STATUS REPORT ON THE GUSTAV WERNER CYCLOTRON AT TSL, UPPSALA

D. M. van Rooyen[1], B. Gålnander, M. Lindberg, T. Lofnes, T. Peterson, M. Pettersson
The Svedberg Laboratory, Uppsala University, Box 533, S-75121, Uppsala, Sweden.

Abstract

TSL has a long history of producing beams of accelerated particles. The laboratory was restructured in 2005/2006 with nuclear physics phased out, the CELSIUS ring dismantled and the WASA detector moved to Jülich. The focus of activities became thereby shifted towards, mainly, proton therapy and, in addition, testing of radiation effects using protons and neutrons in a beam sharing mode. The increase in demand on (a) beam time, and (b) consequential faster changes between various set-ups, necessitated some minor upgrades. For the same reason our energy measuring system needed to be streamlined. As a consequence of the restructuring, night shifts were phased out. By switching off certain power supplies overnight a substantial energy saving has been accomplished.

INTRODUCTION

The Gustaf Werner cyclotron, completed in the early 1950s as a fixed-energy 185 MeV proton synchro-cyclotron, was converted to a variable-energy multi-purpose sector-focused cyclotron during the 1980s. Since this upgrade the accelerator is operated both as an isochronous cyclotron and as a synchrocyclotron. Further details can be found in Ref. [1],[2,[3].

Currently the principal users are the proton therapy facility of the Uppsala University Hospital and the irradiation facilities at TSL which provides neutrons and proton beams for science and accelerated electronics testing for industry. [4]. Heavy ions are available from an ECR ion source of an older generation (6.4 GHz) which was upgraded in 2002 in collaboration with JYFL [5].

In this paper we discuss the general status of our facility and describe concluded and ongoing improvements, new developments and conclude with some comments regarding TSL's future.

OPERATIONAL STATISTICS

User and User Statistics

As a result of the restructuring of TSL in 2005/2006 proton therapy has become our primary user with, on average, 36 weeks of patient treatment per year. Our main secondary user is the TSL irradiation facility. As reported earlier [3] the beam is shared between the primary and secondary users. In this beam-sharing mode proton therapy has command over the destination of the beam. Whereas patient treatments are of rather short duration, the beam is mostly available for users at the irradiation facility. Naturally there is then a limitation to the beams available to secondary users, namely being 180 MeV protons. Whereas the latter is the highest proton energy reachable with the Gustav Werner accelerator, this is the beam used for proton therapy treatments.

Although varying from year to year, an approximate number of beam time hours delivered to the Blue Hall irradiation facility is ca 1000 hours per year.

Scheduled Beam Time

Since 2006 beam is scheduled weekdays 06:00 – 18:00 compared to 24-hour shifts, 6 days/week, previously. However, in the recent four years, requested beam time has increased to such an extent that some weeks needed to be scheduled to 22:00 / 24:00 and others having a night shift.

Beams of Interest to our Users in Recent Years

The fact that our primary user (proton therapy) determines our beam and energy as 180 MeV protons – and does so for a large part of a year (Figure 1), unfortunately excludes being more versatile and run other energies and particles. It thus became virtually impossible to use our cyclotron to its full potential.

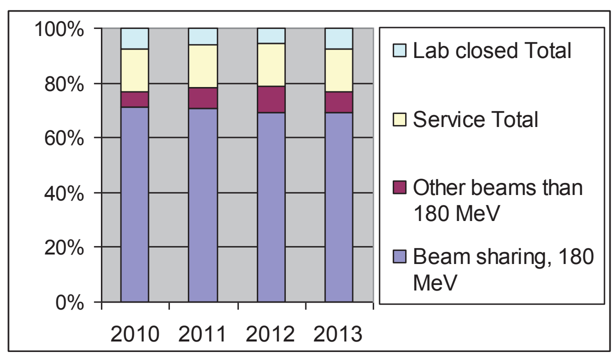

Figure 1: Distribution of total annual hours.

Table 1: Beams of Interest for Current Users other than 180 MeV p

Year	Week number	Mode	Particle	Total energy (MeV)
2010	14	CW	p	25; 50; 100
	19	CW, ECR	Ar9+	400
2011	08	CW	p	25; 50; 80
	15	CW, ECR	C6+; Ar9+	470; 400
	25	CW	p	50; 100
		FM	p	150
	33	CW, ECR	C6+; Ar9+	470; 400

[1] Corresponding author: daniel.vanrooyen@tsl.uu.se

2012	02	CW	p	25, 50, 80
	25	CW	p	38
	51	CW	p	50
		CW, ECR	N7+	546
2013	02	CW, ECR	N7+; Ar9+	546; 400
	25	CW, ECR	Ar9+; Xe27+	400; 1054

Even though the possibilities for lower proton energies and heavy ion beams were rather limited, we still could manage to run several proton beams in the range 25 to 138 MeV, as well as C^{6+}, N^{7+} 39 MeV/nucleon, Ar^{9+} 10 MeV/nucleon and Xe^{27+} 8.3 MeV/nucleon. Details can be found in Table 1.

Beam Time Statistics

Even though the cyclotron is rather old, it is still performing well. Beam statistics for recent years show a not unreasonable loss of beam time due to failures leading to unplanned service (Fig. 2). This has been accomplished by scheduling ample time for preventative maintenance that, in all likelihood, is higher in our case compared to more modern accelerators. Additionally we need to replace the RF vacuum tubes (main stage amplifiers) more often in recent years. The cyclotron is currently mainly run in FM mode where the inherently low duty cycle and beam intensity can only be increased by running at (1) as high Dee voltages as possible, and (2) at an as high repetition rate as possible. Both these latter factors lead to a decrease in the lifetime of the vacuum tube main stage amplifiers and subsequently an increase in service time.

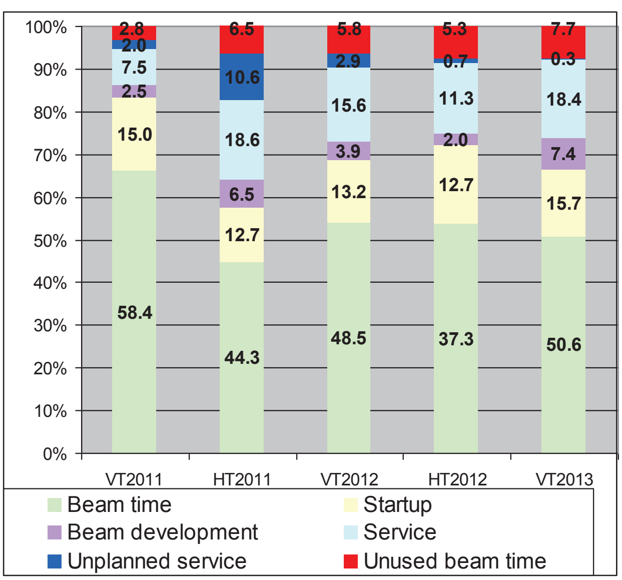

Fig. 2: Beam statistics for the period January 2011 to July 2013.

CYCLOTRON SUBSYSTEMS

The increase in demand on beam time in recent years had as a result a tighter schedule; energy changes and user, beamline or set-up changes needed to be executed much faster. The latter necessitated general improvements and some minor upgrades.

Vacuum

The vacuum system of the cyclotron consists of two 9 000 litre/sec oil diffusion pumps backed by two fore-vacuum systems in parallel. Each fore-vacuum system consists of a rotary vane and two roots fore-vacuum pumps. Along the beam lines 240 litre/sec turbo pumps are mostly used. In 2011 the diffusion pumps were thoroughly cleaned and all seals were replaced for the cyclotron and all beam lines. As a result, the vacuum in the cyclotron improved from ~$5{\cdot}10^{-6}$ mbar to ~$5{\cdot}10^{-7}$ mbar. When running heavy ions an even better vacuum is needed which is accomplished using two Meissner traps allowing a vacuum of ~$2{\cdot}10^{-7}$ mbar to be reached

RF System

In the recent ca four years a program has been executed to document and improve the low voltage part of our RF system. These systems were custom-built in-house and were often not well documented and the designers were not available any more. Even with regards to hardware (resonators, tuning, etc.), the expertise level of personnel has been improved – and therewith also the status of the hardware itself. Some work with regards to the Dee positioning system remains to be done.

Injection and Central Region

The central region was originally designed with only the two Dees remotely positionable relative to the ion source. In 2011 it was decided that a third parameter was needed to be remotely controllable, namely axially positioning the ion source. This upgrade was implemented during the July 2012 service period and is functioning quite satisfactorily. It is of great advantage to have this extra parameter; re-positioning the ion source with only some tenths of a mm gives an increase of beam intensity of up to 100%.

The question has been raised whether a not so good vacuum in the central region can be the cause for the bad transmission of injected heavy ion beams experienced in recent years. This question, and problem, remains as yet unsolved.

Extraction

In general we experience no problems with the extraction system. In August this year a spare electromagnetic channel was tested electrically and is now ready to be installed, should the need arise. It has been a complicated and rather long project reconditioning an old, non-functioning EMC to be operational again.

Diagnostics

New camera system: Instead of harps or scanners, fluorescent viewers are used to diagnose beam characteristics. Due to high radiation levels at certain positions it is advantageous to use Vidicon cameras, which thus still mostly are in use. Being not easily replaceable with spare parts difficult to find, replacement possibilities were investigated. Extensive tests of various CMOS and CCD cameras were done leading to the choice of Eyseo CCD cameras which have replaced certain

ISBN 978-3-95450-128-1

Vidicon cameras. The Vidicon cameras were adapted to output a video signal instead of VHF. A new PLC system controls a number of signals: (a) camera ON/OFF; (b) viewer IN/OUT; (c) feedback as to the physical position of a viewer. The old multiplexer system was replaced by a video matrix switch.

Energy measurements: The method of analyzing the time-of-flight signals have been improved. An automated system has been developed that eliminates subjective analysis of the pulse shape. An, in principal, methodical error has been eliminated.

Control System

The control system functions very reliably. The sophisticated software, that was developed several years ago to enable user controlled beam sharing, functions very well and allows for safe control of the beam. In this respect one must bear in mind that the beam used in the irradiation facility has an intensity of several hundred nA whereas the proton beam used for patient treatment is limited to max. 3.5 nA and that the switching of the beam is done without operator control. Since the implementation of these programs were further developed providing some sophisticated features.

Recently the interface electronics addressing the hardware controlling several of the RF tuning components were upgraded to a more reliable design solving an often occurring problem that communication with such devices became disrupted.

ENERGY CONSIDERATIONS

As mentioned earlier, night shifts have been phased out for most calendar weeks. As can be seen in Figure 3, the major part of our energy consumption is related to the cyclotron main magnet, the next level being beam line bending magnets and the electromagnetic channel (cyclotron extraction region). Studies indicated that a substantial energy saving could be accomplished by switching off certain power supplies overnight. This was done in two phases:

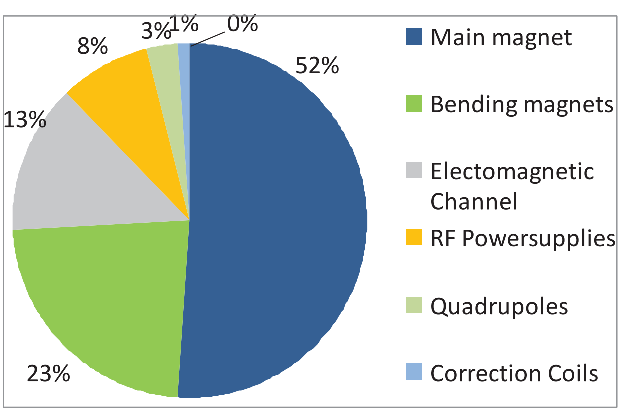

Figure 3: Energy consumption distribution for various parameters.

Phase 1: Since several years ago the cyclotron main magnet, RF powers supplies and extraction elements are set to 0 A (0 V); Phase 2: Based on measurements made in February 2012, it was concluded that all beam elements also can be set to 0 A without influencing the beam transport. A simple cycling procedure is used to ensure repeatability of magnetic fields.

THE FUTURE

In 2015-2016, the proton therapy will move to the newly built Scandion Clinic, a dedicated facility for proton therapy. This situation will open for new possibilities for TSL as a versatile and flexible facility.

The irradiation facilities at TSL, provides accelerated beams for industrial and scientific users for radiation testing and other applications. Today, the choice of beam and energy is restricted to 180 MeV protons during the proton therapy weeks. In the future, however, TSL becomes much more free to provide different beams and energies according to the requests of the users and thus to use the cyclotron to its full capabilities. The amount of beam time for external users will at the same time increase.

However, in order to exploit these new possibilities and to survive in the long run, funding for future operation needs to be solved. At present, there is no governmental financial support for the laboratory and there is clearly a risk of close-down in a few years. TSL is therefore looking for partners/investors who are willing to participate in a long term engagement with the laboratory.

CONCLUSION

The Gustaf Werner dual mode cyclotron-synchrocyclotron is still, in spite of its age, a reliable machine thanks to hard work by a dedicated personnel to keep it well maintained and delivering quality beams. With a highly developed irradiation facility TSL has the potential to continue delivering particle beams to specialized users from all corners of the world. TSL, furthermore, has indeed the potential to expand and accept new challenges. It will be sad if this long and good tradition comes to a premature end.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to K.E.S. Holm, T. Johansen, and O. Jonsson for technical support.

REFERENCES

[1] S. Holm, *Status report on the Gustaf Werner cyclotron in Uppsala*, Proc. 13th Int. Conf. on Cyclotrons and their Applications, Vancouver, Canada, (July 6-10, 1992), 106.

[2] D. Reistad, *Recent developments at the Gustaf Werner Cyclotron and CELSIUS*, Proc. 15th IEEE Particle Accelerator Conference, Washington, DC, USA, (May 1993), 1744.

[3] D.M. van Rooyen *et al.*, Proc. of the 19th International Cyclotron Conference, Lanzhou, China, (Sept. 2010), 84.

[4] http://www.tsl.uu.se/irradiation-facilities-tsl/

[5] D.M. van Rooyen and D. Wessman, *The TSL 6.4 GHz ECR ion source - status, improvements and measurements*, Nukleonika 48, (2003) 99.