TROUBLE RECOVERY AND MAINTENANCE OF AMPLIFIER POWER SUPPLY FOR HIMAC INJECTOR LINAC

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Abstract

In July 2006, a High Power Amplifier (HPA) for Drift Tube LINAC (DTL) broke down in the HIMAC running operation. The trouble was caused by the burst of a one of capacitors in high voltage power supply and by the leaking of the enclosed oil. We designed the plan of the trouble recovery with the primary attention to continue the beam delivery for therapeutical users and carried out it. Accordingly, recovery operations were completed in several hours. We report on details of trouble recovery processes and results of the source analysis. In addition we present the maintenance procedure that has been modified to enhance the prevention of the recurrence.

HIMAC INJECTOR LINAC

HIMAC injector LINAC chain is composed of Radio Frequency Quadrupole LINAC (RFQ) and Alvarez Drift Tube LINAC (DTL) with the operating frequency of 100 MHz, and can accept heavy ions with q/m of more than 1/7 and accelerate up to E = 6 MeV/u, as shown in Fig.1 [1, 2]. DTL has 3 cavity tanks with respective RF power amplifier system which configures three stages: transistor amplifier (TRA), intermediate power amplifier (IPA) and high power amplifier (HPA), as shown in Fig. 2. IPA and HPA using the transmitting tube can perform the maximum output power of 70 kW and 1.4 MW, respectively. The RF power to accelerate C^{2+} ions used for the cancer therapy is estimated of 650-700 kW.

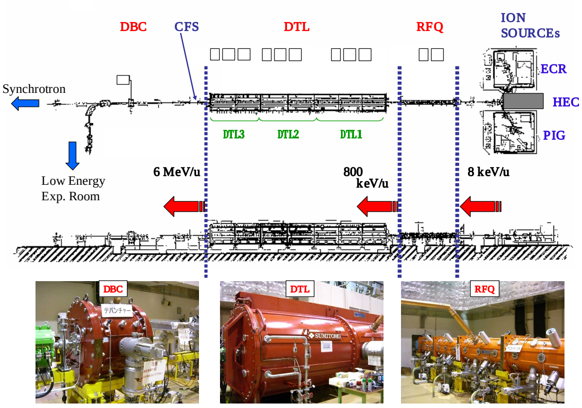

Fig. 1: HIMAC injector LINAC.

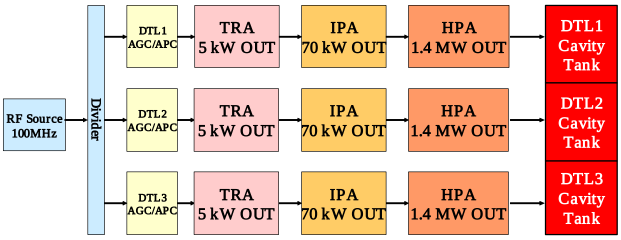

Fig. 2: Diagram of the triple stage RF amplifier system for HIMAC DTL

HPA Plate Voltage Power Supply

To operate HPA on the high power condition, a high DC voltage has to be energized on the plate electrode of the transmitting tube. The HPA plate DC voltage power supply (HPLT_D) is capable of generating the required DC constant voltage of about twenty kilo-volts for three HPAs. In order to suppress the voltage sagging by the RF pulse mode operation, HPLT_D is equipped with the 300 μF capacitor bank which is configured by 10 capacitors connected in parallel. Table 1 lists the specifications of HPLT_D and the installed capacitor, whose sample is shown in Fig.3 (a). By the transformer with the tap changer, the DC voltage is variable of 18, 21, 23.5 kV.

Table 1: Status of HPA plate voltage power supply and installed capacitor bank.

DC Voltage	18, 21, 23.5 kV
Max. DC Current	300 A
Pulse Width	0.1~1.2 ms
Repetition Rate	3 Hz
Voltage Drop Rate	5 %
Capacitance of a Capacitor	30 μF
Total Capacitance	300 μF
Rated Voltage (typical)	24 kV
Weight of Capacitor	180 kg
The number of Capacitors	10

TROUBLE AND RECOVERY PROCESS

Short-Circuited Capacitor

The HPLT_D trouble appeared in a week. The first was a daytime. In HIMAC, the daytime is devoted to the cancer treatment, while the night and weekends are used for experimental studies of physics and biology. According to the alarm message for this trouble, the source of the trouble is either HPLT_D or HPA. In order to discriminate it, we tried the turn on of HPLT_D without loads. The result was that HPLT_D could not be turned on nor generate the high voltage. From a visual inspection of the inside of the HPLT_D cabinet, we found a short-circuited capacitor and accompanying two resistors broken as shown in Fig. 3 (b). All of resistors for the other of capacitors were normal. Under the condition of capacitance of 9 parallel (270 μF), the voltage drop rate is estimated as less than 5 % and is sufficient to obtain RF power to accelerate C^{2+} ions (650-700 kW). Since the cancer treatment should be resumed as quickly as possible, we determined to drive the HPLT_D under the condition of 9 parallel capacitors. Therefore, we separated the short-circuited capacitor from the capacitor bank line and restarted DTL operation. The down time of the beam supply was a half hour.

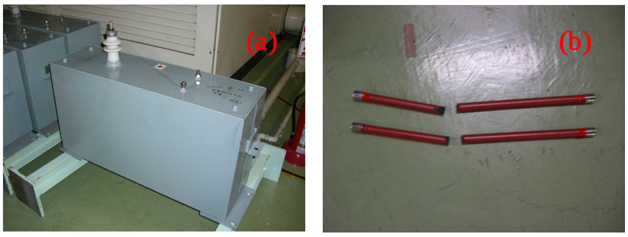

Fig.3. (a) Capacitor for HPLT_D (b) Broken resistors

Capacitor Bursting

Second incidence of the trouble about HPLT_D happened at a midnight of two days later. We have confirmed the foul smell of burned-out oil at the power supply room and the leaking of the enclosed oil from one of the capacitors as shown in Fig. 4 (a) and (b). It was clear that we had to change the capacitor again for the normal operation. And we need it be completed by the next morning, when the cancer treatment resumes. On the other side, an experiment at Biology area happened to stage the 2nd day of three day fractionated irradiation. Thus we had to decide when and how long we stop the beam and work on the recovery of the machine. We reached a conclusion by subtracting estimated necessary time from the 7am time limit, as indicated in Table 2.

Table 2: Our estimated time schedules of the recovery processes for capacitor bursting trouble

Operational Work	Estimated Time
Tentative Repairing	23:00 ~ 1:00
Restart of Beam Supply	For 2 hours
Stop of Beam Supply	3:00 am
Investigation and Restoration	4 hours
Ready condition for cancer treatment	7:00 am

We immediately carried out the cleaning of the interior of HPLT_D and the separation of a burst capacitor. Before scheduled time (1:00 am), the restart of the beam supply to experiment users was achieved. After the beam supply of about two hours to experiments, we went on to work the replacement in a spare capacitor of the separated one and preparations for the medical treatment. All of recovery works were completed by 6:30 am.

Fig. 4. (a) HPLT_D and oil leakage (b) Burst Capacitor

TROUBLE ANALYSIS

Circuit of HPLT_D

Figure 5 shows the diagram of HPLT_D main circuit. Three-phase voltage of 200 Vac is boosted by the transformer with variable tap and is also changed to the direct current by the next rectifier. The direct current is charging the capacitor bank (C1) through a reactor (L1) and resistors (R4 and R7). L1 has a role of the suppression for the incoming current. Also R4 protects the rectifier from the supply current and voltage. Each one of the capacitors is accompanied by two resistors (20

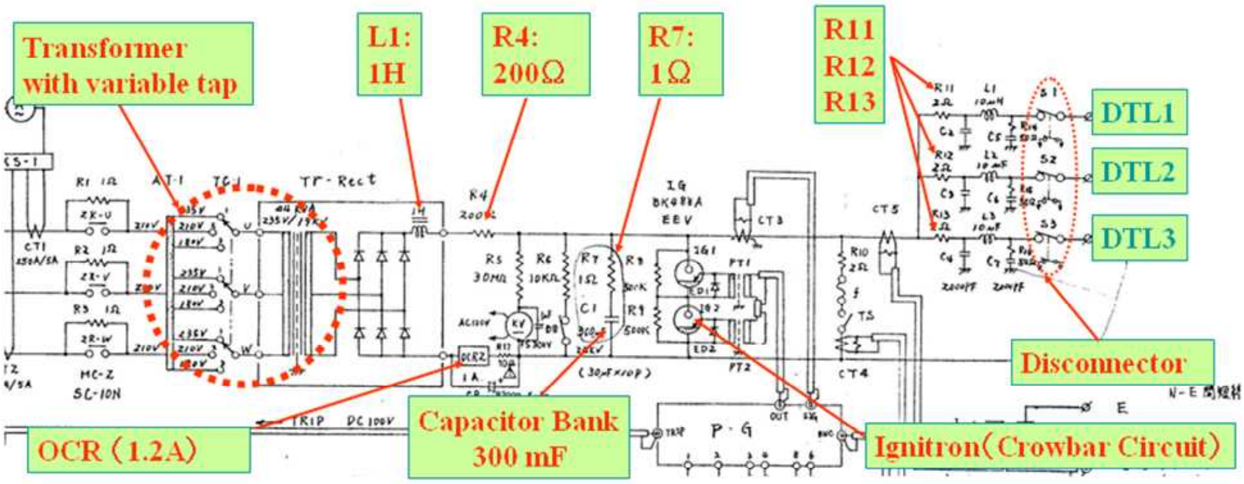

Fig. 5. Main part of HPLT_D circuit

Ohm) which are connected in parallel as shown in Fig. 6. The capacitor bank is responsible for supplying the current to compensate the voltage sagging by the DTL pulse operation.

Analysis of Short-Circuit Capacitor Trouble

The schematic drawing of the capacitor bank circuit is shown in Fig. 6. If a capacitor becomes short-circuited condition for some reason, all amount of stored electric charges in others run through the short-circuited capacitor. Then the attached resistors (R7) are broken in the heating by the high current; these resistors play a role of the fuse. In view of the fact that attached resistors of a short-circuited capacitor were broken, it seems that the mechanism described above happened. The reason of this phenomenon that the capacitor becomes short-circuited is uncertain but is guessed to be the decreasing of the rated lifetime by the degradation of capacitors. In general, the lifetime of the capacitor strongly depends on the repetition times of charge and discharge, the environmental temperature, and impressed voltages. Every capacitor in HPLT_D has been in use for 5 years since 2001. Further discussion is given in the next section.

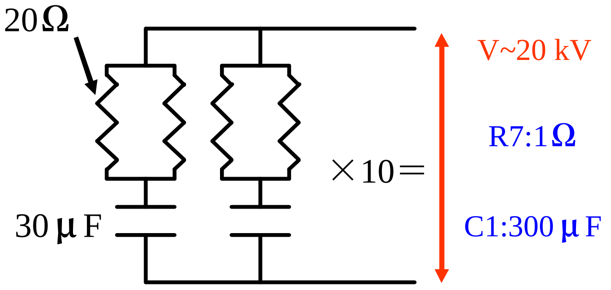

Fig. 6. The schematic drawing of the circuit around the capacitor bank

Analysis of Capacitor Bursting Trouble

We tried to measure the output voltage of HPLT_D on the condition of no-load at the Monday maintenance time of the following week. Table 3 shows measured voltages as a function of the variable tap on the transformer. At the time of trouble, the setting voltage of the variable tap on the transformer was 21 kV. This corresponds to the measured voltage of 24 kV. Taking into account of effects of the exciting voltage by RF operation and the lifetime of capacitor, the actual voltage is well over the rated voltage for the capacitors which is typical of 24 kV and maximum of 30 kV for 1 minute. It is considered that the excess voltage condition inside the capacitor gives rise to the electrical discharge and the burst of the capacitor. As the specification for the impressed voltage of HPLT_D is of about 23.5 kV, we changed the variable tap to the setting voltage of 18 kV.

Table 3: Setting and measured voltage for HPLT_D. The setting of 23.5 kV was not measured because of the capacitor rated voltage of 24 kV.

Setting Voltage of Variable Tap on Transformer [kV]	Measured Voltage (No-Load) [kV]
18	21.5
21	24
23.5	-

MODIFIED MAINTENANCE PROCEDURE

According to the maintenance record of HPLT_D, all capacitors have been exposed to the excess voltage since 2004. At that time, we had received a requirement for the acceleration of low charged state heavy ions (q/M = 1/7). To realize a stable beam supply for that requirement, it was necessary to increase the gain of HPA. Therefore, the setting voltage of variable tap had been set to 21 kV. As it is expected to have caused the decrease of the lifetime of capacitors, we carried out the replacement of all capacitors to brand-new ones. The work has already been finished at Spring 2007.

The enhancement and improvement of the maintenance for HPLT_D is necessary. The precise measurement of the capacitance and the voltage are added in the maintenance procedure for HPLT_D. In order to increase the working efficiency and to shorten time for the replacement of capacitor, we modified the exterior of HPLT_D as shown in Fig. 7. We removed the cable line and duct which is blocking out the replacement work of the capacitor.

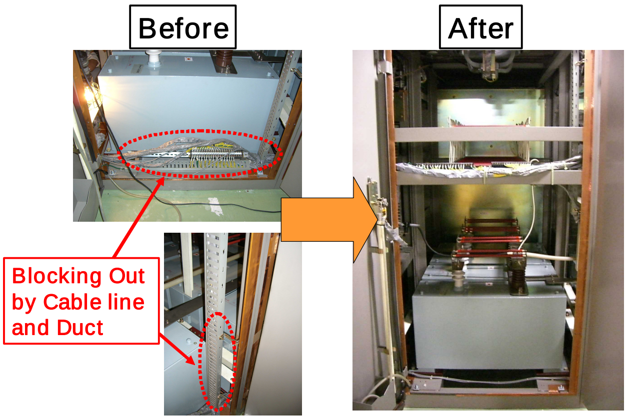

Fig. 7. The remove of the cable line and duct which is blocking out the replacement of the capacitor.

SUMMARY

We described the recovery operation of DTL HPLT_D. In the trouble by the short-circuited capacitor, the down time of the beam supply was a half hour. In another trouble of the burst capacitor, we made a design of the recovery time schedule and carried out it. Our recovery operations along the time schedule realized that the influence for the experimental and medical beam time was kept to the minimum. By our investigation, it became clear that the burst was caused by the excess voltage for the capacitor bank. After the changing the setting voltage of the variable tap to 18 kV and replacing to new capacitors, similar trouble about HPLT_D capacitor is not going on until now.

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