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STATUS OF THE CARBON ION SOURCE COMMISSIONING AT MEDAUSTRON

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Abstract

MedAustron is the synchrotron-based Ion therapy center of Austria. Accelerated proton beams with energies of 62-252 MeV are used to treat patients with cancer since 2016. Carbon ion beam is currently under commissioning and will provide treatment in 2019 with energies of 120-400MeV/u [1]. The Injector features three identical ECRIS from Pantechnik, two of which are used to generate the proton and the carbon beam with an energy of 8 keV/u. The generated beam is sent to a 400keV/u RFQ and a 7MeV/u H-mode Linac. Then follows the injection in a 77 m synchrotron via a middle energy transfer line, where the energies for patient treatment are reached. The beam is sent to four irradiation rooms via a high energy transfer line, two of which are currently used for medical treatment. The medical environment of the accelerator puts strict requirements on the source performances in terms of long term stability and uptime. The extracted carbon intensity needs to be on the order of 150 μA with maximum current fluctuations of ±2.5% on the continuous run. In this work we discuss the status of carbon commissioning with particular emphasis on the experimental results obtained during the ion source tuning [2].

INTRODUCTION

MedAustron Ion Therapy Center (Fig.1) is a medical facility. This creates an environment significantly different than in research facilities [3]. One source of limitation are law restrictions when using technical devices for patient treatment and procedures that the facility needs to fulfill to be certified for clinical operation. Furthermore sensitive data are processed, therefore certain standards are implemented, which affect not only the clinical part, but the company as a whole. This includes access control, available software, workflow and documentation. The other aspect is related to patients themselves. Each delay or failure directly affects people who wait for their therapy, relying on the help provided to them in a difficult situation created by a medical condition, cancer. Therefore, we continuously work to improve uptime, stability and limit even remote failure risks. This puts significant overhead on all our activities, but also motivates us to look for new ways to improve reliability of the system we use.

Although such work is not directly comparable to scientific investigations, it may provide another point of view on requirements and expectations to the systems used in non-scientific conditions. Out of three sources we use one exclusively in the medical environment and the second one (carbon source) is just being prepared to include into the medical accelerator by optimizing source performance to required level. The goal of this paper is to present constraints, challenges, the work invested to improve the system and unique opportunities which medical environment provide us.

Figure 1. MedAustron Ion Therapy Center

MEDICAL ENVIRONMENT REQUIREMENTS

Without external limitations the most effective approach to keep beam properties stable would be occasional re-tuning of the source parameters. In our case such approach is not effective because parameters are fixed and cannot be modified without and official release process approved by the QA department.

To allow the device to be used for patient treatment it needs to go through a certification process, which takes into account potential risks for patient, service personnel, other devices as well as natural environment. This process, implemented mostly on large-scale reproducible products, affects how we are able to work with device on the level of complication of Synchrotron. MedAustron Particle Therapy Accelerator (MAPTA) consists of hundreds of devices (ion sources, various magnets, linear accelerator and beam diagnostic devices). Starting from sub-components, through components and functional units it is needed to undergo through multi-step commissioning to make it possible to certify the whole device as a medical machine. This process is required also for parameters, set points and settings. Only when both the machine setup and parameters are 'fixed', the medical verification can commence. During this process various 'failure scenarios', tests and measurements are done. In the end the clinically released set of parameters is allowed to be used for treatment.

This changes the approach to beam stability in the ion source, as even the small change in parameters does include time consuming process of releasing new medical

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settings. Therefore long term stability, uptime and maintenance planning is of upmost importance.

MAINTENANCE PLANNING

To be able to perform the maintenance two requirements need to be fulfilled:

- Machine cannot be used to treat patients.
- Documentation need to be prepared (such as change impact analysis, change plan, and multiple protocols)

As documentation preparation can take up to a few weeks all activities need to be scheduled well in advance during the so-called service slots. Short service slots occur every 2 weeks, providing 6 hour time for service activities. Long service slots, with 48 available hours are used for bigger tasks and are scheduled every 1.5 months.

Such schedule requires to plan preventive maintenance well in advance to counteract any possible drift or change in the source parameters or failure of the components. In total 29 tasks were defined, grouped into three maintenance types: yearly, half-yearly, quarterly and additional on-demand activities. The tasks range from checks and cleaning to exchanges of o-ring seals and components.

This allow us to identify possible failures early on and plan to exchange affected components. In addition regular exchanges and cleaning keep our source in controlled conditions limiting the need to for recommissioning.

At the moment carbon source is not yet used for medical purposes. Therefore is does not undergo the same processes as proton source. Prolonged use without the major maintenance or exchanges lead to current decrease (see [4]). Carbon deposition on plasma chamber walls changes conductivity of the walls and affects plasma generation. This translates into a lower extracted current of the carbon species we use. Such a situation would not be acceptable in clinical use, therefore we need to identify such factors and introduce measures to prevent such a change. In this particular case, in addition to maintenance plan adaptations, a full source recommissioning was needed.

SOURCE STABILITY

The number of patients MedAustron can treat depends on several factors. Two important ones are beam availability (uptime) and intensity.

On one side maximum beam intensity is limited by legal regulations: taking into account that the safety systems has a certain reaction time, we are not allowed in case of component failure, to exceed a certain maximum dose to the patient. This means that we need to carefully identify and test all failure scenarios by taking preventive actions when needed. This puts a limit on our maximum extracted current.

On the other hand patient treatment is prolonged if the current drops. This can either prolong the time a patient needs to spend in the treatment room, delay treatment time or even require another visit. In addition even short violation of required beam parameters interlocks the machine, leading to a stop of treatment. Therefore, for clinical operation, we can only accept a very stable beam conditions.

As an example of such issue can be presented investigations on the regular current. Initially we were observing 30s current drops on the carbon ion source every 2 hours (Fig.2).

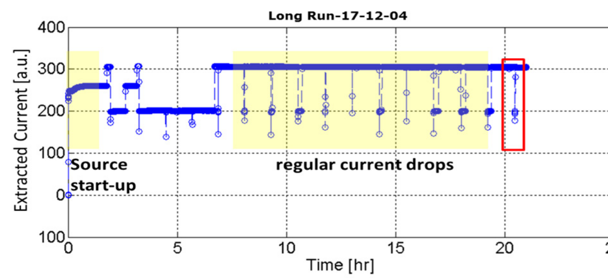

Figure 2. Regular current drops observed in Source 2 [4]. The red rectangle is showing the area presented on the next picture (Fig. 3).

In addition the two step behavior was often triggered by the drops, when beam intensity dropped for some minutes before recovering (Fig. 3). Such beam properties would be not acceptable for clinical operation.

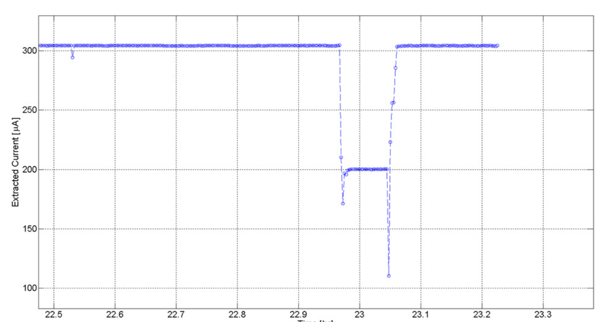

Figure 3. Two step behavior of the current. After the He flow recovers the plasma may stay in a different state leading to a lower source current until it will recover to previous current value.

Investigation of this issue allowed to find correlation to oscillations of support gas flow (He).

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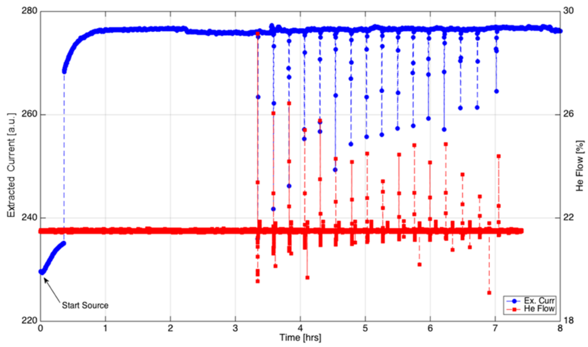

Figure 4. Current drop correlated with support gas flow oscilations

We could finally identify the root-cause of the current oscillations originating from a pressure buildup before the gas flow controller, which was triggering oscillating behavior of flow controller. By upgrading the gas panel system and by adding a pressure relieve valve we could reach a medically acceptable situation for which the beam current is stable for more than 24h (Fig.5).

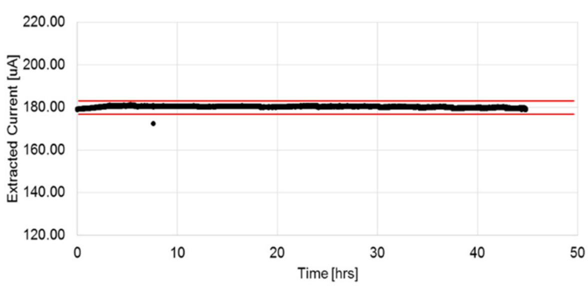

Figure 5. Beam stability after the solving the unstable gas injection.

SOURCE RECOMMISSIONING

Source performance does have an impact on the whole accelerator. We can observe this in the data collected in so-called 'beam QA' which measures beam properties each day, before patient treatment. This provide us an opportunity to observe processes such as radiation damage to detectors, seasonal/temperature performance drifts of some components, aging and effects of the source on the rest of the machine.

At the moment tools for data acquisition and data processing are being actively developed. This should make it possible to record more measurements and understand better when any component of our machine behaves in an unusual way. Due to high statistics, even a sub-millimeter beam deviation or minor decrease in the number of particles is visible. Such events need planned source recommissioning to recover the beam properties to the reference values to increase the stability.

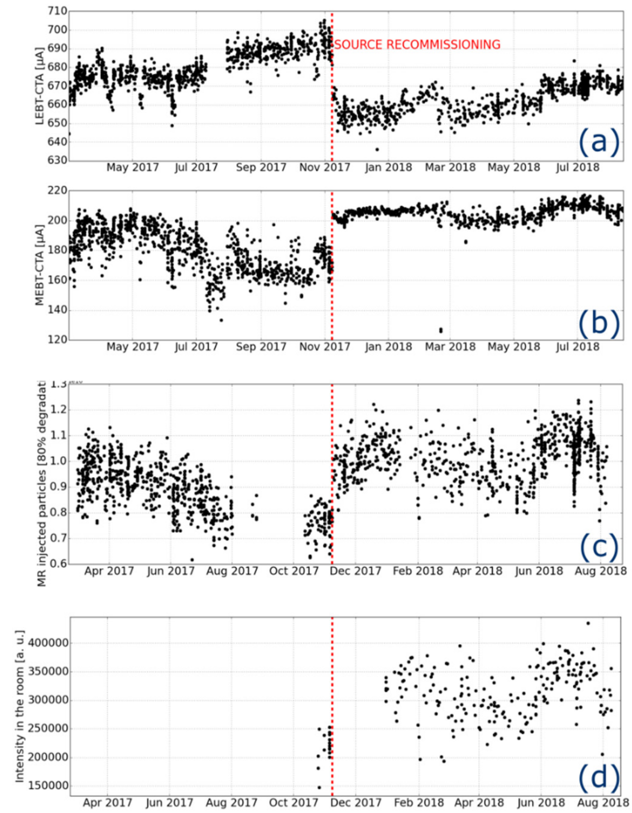

Figure 6. Source recommissioning effect on the machine:

(a) Source current in low energy beamline (LEBT-CTA) is lower after the recommissioning.

(b) In medium energy beam line (MEBT-CTA) we can observe both higher current and significantly better stability

(c) Number of particles injected into the main ring is higher with significant shot-to-shot fluctuation (which is a goal of another investigation)

(d) Intensity in the room. Before Nov-2017 it was only measured by medical groups, later it became also part of daily Accelerator Beam QA.

The results of such work are presented on the Fig. 6.

Recommissioning usually includes extensive scan of source parameters (Fig.7,8). In this particular case a set point was needed that produce a constant emittance in a wide range of extracted current and forwarded power. More information can be found in [4]. As one can observe from these figures, the emittance does not change the emittance if the RF power is varied. This makes it possible to have the RF power as a clinically modifiable parameter as discussed in detail in [5]

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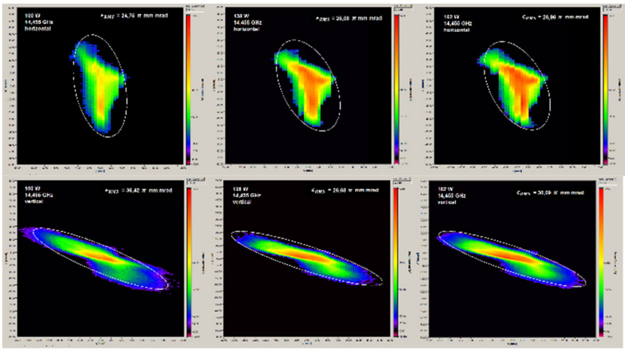

Figure 7. Measured Emittancesof the carbon beam produced using a fixed resonance frequency of 14.455GHz for three different forwarded RF power values.

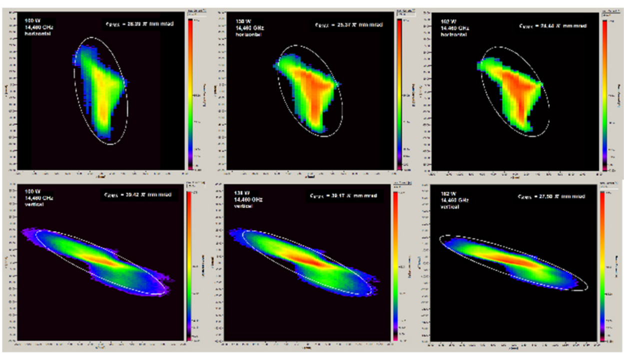

Figure 82 Measured Emittances of the carbon beam produced using a fixed resonance frequency of 14.460GHz for three different forwarded RF power values.

FUTURE PLANS

At the moment our efforts, as Accelerator Physicists in MedAustron, concentrate on the commissioning of the carbon beam for clinical use. This starts with a stable beam current and continues with finding parameters for each device which have an effect on the beam. This work should be finished in 2019, when we will start patient treatment with carbon ions. In that point in time the source 2 settings used for carbon ions, will be “frozen”.

There is one more source waiting to be commissioned in MedAustron: Source 3. It is supposed to be a backup for Source 1 (used for protons) and Source 2 (used for carbon ions). Source 3 should also enable us to test settings, measure source behavior or prepare additional beam species.

In addition, thanks to reproducible conditions we will be able to acquire a collection of data on accelerator performance. Daily measurements are done to verify beam parameters and results are stored. This allow us to analyze long-term trends and seasonal effects. With sufficient amount of data we should be able to better predict machine behavior and preventively act to keep all beam parameters constant. It should also let us do extensive analysis and cross-correlation studies. With improved tools and better measurements this could provide valuable insight on long term stability, aging effects, reproducibility and maintenance which we want to explore.

ACKNOWLEDGEMENTS

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