

OPERATION OF THE LINAC AND THE LINAC RF SYSTEM FOR THE ION-BEAM THERAPY CENTER HEIDELBERG

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Abstract

The Heidelberg Ion Therapy Center HIT is in clinical operation since 2009. It is the first dedicated European particle accelerator for medical treatment. Its central location on the campus of the Heidelberg University Hospital fits perfectly in the clinical everyday life. The accelerator complex consists of a linear accelerator and a synchrotron and is designed for protons and carbon ions, but can also provide helium and oxygen ions.

The LINAC, build in 2006, operates since 5 years in a 24/7 schema which leads to 60000 operating hours up to now. The performance with an availability of better than 99% is much higher than expected and is caused by a solid design and a well planned and foresighted maintenance.

Unavoidable failures during operation can be solved very fast with the on site experts for each section. The combination of personnel, spare parts and permanent ongoing developments is very successful.

An upgrade program for parts of the LINAC and also for the RF system is in planning to keep the up-time high and to improve the performance for further needs.

treatment rooms with a horizontally fixed beam-line, the worlds unique heavy ion gantry and an experimental area.

The ECR ion sources produce proton, helium, carbon and oxygen beam, of which the protons and the carbon ions are used for the medical treatment of localized tumors.

In the injector linac, beams with an AoQ of 1-3 can be accelerated to 7 MeV/u. The synchrotron accelerates the beam to an energy of up to 430 MeV/u for carbon ions, which corresponds to a penetration depth in water or human tissue of 30 cm.

LINAC AND RF SYSTEMS

The LINAC RF system shown in Fig. 2 supplies three RF cavities in front of the Synchrotron to accelerate and form the beam from the ion sources. A 4-rod-RFQ is used to accelerate the beam to 400 keV/u, focus the beam and form bunches. The following IH-DTL accelerates the beam to 7 MeV/u and the Debuncher spreads the bunches longitudinal to match the acceptance of the synchrotron. The cavities are operated at 216.816 MHz. For a beam with an $AoQ = 3$ a power for the RFQ of 200 kW, for the IH-DTL of 900 kW and for the Debuncher of 1.2 kW is needed.

The RF system (Fig. 2) consists of a common master oscillator providing the frequency. A amplifier and splitter is used to distribute the RF signal to the three power amplifiers. Dependent on the needed power, different amplifier stages of transistor and tube amplifiers are combined. The RFQ has a 8 kW transistor preamplifier and a 250 kW tube final stage. The IH-DTL has a 4 kW transistor preamplifier, a 120 kW tube stage and a 1.4 MW tube final stage [2]. The RF system for the Debuncher only uses a 4 kW transistor amplifier.

The analog PI-controller for each system corrects the amplitude and the phase of the decoupled cavity signal.

The RF system was designed by GSI in Darmstadt, Germany and build by Bertronix in Munich, Germany and the company today named Ampegon in Turgi, Switzerland.

OPERATION OF THE ACCELERATOR

The accelerator is operated more than 320 days a year in a 24/7 mode. The medical treatment takes place during the day in the time from 8am to 8pm. In the morning quality assurance measurements are done and in the evening the treatment plans for the next days are verified. The night shifts are mainly used for experiments and the adjustment of the accelerator.

The patients at HIT are treated with carbon ions or protons. The clinical dose is distributed over mostly 20 fractions with a 5+2 scheme. They are treated 5 days in a row with two days rest period, which leads to a residence time of about one month at the center.

INTRODUCTION

The layout of the accelerator of the Heidelberg Ion Therapy Center HIT includes three ECR ion sources, a 7 MeV/u injector linac, a 6.5 Tm synchrotron and a high energy beam transport line to deliver beam for the four target places: Two

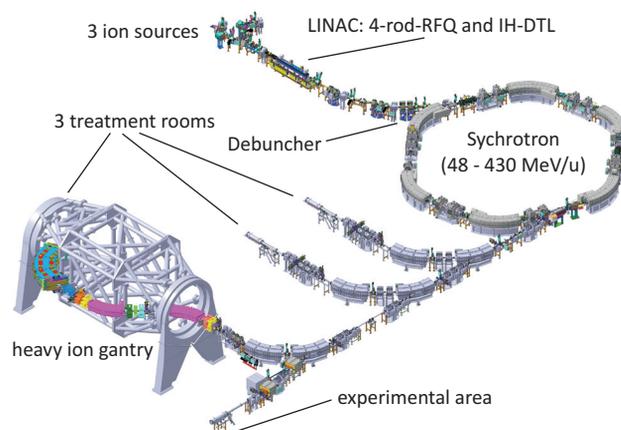


Figure 1: The accelerator of the Heidelberg Ion-Beam Therapy Center (HIT) with three ion sources, the LINAC (7 MeV/u) consisting of a 4-rod-RFQ and a IH-DTL, the synchrotron (48-430 MeV/u), the beam lines to the treatment rooms and the experimental area and the heavy ion gantry [1].

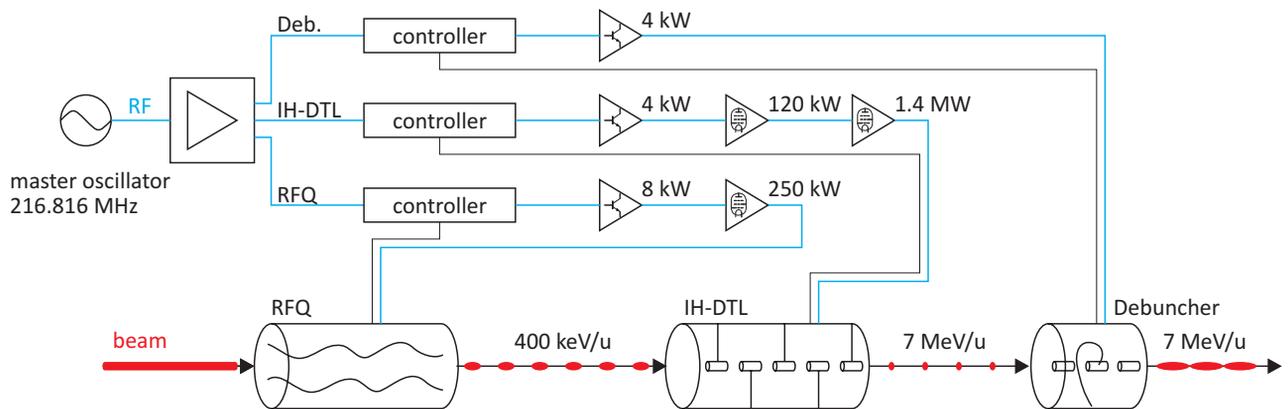


Figure 2: Schema of the LINAC RF System: One Master oscillator at 216.816 MHz, amplifier and divider distributes the RF to the three amplifiers, amplifier for the RFQ (8 kW transistor, 250 kW tube amplifier), amplifier for the IH-DTL (4 kW transistor, 120 kW tube amplifier, 1.4 MW tube amplifier), amplifier for the Debuncher (4 kW transistor). The control loop corrects amplitude and phase of the decoupled signal of the accelerator cavities.

If the fraction scheme is changed dramatically the medical effectiveness of the treatment method differs. Thus shutdowns of the accelerator longer than a few days are only possible when all parallel treatments at a time are finished. Driven by the medical necessity, in 2012 the following maintenance scheme was chosen:

Every three weeks one early shift is used for preventive maintenance, smaller services and software updates. Six times a year are the planned mini shutdowns with a duration of four days from Thursday to Sunday. Thursday and Friday are foreseen for the maintenance tasks with a backup time on Saturday morning, while the Saturday and Sunday is used to power up the machine and make all relevant security checks and quality assurance measurements.

The schedule of these short shutdown periods need to be prepared very well and the cooperation between the different professional groups has to be coordinated. One main issue for each group was to divide all maintenance tasks in tasks with a maximum duration of two days. Unforeseen problems which could lead to a longer holding time and delay of the patient treatment has to be minimized. The needed spare parts and tools for the maintenance tasks have to be on side, since there is no time to order missing parts.

SERVICE AND MAINTENANCE CONCEPT

The RF and Power supply group at HIT consists of two engineers and three technicians which are responsible for the Linac RF system, the Synchrotron RF system, the magnet power supplies, the high voltage power supplies, the extraction system and parts of the power lines at the facility. The group members are completely integrated in the daily operation of the accelerator, responsible for the development of new parts of the systems as well as the service and maintenance.

For the service of the systems one group member is planned for an on-call duty besides the normal working time in the

nights, the weekends and during public holidays, who can give telephone support or be on side within one hour.

The concept to combine the development, the operation and the service guaranties well educated personnel for each task. The development of new parts profits by the practical experience in operating the accelerator, the operation edges down with the knowledge how and why the systems are build and how they work. The knowledge of rarely used systems are renewed during the maintenance phases.

As is known, systems with regularly failures are known the best as systems working fine all the time are known less. It is a hard task to keep the knowledge also for such kind of systems, but for such a high-tech machine this knowledge is needed to keep a high up-time over years. Thus the only possibility is to accompany all evolution steps of the system by local personnel and look beyond one's own nose.

In case of a blackout, the failure can be located in a short time by knowing the system in deep and using the right measuring devices. Even expensive devices which are rarely used are worth when they are needed to find the failure. Not even the defective part has to be pointed, but also the cause for the failure has to be figured out, else wise the new build in pare part will be broken by the same cause.

Spare parts have to be available on side or nearby. Without spare parts no repair is possible and the delivery time has to be added to the blackout time due to the failure.

SPARE PARTS

Spare parts are needed to reach a high availability. Parts become defective by certain reasons. A distinction is made between *early failures*, *constant failures* and *wear out failures*.

The early failures corresponds to fabrication inaccuracies e.g. cold solder joint or weak spots in the material. These failures occur at the beginning of the life time and decrease at the time.

The constant failures are randomly distributed over time and do not correspond to attrition. They can e.g. be caused by external influences.

The wear out failures are caused by attrition of the material. The frequency of losses increases by time.

The superposition of these three kinds of failures leads to the known bathtub curve divided in three time periods: 1. the decreasing failure rate at the beginning, 2. the constant failure rate and 3. the increasing failure rate at the end of the lifetime of a system. The time of the different phases varies due to different systems. An optimum is reached when the first and the last period is short compared to the second phase with a constant failure rate.

As a special kind of early failures cause by a weak system design should be mentioned. Due to the fact that most of the systems in an accelerators are prototypes, the systems are sometimes not designed to operate reliable over time. Some parts do not fulfill the requests and lead to many operational failures.

The spare parts are divided in three categories:

- Categorie 1: non redundant part,
- Categorie 2: redundant parts,
- Categorie 3: parts without influence to operation.

Parts of cat. 1 are non redundant and lead in case of a failure to a stoppage of the system. Parts of cat. 2 are redundant parts or parts that can easily be bypassed within the system. They lead at most to a short interruption of the system. Defective parts of cat. 3 do not interrupt operations. These are e.g. status indicators, service power supply plugs, etc.

Table 1: The decision to take a spare part on stock can be facilitated with the decision matrix. A "+" increased the purchase decision, a "-" lowers it.

	store spare part on side
Category 1	++++
Category 2	+
Category 3	---
MTTF	+++
No long time availability	+++
Long delivery time	++
High storage costs	-
Poor storability	--

Many points have to be considered in the decision to take a spare part on stock: Price, delivery time, mean time of failure (MTTF), long time availability, storage costs, size and storability. The costs of taking the spare part in stock has to face the costs of a blackout during operation as long as the restocking time of the damaged parts are and the influence on technical work-flow as well as the medical efficiency of the method when the treatment is interrupted over days.

Especially the prototype parts or parts which are not used by the industry frequently, normally have a long delivery time. Unfortunately these parts are often very expensive. A good example are the high power RF amplifier tubes with

a delivery time of many month an costs in the range of 100 kEUR. For prototype parts e.g. accelerator structures or magnets it is a good idea to produce the spare parts at once with the original parts to save costs.

MAINTENANCE OF THE RF SYSTEM

Tasks of the periodic maintenance are sight checks and cleaning, monitoring of the tube parameters, the working points and the occurred warnings and interlocks. The air filters are changed and the fans are inspected. Further on, the safety systems are tested periodically.

A main task is the yearly cleaning of the whole system and the big sight check which takes two days with four people. In the cleaning process every single part is inspected. Special attention is set to water trails, color change, dirt on the bottom from broken parts, flash-over tracks, loose cable and broken cable as well as hot spots. Unusual hot spots can be identified very fast with a thermal camera.

Due to the idea to find failures in the system before they lead to a blackout, the cleaning and the sight check are the most powerful tool and has to be done by high educated personnel with the look for relevant details and experience.

All consumption parts e.g. fan belts, highly loaded relay contacts, fans and air filters are exchanged frequently. The electric components like the emergency off system, the tube protection system, the measuring system for the operating parameters, the spark gaps and the interlock systems are tested yearly.

Every three weeks a short sight check is foreseen to check the consumption parts to be aware of malfunctions during operation and to write down the operating parameters. The operating parameters are used for statistics and to monitor the life cycle of the tube.

CONCLUSION

The RF system for the medical accelerator at the Heidelberg Ion-Beam Therapy Center gets 10 years old and where operated more than 60 000 hours up to now. The high availability of more than 99% was reached by a solid system design, well trained personnel, necessary measuring equipment and spare parts on side as well as the continuously ongoing developments of the systems. With the well trained local personnel the response time and repair time in case of a failure was minimized. Downtime longer than a few hours could be prevented successfully.

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