)^7Be$ reaction with thin, 0.1 - 0.2 g/cm^2,isotopically enriched lithium metal targets. The facility is placed in the Marble Room(Fig.2).

The most prominent features of the facility is the very good shielding between the beam dump and the experimental area and the high intensity in the neutron beam. At a neutron energy of 100 MeV, with a proton beam current of 10 μA and a target thickness of 0.1 g/cm^2, corresponding to an energy loss of 0.7 MeV, the estimated neutron flux on an 8 cm diameter(n,p) target is 1.3 x 10^6 neutrons/s. At 185 MeV the flux is 2.5 x 10^6, calculated in a similar way.

Beam lines for heavy-ion reaction studies.

The Gamma-Cave is planned mainly for low-background heavy ion studies. Therefore, only very low intensity ion beams, tens of nA, are allowed for induced activity reasons. The two beam lines I and K in the cave are now taken into operation for experiments. Two large concrete beam dumps, movable by air cushioning, and with hollow cylinders for shielding the Faraday cups, are available.

Beam lines for biomedical experiments.

The present program for biomedical experiments at TSL can be regarded as a continuation of earlier experiments conducted between 1956 and 1977 with the old synchrocyclotron. Three beam lines will be used for biological experiments and clinical tests with proton or other ion beams. One beam line (C) is dedicated for biological experiments, while the two other lines(G and H) are used for proton therapy of tumours. The G line is for narrow beams and the H line for broad beams. A control room is common for the three beam lines. Beam tests at the narrow beam unit started in February 1988.

Charged particle spectrometers.

Three different magnet spectrometers are available for experiments in the Blue hall.

1) High resolution pair spectrometer(PACMAN) for high-energy gamma ray detection.

The analyzing magnet has a clamshell type configuration for the pole pieces, which generates a field in the median plane of the form B(y) =const.$\cdot$y^{-n}. The value of n is chosen slightly larger than 1 in order to compensate for fringe field defocusing effects.

The determination of the trajectories of the positron-electron pair is accomplished by x- and z-plane drift chambers located outside the magnetic field. The experimental program around this spectrometer has started.

Characteristics:

Magnet:	Pole area:220x70 cm^2 Pole gap: Vertical 14 cm front end and 38 cm back end Weight: 45 tons, movable on air pads
Angular range:	25^o - 155^o
Solid angle:	70 msr
Maximum momentum:	200 MeV/c for one trajectory, i.e. 400 MeV gammas can be analysed
Overall acceptance:	$5\cdot10^{-4}$ for a 150 MeV gamma and a 0.1 mm Au converter
Energy resolution	0.5 MeV(FWHM)
Drift chambers:	Type: Graded field Number of chambers: 6 Size: 192x960 mm^2 Number of cells: 8 + 40 Cell length: 24 mm Sense wires: Double,with nylon bridges Gas:50% argon, 50% ethane
Trigger:	Any combination of 16 scintillators

2) Magnetic spectrometer(HESM)

This is an upgraded magnetic spectrometer earlier used at the laboratory. The magnet is a dipole with the following characteristics:

Bending radius	1.35 m
Bending angle:	135^o
d1 and d2:	1.35 m and 0.91 m
∂ and ß	49^o and 51^o
Maximum rigidity:	2.9 Tm
Angular acceptance:	2.0^o
Solid angle:	1 msr
Magnification:	0.8 (horisontal)
Dispersion:	4.8 cm/%Δp/p (perpendicular to central ray) 9.6 cm/%Δp/p (along focal plane)
Momentum resolution:	6000 (for 1 mm target spot)
Energy resolution:	60 keV (at a proton energy of 200 MeV)

The magnet will be equipped with remotely controlled arrangements for changing the angle, changing the field, reading the angular setting and measuring the field. There will be possibilities to mount focal plane detectors; probably these will vary with the actual experimental project.

3) Spectrometer with large momentum and angular acceptance(LISA)

The magnetic spectrometer has been constructed with the initial aim of being used in the study of (n,p) reactions. Scattering angle definition and momentum analysis of the emitted particles are performed in a uniform-field magnet equipped with drift chambers for ray tracing. The experimental program around this spectrometer has sterted.

Characteristics:

Magnet:	Pole area: 90 x 120 cm^2 Pole gap: 14 cm Weight: 40 tons movable on air pads. Dispersion: 12 mm/% Δp/p	
Angular range:	10^o	for one geometry and
Momentum bite:	15%	one magnet-field setting
Position detectors:	2 drift chambers before magnet 2 drift chambers after magnet	
Trigger:	Scintillator telescope	

References

[1] S. Holm and A.Johansson, Proc. 10th Int. Conf. on Cyclotrons and their Applications, East Lansing, Michigan, 30 April - 3 May 1984, p. 598

[2] S. Holm, A. Johansson, D. Reistad and S. Kullander, New Accelerators in Uppsala, Physica Scripta. Vol. 34, 513-532, 1986

[3] S. Holm and D. Reistad, Proc. 11th Int. Conf. on Cyclotrons and their Applications, Tokyo, Japan, October 13-17 1986, p. 80