NUKLEONIKA 2003;48(Supplement 2):S141–S144

Status report of the PSI high power proton cyclotrons

Martin Humbel,
Stefan Adam,
Anton Mezger

Abstract In addition to its traditional activities, of improving the availability of its 1 megawatt proton beam, the PSI cyclotron department has started two new projects. One of these is a further increase of the accelerated beam intensity towards 3 mA, the other one is a substantial enhancement of the proton therapy facility.

Key words Paul Scherrer Institute • cyclotron • RF-power • extraction channel • proton therapy

M. Humbel✉, S. Adam
Department ABE, High Power Cyclotrons,
Paul Scherrer Institute,
WBGA-C32,
CH-5234 Villigen, PSI, Switzerland,
Tel.: +41 56/ 310 33 93, Fax: +41 56/ 310 33 83,
e-mail: martin.humbel@psi.ch

A. Mezger
Department ABK, Operation,
Paul Scherrer Institute,
CH-5234 Villigen, PSI, Switzerland

Received: 8 November 2002, Accepted: 2 April 2003

Operation

The annularly delivered charge and the average proton current are presented in Fig. 1. As shown there, production of a stable 1.8 mA proton beam at an energy of 590 MeV has become routine at PSI's accelerator system [3]. The availability of the high power beam is about 90% with respect to the scheduled beam time. As a result of continuous efforts in optimising the beam quality and due to appropriate positioning of beam collimators, the operation crew succeeded in keeping beam losses at the excellent low level of previous years. However, tuning experience and results of beam development show that the machine, in its present configuration, has reached its maximum proton beam power, and any significant improvement of beam intensity will require major investments into both accelerators, injector 2 as well as the ring cyclotron.

Nevertheless, the start into this year's beam production period was rather a naughty one. A beam stopper positioned in the ring cyclotron at half the extraction energy most probably has been moved into the running beam. The beam power distorted its positioning arm in such a way, that an edge of the copper block hit the beam path even when the stopper was in its parking position. The operation crew was not discouraged by this fact and did a very skilled job: they quickly found a way to accelerate 1 mA of beam current in such a way, that the beam made a distinct excursion around the damaged stopper position.

Maintenance

While the main effort in the past ten years was directed towards increasing the beam current from 100 to 2000 μA, we are now as well concentrating on stable operation at these high beam intensities. This is due to the fact that the medical activities at PSI are of increasing concern. Dealing with patients is only possible if the system is in a status one

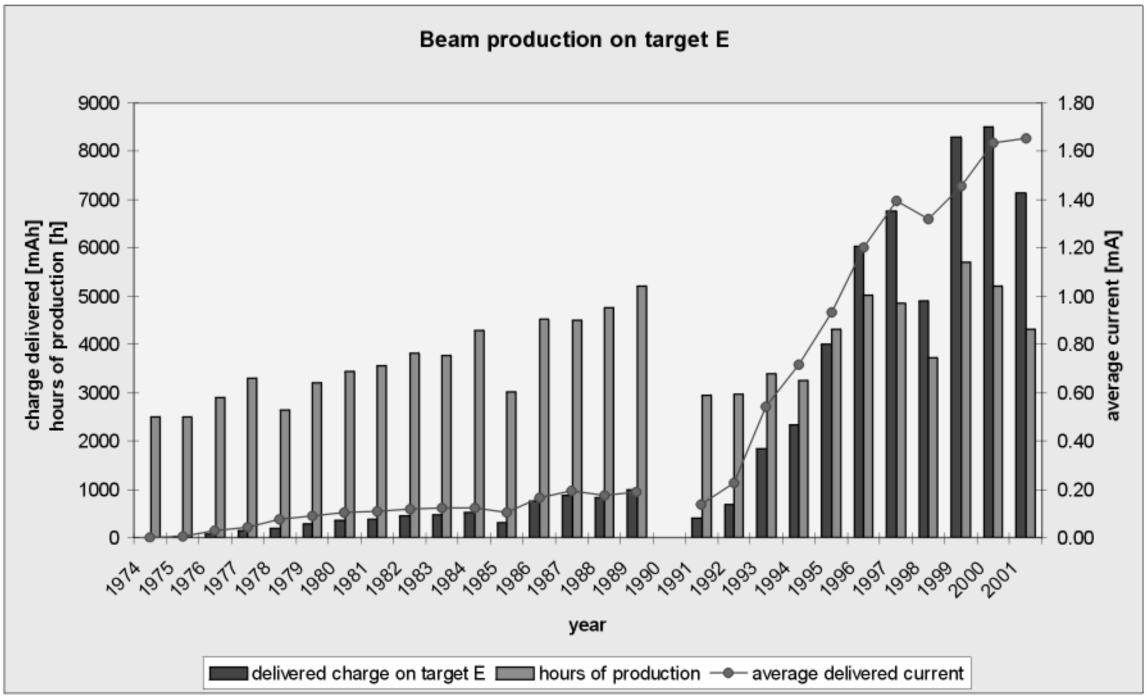

Fig. 1. Delivered charge (mAh) and average proton current (mA) since the start of beam production in 1974.

can rely on. Furthermore, breakdowns that necessitate long repairs are extremely detrimental for many experiments, which have only been allocated a few days of beam time. As proton beam experiments at PSI increasingly move from the long term basic research domain towards applications in solid state and material science, where the typical duration of a run is between hours and a few days, the demands of these user groups become more important.

To meet the needs of this new situation, one has to proceed on two ways. On the one hand, the stability and reliability of the components has to improve, on the other hand technical realizations have to be performed in such a way, that, if ever any damage has occurs, repair time can be kept as short as possible.

Struggling for stability

Voltage breakdowns of the electrostatic extraction channel EEC (shown in Fig. 2) of the 590 MeV ring cyclotron are actually one of the main causes of beam trips, e.g. interruptions of the beam over less than 1 minute. After hours of perfectly stable operation, this element suddenly starts to generate cascades of voltage breakdowns, up to several events per minute. Sometimes beamless conditioning can stop the discharges, sometimes not, but in almost all cases stability returns after some hours, just by itself. The origin of these breakdowns is hardly understood. For instance, it is not yet known whether they occur by some inherent effect, such as depositions on the surface, or by interaction with the beam. A promising new tool for obtaining information concerning these questions is our FORTRAN coded transient recorder “ELFI” [1]. Its collected data can be used to provide statistical overviews over weeks and months, as well as to perform detailed investigations of selected single events. It efficiently supports search for parameters that are correlated with periods when the EEC has a strongly enhanced discharge rate. A fact that has already been established is that a discharge of the EEC in the vacuum is visible on the ionisation monitor. This allows for a clear distinction between discharges in the vacuum and failures in the cable and the feed-through.

Struggling for short repair time

If the ring cyclotron has to be vented, evacuation takes three hours. Additionally, the electrostatic elements at injection and extraction need to be cleaned by conditioning at high

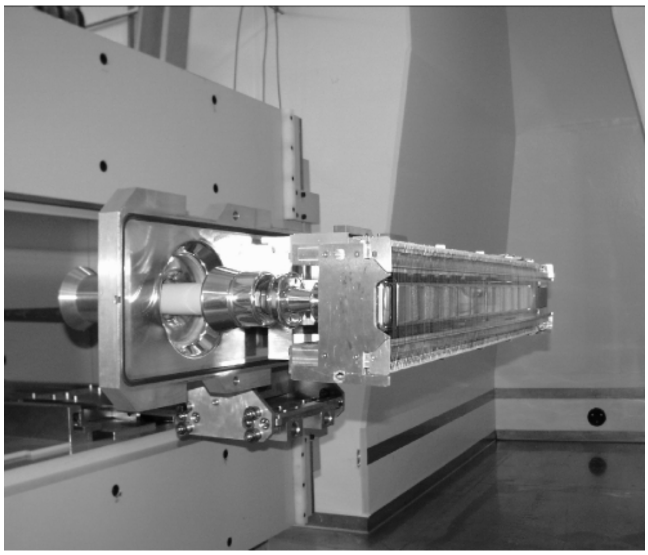

Fig. 2. The electrostatic extraction channel EEC. The band harp in front is on ground potential. The box electrode located just behind the band harp operates at a voltage of –160 kV.

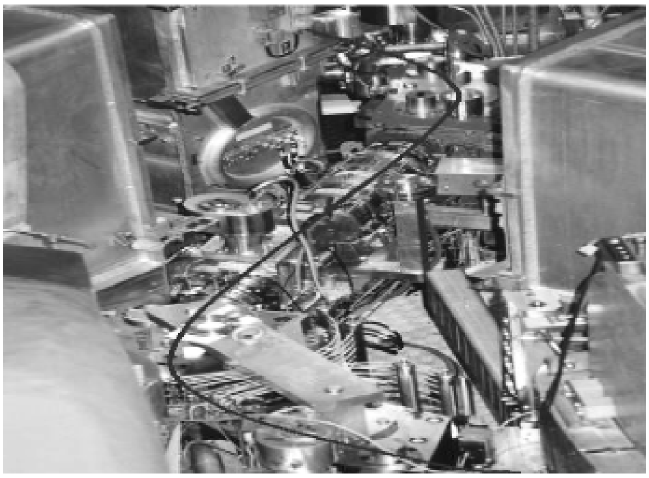

Fig. 3. Center region layout of the ring cyclotron.

voltage. If some damage in the system can be repaired without venting the accelerator, several hours of beam availability can be gained. In view of this aspect, the injection beamline (see Fig. 3) has been rebuilt in a way, its vacuum tube can be vented without involving the cyclotron or the preceding beamline and its electrostatic beam splitter. In the past three months, this construction paid back our investment, because the system suffered from three water leakages in magnets located there. Each of them could be fixed within less than half a day, instead of in at least double that time with the old layout.

Upgrade of the accelerator system

After successful upgrade of the proton beam up to about 2 mA, a second upgrade project has been started targeting an intensity of 3.5 mA. To achieve this goal, several parts of the whole accelerator complex have to undergo modifications, in particular the ion source, injector 2 and the ring cyclotron.

New copper cavities in the 590 MeV ring

The main topic of the upgrade project is the replacement of the old aluminium cavities by ones made of a copper-stainless steel body. This ambitious project has now entered the manufacturing phase [2]. After carefully optimising the layout on a 1:3 model, the first of four cavities is now under production (see Fig. 4) and will be delivered towards the end of this year. There are remaining questions to be examined at the full sized cavity such as, whether the inflatable vacuum seals between the cavity and the beam chamber are able to handle the displacement of the cavity body induced by heating effects. A finite element analysis done independently by the manufacturer and at PSI shows that the rigidity of the cavity support structure cannot be increased to a level withstanding deformation forces of the cavity body. A coupled field analysis covering thermal, structural and RF effects, has been done to calculate the frequency drift, induced by thermal deformation of the new cavity. The finite element code ANSYS was applied to one eighth of the cavity vessel. The simulation yielded promising results, but these need to be verified in practice. After thorough testing of these tolerances and of the high power behaviour, the new cavity will be installed into the ring cyclotron in the spring of 2004.

More RF power in injector 2

In the PSI injector 2 space-charge effects yield a curling up of the beam bunches and hence a naturally shrinking phase width down to 4.5 degrees on the first revolutions. Therefore, for the last ten years, the two side resonators, running at the 3rd harmonic have not been used as components of a flattop system, but acting as additional acceleration elements enhancing the turn separation by 10%. The potential of the space-charge benefits is not yet exhausted. It would be possible to replace the 150 MHz resonators by another pair of 50 MHz main accelerator structures. However, initially there is a cheaper solution available, leaving the resonators unchanged, but supplying more RF power. In fact, the RF generator used to drive the 1:3 model of the copper cavity can be used to feed the former flattop resonators in injector 2 adding a gain of another 10% in beam separation. Equipped with these upgrades, we estimate that the system will deliver an extracted beam current of about 2.5 mA.

Besides the upgrade activities of the accelerators, tests of an RF driven multicusp proton source have been started.

The PROSCAN project

Based on the development and success of proton therapy, PSI decided in 2000 to expand activities in this field by launching the PROSCAN project. The overall objective of PROSCAN is to implement and operate at PSI a base technology laboratory for the advancement of proton therapy using in-house system techniques and applications. The long-term programme aims to optimise the irradiation and treatment technique and to prepare the compact gantry system for transfer to a "marketable product" for hospital applications.

Fig. 4. An 8 mm copper sheet placed in the welding jig is cleaned before the electron beam welding of the stainless steel cooling channels.

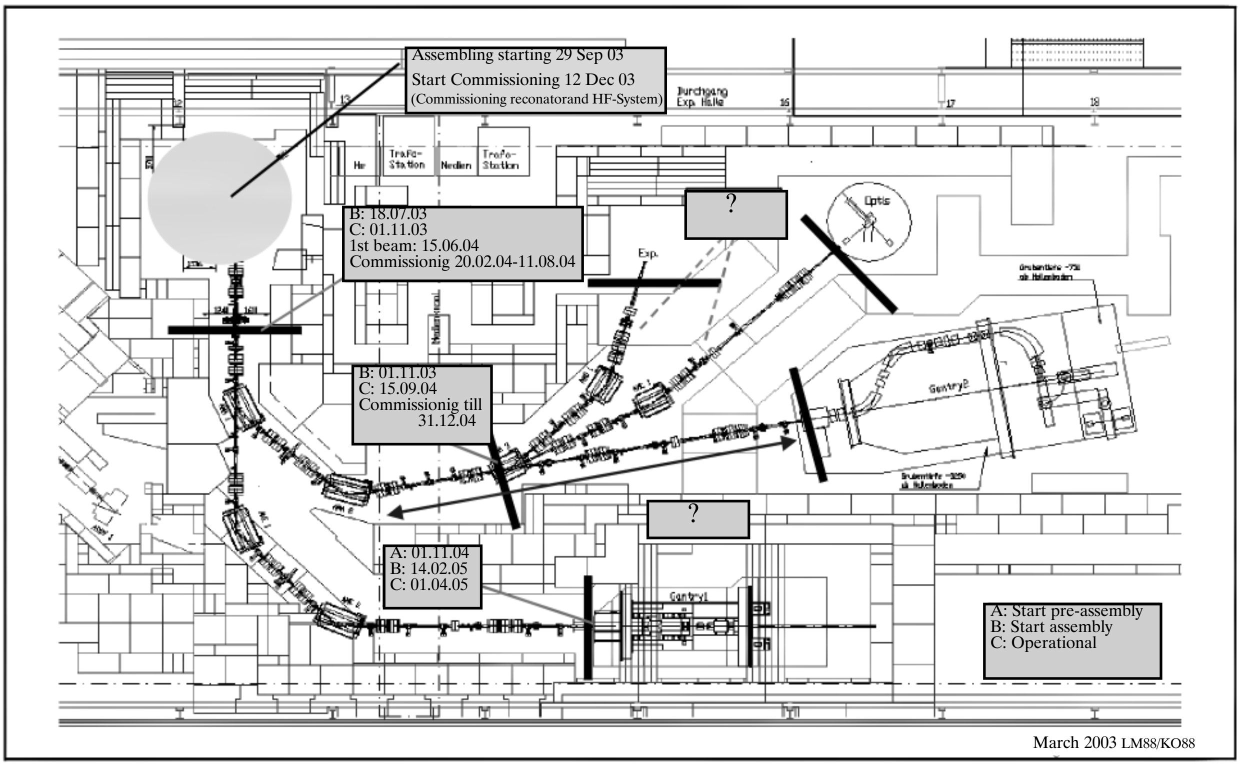

Fig. 5. Layout of the new PSI medical proton application facility PROSCAN.

The status of the project [4] is such that the proton beam generator, a superconducting compact cyclotron is now under construction at ACCEL Instruments GmbH, Bergisch-Gladbach. The layout of the beamlines is completed up to final details (see Fig. 5) and studies of the construction of a new gantry for various application techniques including intensity modulated radiation therapy IMRT are performed at PSI and by an engineering company located in Aarau.

Conclusions

The PSI high power proton cyclotron facility will be able to deliver a substantially enhanced proton beam and PSI will operate a dedicated medical proton application facility in the near future.

References

1. Adam S, Humbel M (2002) Investigations on discharges of high voltage devices based on a transient recorder program. In: Bercher R, Büchli C, Zumkeller L (eds) PSI Scientific and Technical Report 2001. Vol. 6: Large research facilities, p 15
2. Fitze H, Bopp M (2002) Progress in the development of the ring cyclotron cavity. In: Bercher R, Büchli C, Zumkeller L (eds) PSI Scientific and Technical Report 2001. Vol. 6: Large research facilities, pp 7–10
3. Humbel M, Mezger AC, Schmelzbach P-A (2002) In: Bercher R, Büchli C, Zumkeller L (eds) PSI Scientific and Technical Report. 2001. Vol. 6: Large research facilities, pp 5–6
4. Schippers JM, Vranković V, George DC (2003) Beam-dynamic studies in a 250 MeV superconducting cyclotron with a particle tracking program. Nukleonika 48;S2:s145–s147