TANDEM ACCELERATOR AS AN INJECTER FOR THE MEDICAL-USE SYNCHROTRON AT THE WAKASA WAN ENERGY RESEARCH CENTER

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Abstract

The Wakasa wan Energy Research Center (WERC) has an accelerator system with a 5 MV tandem accelerator and 200 MeV proton synchrotron. One of the significant applications of the system is a clinical trial of cancer therapy, therefore, stable and efficient operation is required for the system, especially for generating and keeping the high voltage of the tandem accelerator.

INTRODUCTION

We have operated the accelerator system with a 5 MV tandem accelerator and a 200 MeV proton synchrotron since the completion of the construction and beam commissioning at WERC in 2000. The system has been used for the irradiation on the industrial material and biological targets, ion beam analyses such as PIXE, RBS, ERDA, NR and proton cancer therapy [1]. Figure 1 shows the schematic layout of the accelerator system.

Beams are used for not only usual target but also "human body", therefore, it is important to keep the stable

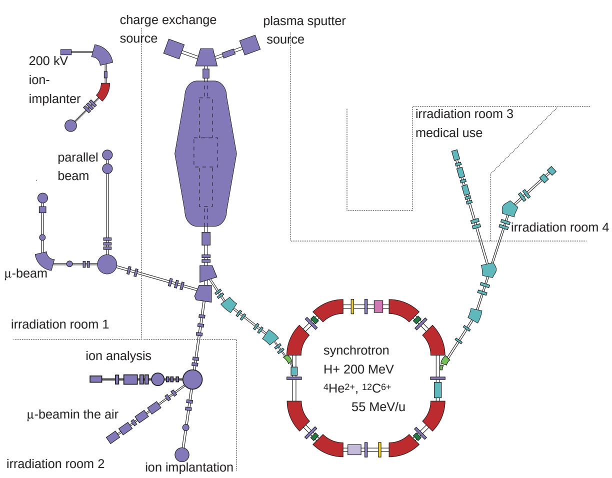

Figure 1 The schematic layout of the accelerator system at the WERC. The system consists of two ion sources, a 5 MV-tandem accelerator, a 200 MeV proton synchrotron and nine dedicated beam lines in four irradiation rooms.

operation lest the treatment schedule is lost. It is required to share the machine time between the therapy use and the others efficiently, steady the beam quality based on the treatment standard and supply beams in the long term without any nonscheduled suspensions.

In the following, the specification of the tandem is described first, the status of the operation of the tandem accelerator including the medical applications next, and then some troubles in the operation are presented.

TANDEM ACCELERATOR

Ion Source

In case of medical use of the accelerator system, the tandem accelerator is used for an injector of the synchrotron. A plasma sputter type ion source is operated for pulsed negative hydrogen beam to be extracted. Usual peak intensity of the beam with a repetition of 25 Hz and duration of 250 µs is 5 mA. After the pulse frequency and duration of the beam is divided into 2 Hz and 25 µs by the electric deflector, that is the acceleration frequency of the synchrotron, the beam is injected to the tandem accelerator.

Acceleration Voltage

The maximum acceleration voltage of the tandem accelerator is 5 MV. The high tension is generated by the cascade of 58 voltage doubler rectifiers (Schenkel circuit). The Schenkel rectifier is fed with an RF power by an oscillator triode (RS3041CJ) and an RF transformer. The oscillation is produced by switching the triode periodically. The RF output power is controlled by on-time duration of the tube. The frequency of the oscillation is chosen at 42 kHz so as to minimize the current of the primary coil, and then it becomes almost equal to the resonance frequency of the secondary coil and the capacitance between the RF electrode and the inside wall of the pressure tank of the accelerator. The oscillator can compensate the maximum load current of 1 mA by the current flow through the divider resistor and the charge conversion of the negative ion to positive.

Insulation

The central terminal at the potential of maximum 5 MV and two tube sections for the acceleration of negative and positive ion are sustained by the insulation columns made with UNILATE®[2]. UNILATE has a main component of PET with mixtures of glass fiber, inorganic filler and others. The components are extruded into plates. The plates are laminated and heat-pressed. The potential distribution is clamped on the surface of the column supporting the low energy side tube by the surface electrode and dividing resistors. The surface of the column for the high energy side is equipped with the rectifier cascade. Both the long sides of the column plate are voltage-clamped by the electrodes for mounting rectifier diodes, however, the central zone from the ground to the high tension ends has no electrodes for the voltage clamp. This should cause the breakdown on the surface.

Injection to the synchrotron

A proton beam with energy of 10 MeV and typical pulse height of 4 mA from the tandem accelerator is injected to the proton synchrotron and accelerated up to 200 MeV. After the acceleration, a beam with an intensity of about 3~4 nA is slowly extracted and transported to the treatment course.

Specifications of the tandem accelerator are given in Table 1.

Table 1. Specifications of tandem accelerator

Generation of HV	Schenkel rectifier
Maximum terminal voltage	5 MV
Maximum load current	1 mA
Voltage ripple	2 kV@ 5 MV
Insulation Support	UNILATE®
Insulation gas	SF_6 6kgf/cm^2 gauge
Accelerator tube	glass-metal organic bonding
Charge exchange	Ar-gas stripper Recirculation and concentration by 4 TMP (50 *l*/s/pump)
Injected ion *ME*	6 MeV amu

MEDICAL APPLICATION

We have treated 62 cases of cancer by the end of November 2009 since April 2002. We started treatment for prostate cancer first because it is easy to fix the position of the diseased part during the treatment. In 2003, we introduced the method of stereotactic irradiation coincident with respiratory cycle and started trial of treatment for cancer in other viscera such as liver and lung which move their position in the body by respiratory cycle. Table 2. tabulates the numbers of the treatments and treated parts for each fiscal years (April – March).

OPERATION AND MAINTENANCE

Machine Time

The tandem accelerator supplies beams for all the experiments. Figure 2 shows the operation times for each fiscal year. The upper and lower halves of Figure 2 summarize the machine times for each kind of beam and application, respectively. Total machine time gets more every year and amounts to 4540 hours in 2007.

Table 2: Treatments and treated parts

Fiscal Year	Prostate	Liver	Lung
2002	6		
2003	7	1	
2004	8	1	
2005	7		
2006	7	1	1
2007	8	2	
2008	6	1	
2009	6		

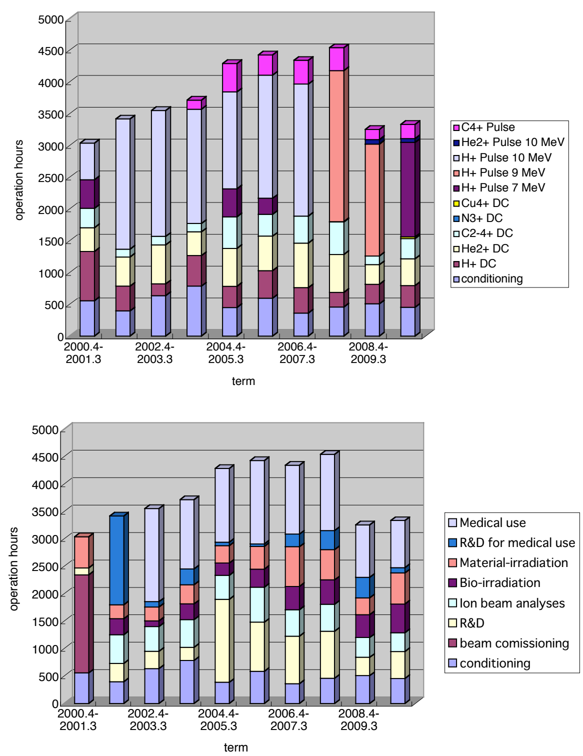

Figure 2. Change of the operation hours of the tandem accelerator. In the upper half, the machine time is summarized for each ion and energy and in the lower for each application.

The upper half of Figure 2 shows that the protons injected to the synchrotron were accelerated to not only 10 MeV (indicated as "H+ pulse 10 MeV" in the figure) but also 7 MeV("H+ pulse 7 MeV") April 2000 through March 2001. This was caused by poor insulation of the insulation column and/or accelerator tube. Improvement of insulation such as fixation of the potential in a short distance on the insulation, utilization of the spark gap and conditioning of the accelerator tube made it possible to apply the voltage of 5 MV stably, therefore, proton is always accelerated to 10 MeV for injection to the synchrotron later. Few overhauls and repairs due to the improvements increased total operation time. However, in 2008, the machine time decreased to the level in the starting of the facility. The insulation breakdown inside of the column support shunted the series of the rectifiers. Current-limiting resistors in the shunted section is directly fed with the RF to be burned out.

Number of treated cases has been almost constant for these ten years, however, Figure 2. shows that the operation time used for the treatment rather decreased in the terms. This is a result of reduction of waiting time before treatment, alternating use of two ion sources and sharing a day with two or more experimental thema.

Improvement of Insulation

The insulated support had a few breakdowns caused by short between the terminal and ground potential through the tube. Our machine has a co-axial structure of the tube and the column support with Schenkel rectifier and there are no fixation of the potential between the tube and the support. The tube is supported at five points, i.e. both ground-side ends of tubes, terminal position and both middle points of tubes. When the terminal potential is shorted to the ground along the tube, difference of the potential between tube and the middle points of the Schenkel column becomes so large as to break the insulated support because of the charge remaining in the stray capacitance in the Schenkel rectifier. Another spark gap was set between the tube and the support at the middle point for the charge so as to go to the ground through the dividing resistor of the tube. The short along the tube is triggered by the beam loading and the poor insulation of the tube above the terminal potential of 3.5 MV, therefore, the ion-optical condition of the injection system was searched in every operation and daily careful conditioning of the tube was done.

Inspection of Insulator

UNILATE has a laminated structure. The structure can yield small detachments in the insulator. The electric field around the delamination should be specifically so large as to cause the discharge leading to the further breakdown. To find the delamination in the insulator, the ultrasonic nondestructive testing is effective. We apply the ultrasound phased array method for the inspection of the inside of the insulator.

Creeping Discharge

Each Schenkel column plate has a zone without any electrodes for the potential formation on the surface. The distribution of the potential is in so delicate state that traces of creeping discharge are found on the surface. Carbon becomes detached along the trace in case of the discharge of the organic matter, therefore, the withstand voltage must be reduced. The leakage current pass along the trace shorts the rectifier to reduce the Q value of the RF oscillation by the heat loss of the RF power in the current limiting resistors. As many traces found are removed as possible.

Discharge of RF Transformer

The discharge between the layers of the coil of the RF transformer or to the ground from the coil or the RF electrode changes the resonance characteristic of the RF oscillator. Especially, the discharge between the RF electrode and the ground is equal to the insertion of the dumping resistor to the LC resonance circuit. The reduction of the Q-value increases the plate current of the oscillator tube by the feedback action of the terminal potential stabilizer. Every layer of the transformer, RF electrodes, RF feed lines and supports of the RF electrodes are inspected whether they have traces of the discharges.

SUMMARY

We have a synchrotron accelerator system at the Wakasa Wan Energy Research Center. One of the important purposes is for the medical use. A 5 MV tandem accelerator works as an injector for the synchrotron, that seems to be rather challenging architecture of the system. The medical use machine is required to be operated without any suspension, however, it is very hard to keep the acceleration high tension and the insulation performance and we have sometimes discharges in the accelerator to lose the performance.

Some improvements for the insulation, operation and maintenance have been performed so as to increase the total machine time and MTBF. In 2007, total machine time amounted to 4540 hours. The figure means the tandem accelerator works for most hours a year as possible taking scheduled suspension of holidays and periodic inspections and maintenances into account.

In 2009, we finished the trial program for the cancer therapy. Requests for the use of heavy ion such as ^{12}C beam should be getting more than for last decade. It is one of the features of the tandem accelerator that any kinds of heavy ions are accelerated. However, recent performance of the insulation is getting worse. In order to take advantage of the characteristic, repair of the insulator might be necessary. Review of the structure of the column support, i.e., method of clamp of the potential on the Schenkel column, might be also required for another decade operation.

REFERENCES

[1] S. Hatori, T. Kurita, Y. Hayashi, M. Yamada, H. Yamada, J. Mori, H. Hamachi, S. Kimura, T. Shimoda, M. Hiroto, T. Hashimoto, M. Shimada, H. Yamamoto, N. Ohtani, K. Yasuda, R. Ishigami, M. Sasase, Y. Ito, M. Hatashita, K. Takagi, K. Kume, S. Fukuda, N. Yokohama, G. Kagiya, S. Fukumoto and M. Kondo, Nuclear Instruments and Methods in Physics Research B241 (2005) 862

[2] http://www.unitika.co.jp/plastics/E/unilate/index.html