NEW PRIORITIES AND DEVELOPMENTS AT NAC

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Abstract

The facilities at the National Accelerator Centre (NAC) are utilized for proton and neutron therapy, the production of radioisotopes and for nuclear physics experiments. This implies an operating schedule with nine energy changes per week. Mainly due to this the reliability of beam delivery deteriorated to such an extent that we recently had to revert to a beam schedule with only four energy changes per week. This necessitated redefinition of the priorities for our proton therapy program. The request for higher proton beam currents at 66 MeV, for radioisotope production, stimulated the design of dedicated flat-top systems for both the light-ion injector cyclotron (SPC1) and the separated-sector cyclotron (SSC). We also investigated the feasibility of accelerating high-intensity proton beams (500μA) in the SSC by using the high-intensity space-charge mode developed at PSI. The design of a vertical beamline and modifications to the existing beam transport system for the new high-intensity target station are in progress. Further developments include an additional septum magnet for the SSC extraction system and a new Local Area Network computer-control system for the RF systems. The progress with these projects will be presented and the status of the facilities discussed.

1 INTRODUCTION

The NAC cyclotron facilities [1] include two solid-pole injector cyclotrons (SPC1 and SPC2) and a k=200 MeV SSC providing light and heavy ion beams to support the multi- and inter-disciplinary research program of the laboratory. The k=8 MeV injector SPC1 has an internal source for light ions and routinely pre-accelerates proton beams for radiotherapy and radioisotope production. SPC2 is similar to SPC1, but uses axial beam injection from external sources for heavy ions (ECR source) and polarized protons serving nuclear physics experiments. SPC2 can also be utilized for the therapy applications instead of SPC1. This cyclotron configuration is very versatile in providing beams with different properties but complex to operate and maintain.

2 CYCLOTRON OPERATION

The weekly operating schedule from August 1996 to October 2000 included four proton therapy sessions at 200 MeV, three neutron therapy sessions with 66 MeV proton beams and four sessions of radioisotope production at the same energy. Nuclear physics experiments with light and heavy ions as well as polarized proton beams are scheduled for the weekends. This schedule necessitates nine energy changes per week. The average time per energy change between 66 MeV and 200 MeV is 2.4 hours. The average time for setting up a nuclear physics beam is 5.1 hours. The operating statistics in table 1 show a steady increase in equipment failures from 6.9% to 14.5% of scheduled time during the period from 1996, when the schedule with nine energy changes per week was introduced, to the year 2000. This was expected since a large number of mechanical components such as short-circuit plates, coupling and trimmer capacitors, slits and the variable transformers of power supplies have to be adjusted during energy changes. Analysis of the operational statistics shows a clear correlation between beam interruptions and the number of energy changes. Time lost due to equipment failures during energy changes are about double that for normal running conditions. The main contributions are from faulty operation of RF systems followed by magnet power supplies and vacuum equipment. Further reasons for the steady increase of down-time are the ageing of equipment and the constant decline in the number of experienced staff.

Table 1: Distribution of scheduled beam time per calendar year for the past 5 years

Year	**1996**	**1997**	**1998**	**1999**	**2000**
Scheduled time as percentage of calendar time (%)	89.1	87.5	88.6	87.7	80.0
Scheduled time (hours)	7829	7663	7761	7682	7034
Number of 8 hour shifts with beam on target (per month)	63.7	61.7	61.1	63.1	53.5
Interruptions due to equipment failures (%)	6.9	9.6	7.1	10.0	14.5
Interruptions due to electrical supply failures (%)	2.0	1.0	2.6	0.8	0.9
Beam development (%)	3.0	0.8	1.3	0.0	1.01
Energy changes (%)	9.3	11.1	13.2	10.0	9.4
Beam tuning (%)	0.6	0.2	0.2	0.4	1.1
Beam available (%)	78.2	77.3	75.6	78.8	73.1
Total (%)	100	100	100	100	100

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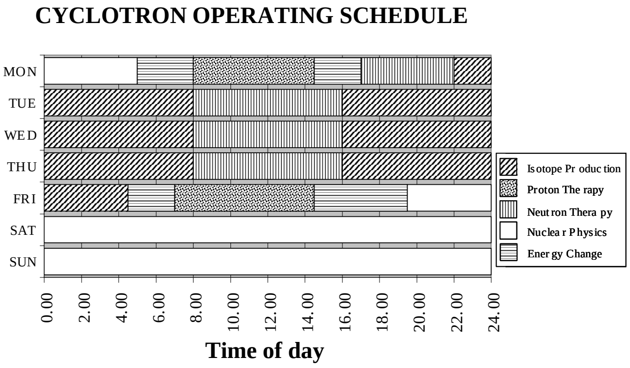

Figure 1: Present weekly cyclotron operating schedule.

It became difficult to maintain the proton therapy program since the available beam time dropped below 90% of the scheduled time. To curb further deterioration of beam delivery the number of energy changes will in future be limited to four, as shown in figure 1. With this schedule it is, however, not possible to continue with fully fractionated proton therapy.

3 SPC1 and SSC FLAT-TOP SYSTEMS

To improve the intensity and quality of the 66 MeV proton beam for production of radioisotopes and neutron therapy, fixed-frequency flat-top systems are being designed for SPC1 and the SSC [2]. At this energy the RF systems of both machines operate at a frequency of 16.37 MHz. Previously an experimental 5th harmonic flat-top system, using the existing main resonators of SPC1 over the frequency range from 16.37 to 26 MHz, which corresponds to the energy range of 3.15 MeV to 8 MeV for SPC1, was tested [2]. Double the previously extracted beam current from SPC1 could be obtained. This system is now being modified to operate at a fixed frequency of five times the fundamental frequency of 16.37 MHz, at which the high-intensity proton beam is accelerated. The additional transmission lines and amplifiers, which can now be considerably simplified, are at present being redesigned and will be installed later this year. A single half-wave resonator [2] will be installed in one of the valley vacuum chambers of the SSC and should allow extraction of 66 MeV proton beams with intensities of up to 500 μA. The calculated power consumption at the required dee voltage of 62 kV is 5.1 kW. A half-scale model, shown in fig 2, was built to verify the calculations, which were done with the program SOPRANO.

Table 2: Calculated and measured results for the full and half scale SSC resonator model

FLATTOP RESONATOR	CALCULATED		MEASURED
	Full scale	Half scale	Half scale
Frequency MHz	49.1	99.57	99.7
Q-value	9500	14000	4000
Sector angle	16.5º	16.5º	16.5º
Height mm	545	230	230
Maximum width	1162	613	613
Length mm	3024	1508	1508
Acceleration gap mm	60 – 100	30 – 50	30 - 50

Figure 2: Half scale model of the horizontal half wave resonator for the SSC

The radial voltage distribution, shown in figure 3, resonance frequencies and the Q-value were calculated and measured. The dimensions of the coupling and trimmer loops were finalised. Table 2 shows some of these results.

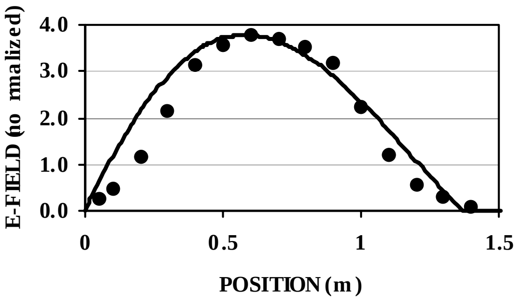

Figure 3: The calculated and measured voltage distributions along an acceleration gap of the SSC resonator model are shown by the solid line and points, respectively.

4 MODIFICATIONS TO THE HIGH-ENERGY BEAMLINE

4.1 High-intensity beamstop

To facilitate optimisation of the SCC extraction efficiency for high-intensity 66 MeV proton beams, a 50 kW beamstop is being designed and will be installed in the high-energy beamline close to the SSC during next year. In order to minimise exposure of staff to radiation during service periods and repair work, facilities for quick removal and shielded storage of the beamstop are incorporated in the design.

4.2 Matching the beam to the vertical target station

A new target station for radioisotope production with the 66 MeV high-intensity proton beam is being designed. The target will be located in an existing vault below floor level and will be installed without disrupting the current isotope-production program. In order to match the horizontal beam emittance, which is a factor 5 larger than the vertical emittance, to the 90 degree vertical bending magnet, the vertical and horizontal phase spaces will be rotated by 90 degrees with five quadrupoles, which will be rotated through 45 degrees with respect to the normal orientation used for beam focusing only.

5 HIGH-INTENSITY MODE BEAMS

The possibility of operating the SSC in the high-intensity space-charge mode, developed at the Paul Scherrer Institute (PSI) in Switzerland [3], was investigated. Calculations performed at PSI showed that operation in this mode is possible for the SSC with a 500 μA proton beam injected at 3.15 MeV, provided that the beam can be sufficiently bunched at injection. The required bunch length is 6 RF degrees, compared to the present bunch length of 8 to 9 RF degrees at lower beam intensity. Figure 4 shows the calculated charge distributions of beam pulses for a 500 μA proton beam at various turn numbers inside the SSC. Due to space-charge forces the beam pulses spiral to a spherical charge distribution within 14 turns, after which there is no further change in the beam width up to extraction. An initial bunch length of 25 mm, which corresponds to 6 RF degrees, as well as a bunch height and width of 4 mm and 6 mm, respectively, were assumed for the calculation.

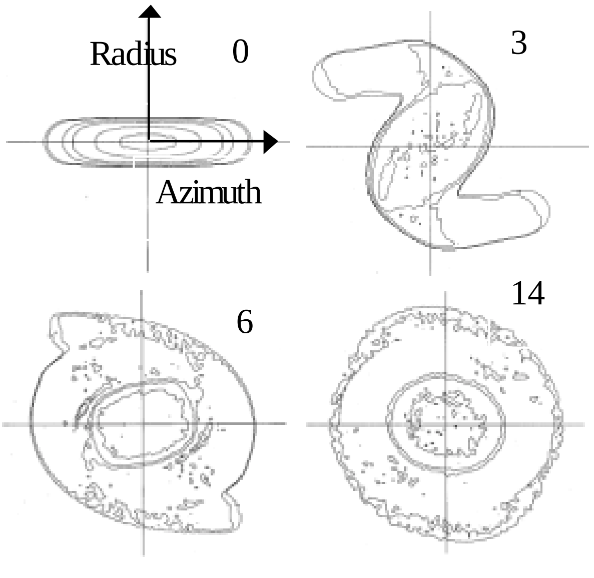

Figure 4: The shape of beam pulses at various turns in the SSC for a 500μA proton beam.

6 DOUBLE DRIFT BUNCHER FOR SPC2

A buncher operating at the second harmonic has been installed in the injection beamline before SPC2 with the aim of obtaining higher beam intensities. The new buncher, in conjunction with the existing buncher, which operates at the fundamental frequency, forms a double drift buncher system. During initial tests an increase of 25% in the beam intensity at injection was obtained, which is in agreement with the calculated value.

7 THE CONTROL SYSTEMS

The existing accelerator control system consists of a local area network of personnel computers running with OS/2 operating systems, an SQL Server database and locally developed data distribution system. This system is now being extended to operate with Microsoft Win32 operating systems and with enhancements being added to the data distribution system, various Windows programming languages (Visual Basic, Visual C++, Delphi) can now be used on the system. A Java interface was also recently added and developments are taking place on a new neutron therapy control program that uses TCP/IP socket based client/server programming and a beam orbit plotting program that makes use of multi tier Java technology. The SPC2 RF system is now also integrated into the control system. A user interface, written in Visual Basic, is the principal method of control. Posts for six new software developers were created at the beginning of this year and with the increased manpower the latest technologies including JAVA, XML, CORBA and other operating systems like LINUX and LYNXOS can be incorporated in the control system.

8 FUTURE PLANS

Fully fractionated proton therapy at NAC requires four treatments per week, over a period of up to six weeks per patient, which is at present difficult to achieve in conjunction with the beam requirements for neutron therapy, production of radioisotopes and nuclear physics experiments. The acquisition of a dedicated 200 to 250 MeV cyclotron is now being considered. Two new treatment vaults and the already planned second proton therapy station [4] would be required to supplement the existing horizontal beam facility. These facilities could also be used to establish advanced beam scanning methods as well as to considerably increase the numbers of patients treated. This project would only be viable if a suitable commercial partner could be found.

9 REFERENCES

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