OVERVIEW OF THE MAGNET ACTIVITIES AT HIT

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Abstract

The Heidelberg Ion Beam Therapy Centre (HIT) is the first facility in Europe with a dedicated heavy ion accelerator for cancer treatment with carbon ions and protons. Today, after three years of regular operation, up to 45 patient irradiations per day can be applied with two fixed beam treatment rooms in use. The accelerator comprises 146 normal conducting magnets ranging from 9 kg LEBT double steerers to the 74 tons 90° dipole on the gantry. Due to its medical application a high reliability is demanded from all subsystems. To avoid unscheduled shut downs due to magnet failures we set up a concept based on an exceptional spares inventory and preventive maintenance which will be presented in this paper. Moreover, we will discuss other activities concerning the magnets such as copper passivation and corrective maintenance.

INTRODUCTION

Owned by the Heidelberg University Hospital the Heidelberg Ion Beam Therapy Centre (HIT) is dedicated to the treatment of cancer patients but offers the opportunity for basic research and development as well. The accelerator part includes a 7 MeV/u injector linac consisting of two ECR ion sources, a radio frequency quadrupole (RFQ) and an IH-type drift tube linac (IH-DTL) [1]. A synchrotron with a circumference of 65 m accelerates protons and heavy ions up to 220 MeV/u (protons) resp. 430 MeV/u (carbon, oxygen) [2]. The medical part consists of two horizontal treatment rooms and a heavy ion gantry for 360° patient irradiation, which is a worldwide unique device [3]. Since November 2009 over 1000 patients have been treated in the horizontal treatment rooms.

The design of the magnets as well as the other parts of the accelerator has been performed by GSI Darmstadt. For each magnet type a specification has been elaborated. These have been the base of the tender which led to the placement of orders to three different companies: the triplets of the LINAC have been built by Danfysik [4], the synchrotron dipoles have been manufactured by Tesla [5]. All other magnets of the facility are a product of Sigmaphi [6]. Altogether there are 27 different magnet types in use, some of them, like the dipoles on the gantry, only occur once. Depending on the location in the machine the magnets are running in a DC mode with ion specific settings (LEBT, LINAC, MEBT), are ramped (synchrotron) or pulsed (HEBT). With one exception the DC and pulsed dipoles are field controlled. Since 2012 a magnetic field feedback control for the ramped synchrotron dipoles is used in clinical operation [7].

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SPARES INVENTORY

The goal of the magnet spare parts holding must be the minimisation of down time in case of a breakdown. Whereas the magnet yoke, normally made from laminated iron sheets, can be regarded as indestructible, the magnet coil might be subject of water leaks or electrical shortcuts. If the location is not accessible from outside a repair is nearly impossible. Amongst small parts, e.g. for the connection box, the focus of the spares inventory should lie on the coils. One option is to hold the copper hollow profile of the coils as raw material in stock. This is a cost effective approach which avoids long delivery times of the raw material. On the other side time for coil winding still leads to a non negligible shut down. This can be avoided if complete coils which are ready for insertion are hold in stock. This causes higher costs but reduces downtime to a minimum.

In case of the HIT machine, where one hour of shutdown is a cost factor of several thousands of euros, this highest spare part standard has been chosen. For each type of coil, even for the 90° gantry dipole, at least one spare coil has been ordered. For some dipoles upper and lower coils are required due to the incompatibility of the connections. The insertion of the large coils into the facility has been a challenge by itself. In case of the 90° gantry dipole a specialised company was charged for the transportation of these coils within the HIT building (Fig. 1).

Figure 1: Bringing-in procedure of the 90° gantry dipole spare coil into the gantry hall by a specialised company.

COPPER PASSIVATION

Copper forms oxides in two valency stages: black copper(II)oxide (CuO) and red copper(I)oxide (Cu_2O). Whereas the outer surface of the copper conductors is gradually covered by a patina, the surface of the cooling channel is permanently exposed to corrosion. To decelerate this process the HIT magnets have been copper passivated at GSI

Darmstadt before installation in our facility. During the passivation process a coherent coating, normally an oxide layer, is formed on the surface of the cooling channel that protects the copper from porous corrosion. In our case the inhibitor in use (sodium tolyltriazole) produces a polymeric barrier against corrosion.

The passivation has also been performed for the spare coils. With the help of a special passivation device built by GSI Darmstadt (Fig. 2), mainly consisting of a vessel and an immersion pump, a thin solution of the copper inhibitor has been pumped through the cooling channels of the coils for up to three days. Afterwards the channels have been rinsed with demineralised water for one day. After drying with compressed air and filling with nitrogen the conductor ends have been sealed and the coils put into stock.

Figure 2: Passivation device from GSI Darmstadt connected to a spare coil.

The effectiveness of the procedure could be traced in the separate cooling system of the rf amplifier for our linac cavities. After the passivation of the heat exchanger the amount of residues on the filters clearly diminished.

PREVENTIVE MAINTENANCE

After having started with a scheme of two yearly service periods (summer/winter) of two weeks each, we have now switched to six maintenance periods equally distributed over the year. Each period consists of two maintenance days (Thursday and Friday) followed by one day of recommissioning (Saturday) and one day quality assurance (Sunday). Moreover, about every second Monday the morning shift is used for service purposes.

Magnet maintenance is foreseen on four periods. Two periods serve as reserve for unscheduled works. The visual inspection (Tab. 1) includes checking of electrical grounding, coil epoxy resin, connection box, conductors, screw joints, soldering joints, hose clamps and corrosion. Retightening of screws is carried out yearly for half of the magnets which effectively corresponds to an interval of 24 months. The most redundant error found during the interlock tests are sticking flow meters.

Table 1: Magnet maintenance matrix. Fields with × are done for all magnets; fields with ½ are done for half of the magnets. Maintenance period two and six are reserve.

maintenance task	**maintenance period**			
	1	3	4	5
interlock tests of flow meters and thermo switches	×		×	
logging of water flows	×		×	
visual inspection of magnets	½	½		×
retightening of screw joints of half of magnets		½		

CORRECTIVE MAINTENANCE

Overheating

One of the first and most crucial magnet failures occurred in November 2007. HIT has still been in the commissioning phase when beam time was stopped by a failure of one of the two 45°-dipoles into the first horizontal treatment room. The on-site inspection revealed a terrible sight: the plexiglass cover of the electrical connection box was charred and water was running on the ground. From more detailed inspection the reason for the mess could be found: loose screws at the electrical bridge between the upper and lower dipole coil, two copper bricks brazed to the conductors, caused a bad contact. As a consequence the current flew via the screws instead the contact face. This led to an enormous heat evolution and the described scenario. Every endeavour has been made to fix the damage as quick as possible. After three days of preparation including machining of melted parts and cleaning of the connection box, the repair of the electrical and water connections was performed with support of GSI Darmstadt. After 13 hours repair time the magnet could go into operation again. As a consequence of this incident all screws in the connection boxes have been checked for tightness. We have found another magnet with partly melted copper bricks and replaced these preventively.

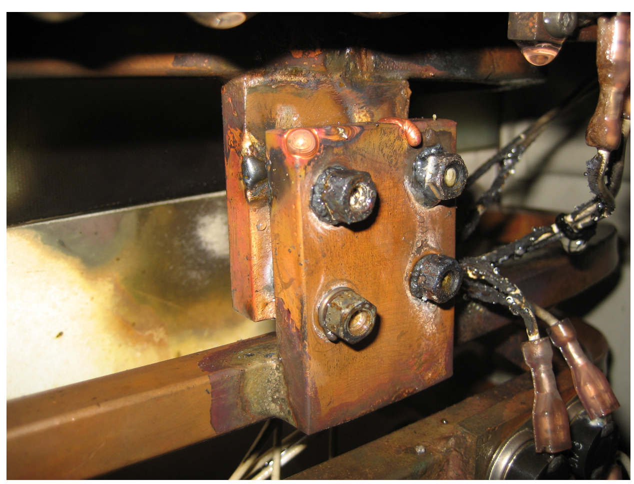

Figure 3: Electrical bridge in the magnet connection box after contact problem.

Plugging

It was in November 2010 when first problems with the inflector magnet into the synchrotron appeared. The operation of the dipole magnet was interrupted due to an interlock caused by the thermo-switches in the magnet connection box. From pictures taken with a thermal imaging camera it was obvious that we deal with a real temperature limit violation. It could also be seen that the temperatures of the four cooling circuits show large differences and that especially one circuit (upper circuit of lower coil) had temperatures which definitely exceed the switching temperature of the thermo sensors (70°C). Detailed investigation of the cooling system followed revealing a 50% reduced water flow of the critical cooling channel compared to the specification (2 l/min). It was also suspicious to find a black powder in the cooling water at the outlet which could later on be identified as CuO by means of an X-ray diffraction analysis. As the blockage could not be resolved by simple water rinsing, the thermo switches were selectively replaced by sensors with a trigger temperature of 100°C. With this the operation could be continued for three months until the temperature interlock appeared again. The critical circuit was then connected to a separate connection available at a cooling water distributor of the synchrotron and the water flow direction was regularly alternated. This allowed us to continue operation. As an attempt by a professional company to unblock the water circuit with special chemicals failed, we finally replaced both coils of the magnet during the summer shutdown 2011 with the spare coils in stock.

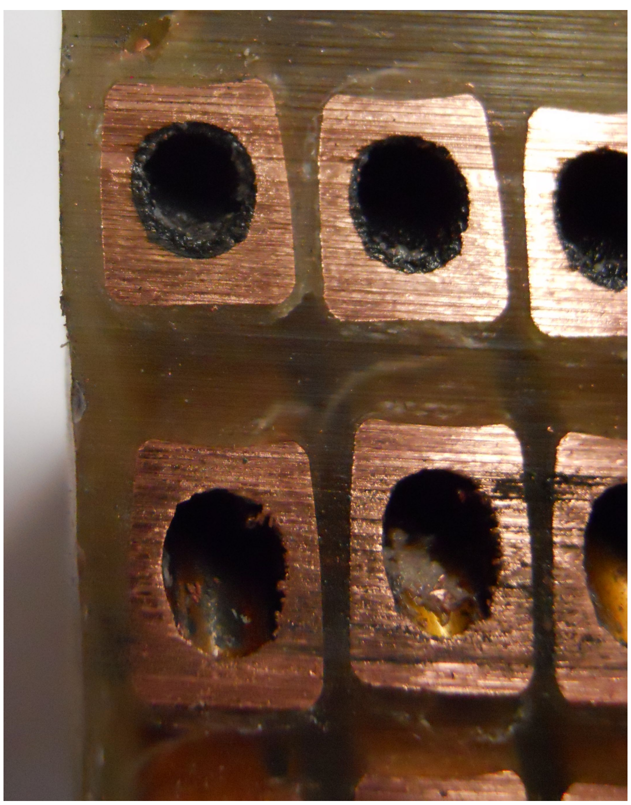

Figure 4: Copper oxide (CuO) layer inside the cooling channel (nominal diameter 4 mm) of the inflector coil.

For HIT it was essential to understand the reason of the plugging to be able to react adequately if a similar problem occurs again. We therefore performed several tests with the dismounted coils at the supplier site [6], investigated the deposit under an optical microscope and finally cut the coils into pieces. This showed the whole extent of the problem (s. Fig. 4). The corrosion layer on the surface of the cooling channel reduces the effective diameter considerably explaining the low water flux. One could also discover that the thickness of the corrosion layer increases from the cooling water inlet to the outlet. As a consequence we doubled the number of cooling water connections from four to eight when mounting the new coils and thus reduced the maximum temperature in the coil significantly. This should slow down the corrosion process to an acceptable measure.

OUTLOOK

We will continue our efforts to get a better understanding of the corrosion process. The oxidation depends not only on the temperature but also on cooling water properties like pH-value, oxygen content and conductivity [9]. Whereas the conductivity is already measured permanently, the other quantities are not very well known. It will be a task for the future to determine these values to be able to estimate the risk of corrosion in our magnet cooling system and take measures to reduce it.

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