PRESENT STATUS AND NEW DEVELOPMENTS AT NAC

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Abstract

The present status and operation of the multi-disciplinary cyclotron facilities at NAC are presented. Recent developments to implement a more versatile system for beam extraction from the separated-sector cyclotron (SSC), to facilitate non-destructive measuring of beam properties and to integrate the old rf-control software into the present distributed computer control system are described. To comply with the increasing demand for higher beam intensities for the production of radio-nuclides with 66 MeV protons, a dedicated rf flat-top system for both the light-ion injector cyclotron and the SSC is proposed and reviewed.

INTRODUCTION

The NAC cyclotron facilities [1] feature 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 programme of the laboratory. The k=8 MeV injector SPC1 has an internal source for light ions and routinely pre-accelerates proton beams for radio-therapy and radio-nuclide production. SPC2 is similar to SPC1, but it makes use of axial beam injection from external sources for heavy ions (ECR) or polarized protons serving nuclear physics experiments. SPC2 can also stand in for the therapy applications of SPC1. Such a cyclotron configuration is extremely versatile in providing and utilising beams with vastly different properties, but consequently the facilities are also very complex to operate and maintain. This poses a serious problem now as resources become increasingly scarce, and impacts negatively on beam delivery.

1 CYCLOTRON OPERATION

Over the last four years nine energy changes each week have been employed which require an extremely tight beam schedule. Beams are provided for proton therapy at 200 MeV on 4 days per week, for neutron therapy as well as isotope production with 66 MeV protons on 3 days and 4 nights per week, and for nuclear physics research over weekends. Beam-time for each application is severely restricted and the 66 MeV proton beam is switched between neutron therapy and radio-nuclide production. Such a crowded schedule is unique for a facility like the NAC cyclotron configuration and makes excessive demands on our technical and human resources. To prevent a further deterioration of beam delivery the present schedule will soon be modified to four energy changes per week as is illustrated in figure 1.

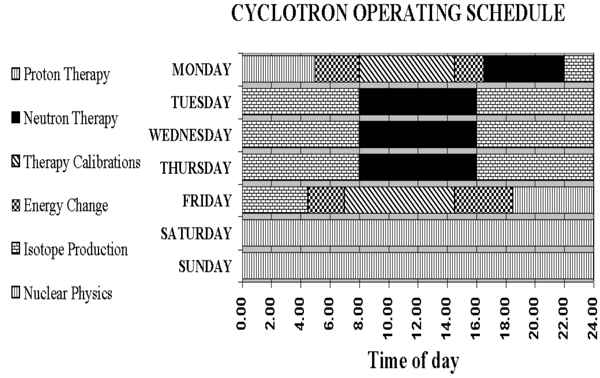

Figure 1: The modified weekly beam schedule.

During the past year 7682 hours (87.7% of calendar time) were scheduled for beam of which 78.8% were delivered on target. Heavy ions accelerated the last 12 months were 5.7 MeV/A ^{27}Al, 6 MeV/A ^{20}Ne, 33.3 MeV/A ^{12}C, 5 MeV/A ^{28}Si and 5.7 MeV/A ^{127}I. A polarization of 70 to 80% was achieved for polarized proton beams with beam currents ranging from 150 nA to 200nA on target.

2 SSC BEAM EXTRACTION

At present beam extraction from the SSC makes only use of two septum magnets (SPM1 and SPM2), and a centering error of the orbits which can be adjusted to obtain the required beam separation at the entrance of SPM1. For the 66 MeV proton beam the orbit separation is then limited to about 40 mm and can provide single turn extraction up to a beam intensity of ~200 μA. For higher beam intensities it would be advantageous to make use of an electrostatic deflector (EEC) as the first extraction component, because it has a very thin (0.2mm) septum. Such an EEC is already available but it cannot be used effectively without an additional septum magnet

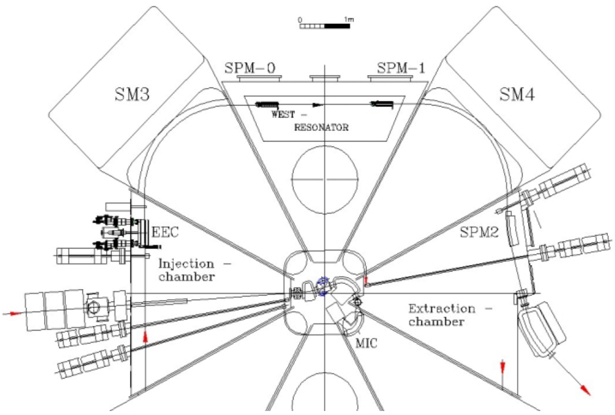

Figure 2: The proposed extraction system.

(SPM0) as shown in figure 2. SPM0 and a modified SPM1 with a new drive system have been installed in the west resonator at the beginning of the year. The EEC is being modified at present to provide the larger width required for higher beam intensities and will be installed as soon as it is tested. The new extraction system should benefit the 200 MeV proton beam as well.

3 SPC1 FLAT-TOP

For a final energy of 66 MeV, SPC1 produces a 3.15 MeV proton beam at a frequency of 16.37 MHz with an intensity of about 300 μA after extraction. A 5th harmonic flat-top system has previously [2] been investigated using the existing main resonators of SPC1 over the frequency range from 16 to 26 MHz (energy range of 3.15 to 8 MeV for SPC1). The maximum beam current extracted from SPC1 was doubled at 16.37 MHz. Using a fixed frequency flat-top system which is only necessary for the high intensity radio-nuclide production beam will simplify the operational requirements considerably. The additional transmission line and amplifiers were redesigned and we plan to install them by the end of the year.

4 SSC FLAT-TOP

To improve the intensity and quality of the 66 MeV proton beam for the production of radio-nuclides and neutron therapy, a fixed-frequency flat-top resonator was being investigated [3]. The design of a flat-top resonator which can be installed in one of the valley vacuum chambers is underway and should allow the extraction of beam intensities of up to 500 μA. A full-scale model will be built in the near future to test the calculations, RF amplifiers and coupling system. If the test results compare well with the expected values, the full scale model will be adapted to be used as the final resonator.

5 HIGH-INTENSITY MODE BEAMS

The possibility to operate the SSC in the high intensity space-charge mode which was successfully developed at the Paul Scherrer Institute (PSI) in Switzerland [4], has been investigated. Calculations performed at PSI showed that operation in this mode is in principle possible with a 500 μA proton beam injected at 3.15 MeV, provided that the beam can be sufficiently bunched at injection into the SSC. The bunch length required is 6 RF degrees, compared to the present bunch length of 8 to 9 RF degrees at lower intensity.

Figure 3 depicts the charge distribution of a bunch of protons which represents such a 500 μA beam at various turn numbers inside the cyclotron. The results show the spiralling of the beam bunch due to space charge forces towards a spherical charge distribution within 14 turns. The initial lenght of the beam is 25 mm and it is 4 mm high, 6 mm wide and has a starting phase width of 6 RF degrees. The beam does not change its shape from the 14th turn to the last one before extraction. An extensive study of space charge effects in the transfer beamline and near injection into the SSC is in progress.

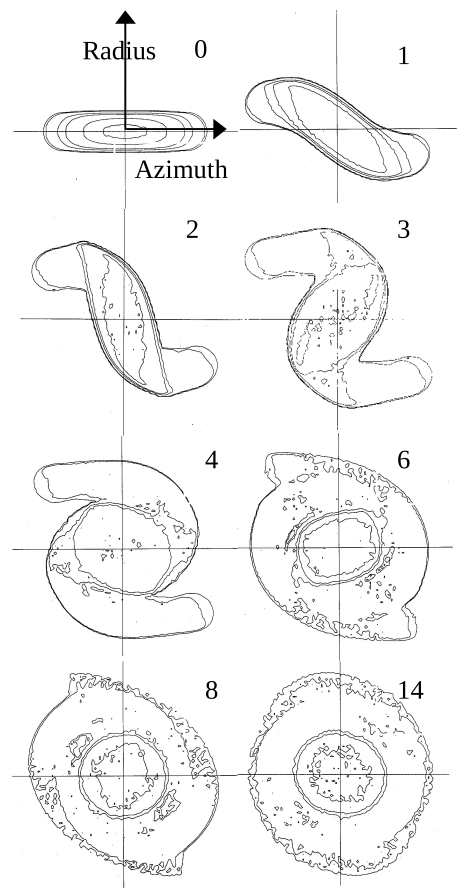

Figure 3: The shape of a 6 mm wide and 4 mm high 500μA beam in the SSC at various turns.

6 THE RF CONTROL SYSTEMS

All the RF control systems are currently running on old CP/M computers. A start has been made to transfer the control to more modern PC systems. Figure 4 shows the user interface to control the SPC2 RF-system. A PC-

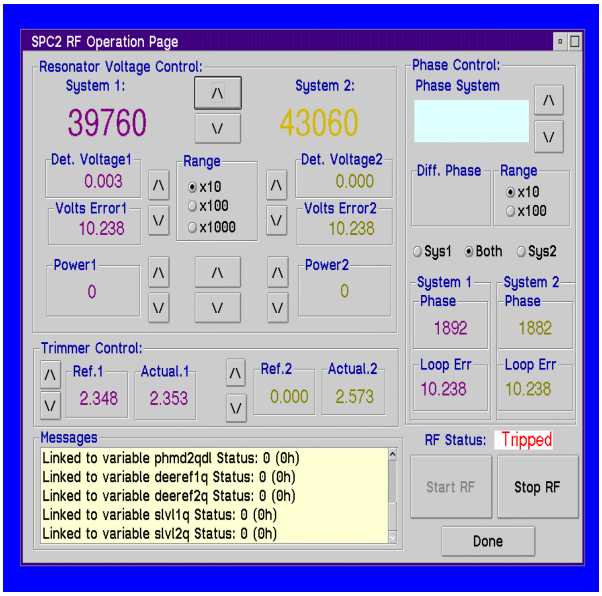

Figure 4: The RF control page for SPC2.

computer controls the hardware components of the RF system that generate, amplify, phase shift and distribute the RF-signal and handle time dependent processes by communicating with the hardware through the SABUS and CAMAC crates. This computer, the local computer, can be accessed by all other computers (console computers) on the LAN [5].

7 NON DESTRUCTIVE BEAM POSITION MEASUREMENTS

To monitor the beam position of the 100 μA 66 MeV proton beam currently used for radio-nuclide production and the 35 μA beam for neutron therapy in real time we plan to use a number of non-destructive beam profile monitors. A beam profile monitor which consists of four segments was built and is in the process of being tested. To determine the beam position from the signals of the four segments we plan to use the system that was developed at IUCF[6].

8 CONCLUSION AND FUTURE PLANS

After more than thirteen years of successful operation, the NAC cyclotron facilities are now showing signs of increasing equipment fatique which in combination with an excruciating beam schedule and an acute shortage of resources is leading to a deteriorating reliability of beam delivery. The main problem can be related to the high number of energy changes required to serve the demanding different research programmes, in particular the challenges posed by clinical research with fractionated proton therapy which we were able to support with an extraordinary effort of nine energy changes per week since August 1996. In an attempt to alleviate the stress on the cyclotrons and personnel, a less strenuous beam schedule will be introduced in the second half of this year, but there is no guarantee that such a measure is sufficient in the long run.

Since fully fractionated radio-therapy requires a least four treatments per week, over a period up to six weeks per patient, a competitive clinical proton therapy programme is only viable with a dedicated 200 to 250 MeV proton accelerator, preferable a cyclotron. We are now investigating such a project proposal to find a suitable commercial partner. This project would include further treatment facilities like the planned second proton therapy station [7] to supplement the existing horizontal beam facility and could be used to establish advanced beam scanning methods as well as to increase patient numbers considerably.

At the same time, the number of energy changes for the existing cyclotron facilities could be reduced to two per week and much more beam time would become available for neutron therapy and the production of radio-nuclides. Together with the expected increase in intensity of the 66 MeV proton beam, this would provide the prospect of a vastly improved cost recovery for the laboratory.

REFERENCES

[1] H. N Jungwirth et al, Progress with New Beams and Facilities at NAC, Proc. of the 15th Int. Conf. on Cyclotrons and their Applications, (IOP Publishing, London, 1999), p 625.

[2] J. L. Conradie et al, A Flat-top Acceleration System for the NAC Light Ion Injector Cyclotron, Proc. of the 14th Int. Conf. on Cyclotrons and their Applications, (World Scientific, Singapore, 1996), p 249.

[3] J. L. Conradie et al, A Flat-top System for the NAC Separated-sector Cyclotron, Proc. of the 15th Int. Conf. on Cyclotrons and their Applications, (IOP Publishing, London, 1999), p 215.

[4] S. Adam, Space Charge Effects in Cyclotrons- From Simulations to Insight, Proc. of the 14th Int. Conf. on Cyclotrons and their Applications, (World Scientific, Singapore,1996), p 446.

[5] H. F Weehuizen et al, The New Distributed Control System of the NAC, Proc. of the 13 th Int. Conf. on Cyclotrons and their Applications, (World Scientific, Singapore, 1993), p656.

[6] T.J.P. Ellison, Nondestructive Diagnostics for Measuring the Phase, Position and Intensity, of 15 enA Beams from the IUFS Cyclotron, Proc. of the 11 th Int. Conf. on Cyclotrons and their Applications, (Ionics , Tokyo, 1987), p279.

[7] J.C. Cornell et al, New Beamlines for Proton Therapy at NAC, Proc. of the 15th Int. Conf. on Cyclotrons and their Applications, (IOP Publishing, London, 1999), p 133.