OPERATING EXPERIENCE OF THE J-PARC LINAC

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Abstract

The beam commissioning of the J-PARC linac started in November 2006 and 181 MeV acceleration was successfully achieved in January 2007. The linac has delivered beams to the 3 GeV Rapid Cycling Synchrotron for its commissioning, and then, the subsequent Main Ring Synchrotron and the neutron target commissioning. The linac uses a Cs-free LaB_6-driven ion source and 20 units of 324 MHz klystrons. As of June 2008, the operation times are about 3,000 and 6,000 hours for the ion source and the RF source, respectively. The operating experience of the linac is described.

INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) is a multipurpose facility with 1 MW class proton beam[1]. The facility is under construction at the JAEA/Tokai site as a joint project between the Japan Atomic Energy Agency (JAEA) and the High Energy Accelerator Research Organization (KEK). The J-PARC accelerator consists of a linac, a 3 GeV rapid cycling synchrotron (RCS), and a 50 GeV main ring synchrotron (MR). At the initial stage of the project, the linac accelerates a negative hydrogen beam up to 181 MeV with a current of 30 mA, a pulse width of 0.5 msec and repletion of 25 Hz.

The linac consists of an RFQ, a Drift Tube Linac (DTL) and a Separated-type Drift Tube Linac (SDTL). The features of the linac are described in [2]. High power conditioning of the cavities and beam test started in October and November 2006, respectively, then 181 MeV energy acceleration was achieved in January 2007. Since then, the linac beams have been used for the linac commissioning for its own, for the RCS commissioning, for neutron production, and for RF capture experiment at the MR.

We have adopted a three to four weeks commissioning cycle, which consists of a two or three week beam commissioning run and a one or two week interval. Adjusting the terms of intervals to accommodate appropriate maintenance periods, 17 beam commissioning cycles have been experienced from November 2006 to June 2008. Detailed beam commissioning results are described in [3].

FRONT END

The J-PARC linac uses a Cs-free, LaB_6-driven, multicusp H^- ion source[4]. The diameter and the length of the plasma chamber are 100 and 120 mm, respectively. The source plasma is confined by the multicusp magnetic field by 18 rows at the sidewall and four rows at the upper flange. The filament is a cylindrical spiral structure LaB_6 and the size is 29.5 mm and 49 mm in diameter and height, respectively.

Figure 1 shows the history of the ion source operation. During intervals between commissioning cycles, we have performed maintenance or ion source study. The pink and green bars denote the typical H^- beam current in the commissioning days and the ion source study days, respectively. The maximum beam current from the ion source is 38 mA at the arc duty factor of 0.8 % (0.32 msec in pulse width and 25 Hz). Since the commissioning tasks doesn't always require a high peak H^- beam current, the ion source has been operated either at the low current mode of 5 mA or at the high current mode of 30 mA. To keep the condition of the plasma chamber surface good, the ion source keeps running of the filament or beam extraction during the nighttime in the commissioning days. Operation time of the source has been reached to 3,360 hours as of June 2008.

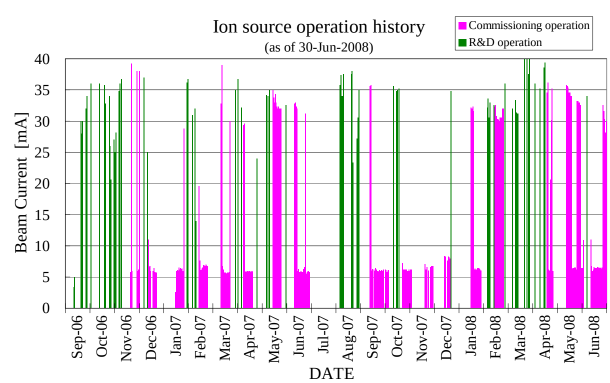

Figure 1: Operation history of the ion source.

On October 6 and December 18, 2006, filament had troubles of short-circuit to the neighboring spirals. The troubles were caused by filament deformation due to the arc power heating. Then the filament shape was modified to have a wider gap between spirals from 0.3 to 0.6 mm. We have not had similar troubles since then.

On August 21, 2007, we had a cutting off of the filament. We consider that the filament was broken by some strong mechanical stress because the filament showed no signs of remarkable consumption. The filament was replaced with a studious care. That filament lasted by June 28, 2008. The beam time was 2,030 hours,

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which consists of 780 hours in high current mode and 1,250 hours in low mode. We have not had enough statistics regarding the lifetime, but we have a confidence that the LaB_6 filament is of practical use for a few weeks user run.

DTL/SDTL CAVITIES

The DTL consists of 3 tanks operating at 324 MHz with final output energy of 50 MeV. The transverse focusing is arranged in an FD lattice utilizing electro-magnet. After high-power conditioning of the DTL was completed up to 1.2 times as high as the nominal power level, the beam commissioning of the DTL was achieved in the second run, December 2006[5,6].

We have 32 SDTL tanks but two of them are used as debunchers. The inter-tank sections contain electromagnet quadrupole doublets with beam position monitors inside. Either steering magnet, wire scanner, or gate valve is arranged in between the doublet. The 181 MeV acceleration was achieved on January 24, 2007. We haven't had noteworthy troubles for the DTL/SDTL cavities during the commissioning.

We have 111 and 33 Q-magnet power supplies in the DTL and the SDTL sections, respectively. We had several troubles for these power supplies: replacement of the IGBT unit (2), repair of control unit (2), loose connection of switch (2), and others (1). Some of them happened or found during the maintenance period and not all the failures caused the beam trip. The downtime of the beam is 2 or 3 hours when the failed power supply is replaced by a spare.

We had water leakage in the accelerator tunnel twice due to the flow meter glass breakage. The cause was assumed that small cracks made in the fabrication or in the installation process grew by some shock. All the 64 flow meters, which were the same type of the broken ones, were replaced by commonly used type and installed carefully in summer, 2007. Since then, we have not had the similar troubles.

RF SYSTEM

Figure 2 shows the RF subsystem. Six high voltage DC power supplies (HVDCPSs) supply the pulsed power to the 20 klystrons. Transmitter systems that control the klystrons and solid-state amplifiers provide RF power to the structures. Stabilization of the cavity fields is well performed with a feed-back and feed-forward control system[7].

The HV trip rate as a function of run number is shown in Fig. 3. At the early stage, we had occasional malfunctions of the crowbar circuit in the HVDCPS. That was improved by replacement of the registers at the current transformer (CT). However, in runs 14 and 15, fault rate increased suddenly. This was caused by discharges between the CT for modulation anode current measurement and the neighbouring wire. The insulator near the CT was replaced as a temporary measure, and we are planning to modify the arrangement around the CTs as a permanent measure.

Other than the power supply itself, HV trips have been caused by timing related matters such as setting error, timing signal failure, 12 MHz master oscillator failure. In these cases, the interlock stops the system because the monitor shows the abnormal state. These issues have been settled one by one based on these experiences.

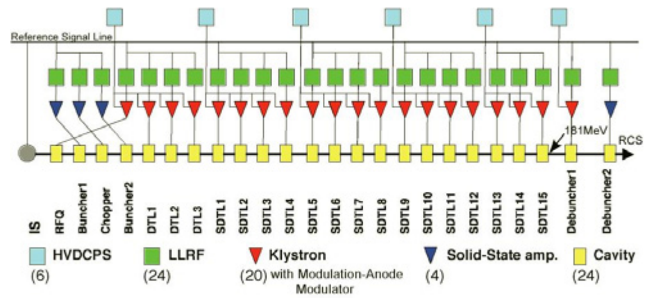

Figure 2: J-PARC linac RF system.

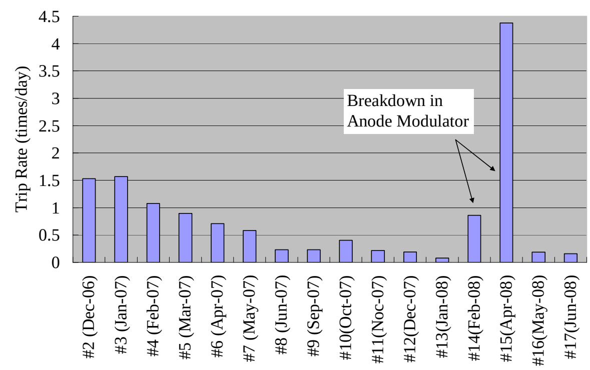

Figure 3: HV trip rate as a function of run number.

We have totally 23 klystrons (Toshiba E3740A) including 3 spares. Figure 4 shows the operation hours of the klystrons in use. The current average operation time is 6,460 LV-on (filament) hours and 5,960 HV-on hours as of June 2008.

Klystrons are consumables (limited lifetime) and costly parts for linac. Reliability engineering approach is taken to estimate the lifetime. So far, we have no failed klystrons, but we can assume the lower limit of Mean Time To Failure (MTTF). If we assume the exponential failure distribution α=exp($-\lambda$T), that refers to the random failure, where λ, 1-α and T are failure rate, confidence level and operation time, respectively. If we take a confidence level of 90 %, failure rate is

$$\lambda = -\ln(1-0.9)/T = 2.30/T \quad (1)$$

If we put the total operation time T=129,292 (hours) for all 20 klystrons, upper limit of failure rate and lower limit of $MTTF_{lower}$ are

$$\lambda_{upper} = 1.78\times10^{-5}\ (1/hour) \quad and$$

$$MTTF_{lower} = 1/\lambda_{upper} = 56{,}200\ (hours)$$

The Poisson distribution denotes probability of klystron failure as the similar manners in [8]

$$f(x) = \frac{\mu^x}{x!} e^{-\mu} \qquad (2)$$

Then, with 20 klystrons and 5,000 hours per year operation, we expect the average number of consumption per year is

$$\mu = N\lambda t = 20 \times 1.78 \times 10^{-5} \times 5{,}000 = 1.78$$

Figure 5 shows the number of failure klystrons after one or two year operation. Above analysis shows that the average consumed number in one year is about 2, but there are high probability of 3 or more klystron failures. It may be said that the 3 spares we have are too short to keep operating for user run. In addition, above estimation would be somewhat optimistic because it is based on the random failure, or constant failure rate (CFR) distribution. This kind of failure tends to follow the increase failure rate (IFR) distribution. Some of them would fail almost simultaneously. In the latest run in September 2008, meaningful emission degradation for 5 klystrons is observed. We should carefully keep an eye on them.

UTILITIES

We have had unscheduled stop three times due to the cooling water pump trip. This brings almost all the linac system sudden stop including high power RF system. It takes several hours to resume the operation. This pump is for the cooling system of the cavity tanks, which is made of steel. Rust has accumulated and sticks into the magnetic field of the canned pump. Then the line current increases and reaches to the breaker trip level. We have taken a careful quality control of the cooling water and monitoring the pump current for the time being. The type of the pump itself is reconsidered as a permanent measure.

At the initial stage of the beam commissioning, we had occasional stops by the flow rate interlock due to the total cooling water flow decrease and flow balance change. We have had accumulated these operation experiences and the frequency of such failure is going down.

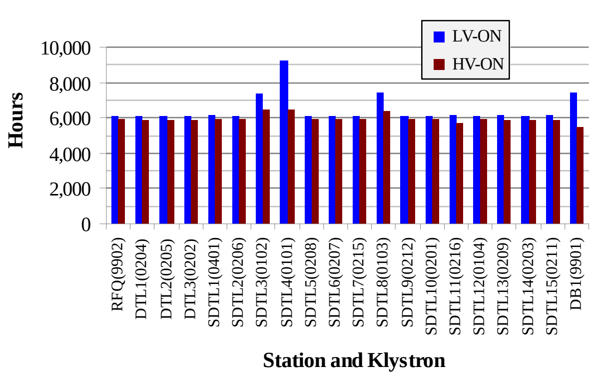

Figure 4: Total klystron operation hours.

SUMMARY

The J-PARC linac has been successfully commissioned and operational experiences have been accumulated. The Cs-free, LaB_6 filament driven ion source demonstrates good performance from a point of view of beam current and lifetime. The DTL and SDTL cavities have been operated without serious troubles. The trip causes are overcome one by one for the RF source and trip rate has been greatly decreased. The average operating hour of the klystrons exceeds 6,000 and the spare issues are discussed. Although we had many cooling water related failures at the initial stage, they are improved and the availability has been increased. Based on these experiences, we will go into a new phase of the user run from December 2008.

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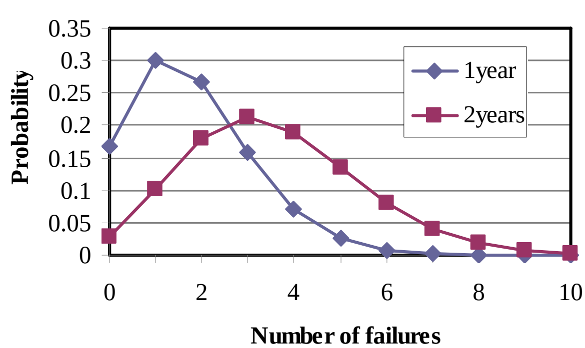

Figure 5: Probability of failure of klystrons in the first and second year.