STATUS AND RECENT MODIFICATIONS TO 324-MHz RF SOURCE IN J-PARC LINAC

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Abstract

This paper describes the present status of and the recent modifications to the 324-MHz RF source in the J-PARC linac. The recovery from the Great East Japan Earthquake Disaster, the status of the 324-MHz klystrons, the failure of 3 high-voltage transformers (HVTRs), and the discharge suppression for the anode-modulators are described.

INTRODUCTION

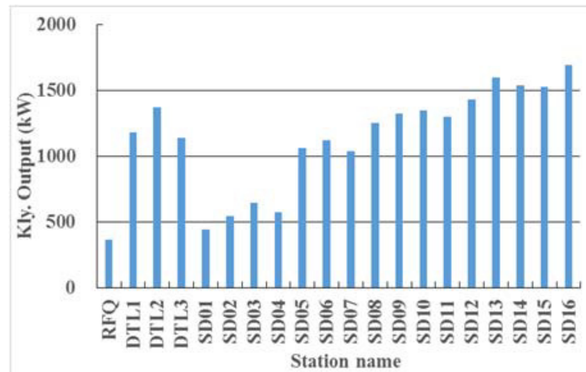
The J-PARC (Japan Proton Accelerator Research Complex) linac [1] began 400-MeV operation on January 17th of this year [2]. The linac comprises two RF sources: a 324-MHz RF and a 972-MHz RF source. The 324-MHz RF source, which is primarily composed of 20 klystrons and the power supply systems for these klystrons, has been in operation since 2006. The majority of the 324-MHz RF source components have total operating times of over 35,000 hours. This paper will give a brief overview of the present status of this system, along with a summary of recent modifications necessitated by various external and internal factors, such as the Great East Japan Earthquake Disaster and the recent 400-MeV upgrade.

PRESENT STATUS

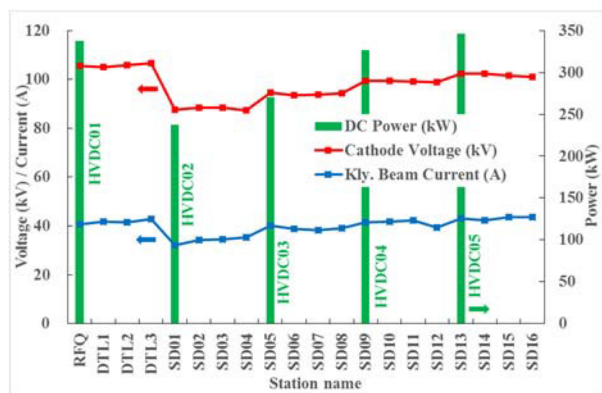
From November 2006 [3] to May 2013, the output energy of the J-PARC linac was 181 MeV. The 324-MHz RF source of the 181-MeV linac [4] was composed of 20 klystrons (TOSHIBA, E3740A [5]) and the power supply systems for these klystrons consisted of 6 high voltage DC power supplies (HVDC01-06) and 20 anode-modulators (one anode-modulator connected to one klystron). Four HVDCs, numbered HVDC01 - HVDC04, connected four anode-modulators and klystrons. In addition, three anode-modulators and klystrons (stations SDTL13, 14, 15) were linked by HVDC05, and HVDC06 connected one anode-modulator and one klystron (DeBuncher01 station).

Between August and November 2013, the linac was upgraded from 181 MeV to 400 MeV. The 324-MHz RF source was adjusted to comprise 20 klystrons, 20 anode-modulators (stations RFQ, DTL1-3, SDTL01-16), and 5 high voltage DC power supplies (HVDC01-05). HVDC05 was then composed of four anode-modulators and klystrons (SDTL13, 14, 15, 16) and HVDC06 was relocated to the 972-MHz RF source.

At present, the typical operational conditions of the 324-MHz RF source are as follows: the repetition rate is 25 pps, the RF pulse width is 600 µs, and the power supply pulse width is 700 µs. Figure 1 shows the measured values of the klystron output powers, the cathode voltages and the beam currents of the klystrons, and the HVDC powers, when negative hydrogen ion beams of 15 mA and 500 µs are accelerated. Similar neutrino, neutron and muon experiments are scheduled to take place in June 2014.



(a)



(b)

Figure 1: The measured values of the 324-MHz RF source. (a) The klystron output powers. (b) The cathode voltages and the beam currents of the klystrons, and the HVDC output powers.

RECENT MODIFICATIONS

In this section, modifications made to the 324-MHz RF source since September 2010 are primarily described. (Revisions and performance up to August 2010 have been described in ref. [4].)

Recovery from Earthquake Disaster

A large earthquake with a magnitude of 9.0 struck north-eastern Japan on March 11, 2011 (the Great East Japan Earthquake Disaster). The J-PARC is located in Tokai-mura, Ibaraki-ken, which is approximately 200 km from

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Figure 2: A broken anode-modulator anchor bolt [10].

the epicenter of this event. The earthquake's intensity at Tokai-mura measured a "6-lower", which equates to the third highest intensity on the ten-ranked Japanese seismic scale. As a result, the flooring of the linac facility building ground-floor was displaced in both vertical and horizontal directions [6].

Concerning the components of the 324-MHz RF source, the most significant damage was the subsequent decrease in the external resistance of the ignitrons [7]. Ignitrons (National Electronics, NL7703EHVNP [8]) are used as crowbar switches [1,9], and comprise 29 components of the 6 HVDCs (HVDC1-6). The external resistances between the ignitors and the cathodes, which are infinite at normal level, decreased by under 10 Ω in 24 components (82.8% overall). The cause of this decrease was taken to be the shaking sustained in the ignitrons during the earthquake, which resulted in the spillage of the mercury in the ignitrons onto the ignitors. To repair the 24 faulty ignitrons, the method of impressing DC voltages (2 – 10 V) between the ignitors (-) and the cathodes (+) was used. As a result of this treatment, 20 pieces were recovered (a recovery rate of 83.3%). The 4 remaining faulty ignitrons were replaced [7].

The other main effects of the earthquake are as follows [7,10]: (i) Many of the klystron output windows sustained unexpected forces, and some of the anode-modulators' anchor bolts were broken (Figure 2). A number of racks, where the low-power sources and control modules are mounted, canted in various directions, preventing many of the rack doors from opening. (ii) Damage to the roofs of the two HVDC rooms led to rain leakage. (iii) As a result of the suspension of the electricity service, all the klystron ion pumps had been turned off for a long time.

With the aim of resuming accelerator operation as soon as possible, many recovery tasks were performed without delay. Fortunately, there were no fatal errors in the 324-MHz RF source components, which would require long-term repair. Consequently, at the beginning of November 2011, overnight operation of the RF source resumed. Beam operation resumed on December 9, 2011, 273 days after the earthquake of March 11.

324-MHz Klystrons

In the 324-MHz RF source, 20 klystrons have been in operation since November 2006. A total of 6 klystrons have been replaced to date.

Four were replaced as a result of malfunctions: (i) SN0201 in station SDTL10 (which required higher power) caused frequent discharge inside the tube, so it was exchanged with SN0401 in station SDTL01 (which required lower power) in December 2010. (ii) It was observed that SN0205 in station DTL2 was experiencing frequent discharge between the anode and the body [11], so it was replaced with SN0213 (a new klystron) in February 2013. (iii) SN0209 in station SDTL13 was not capable of sustaining the required voltage so, in February 2014, it was replaced with SN0801 (a new klystron). (iv) SN0211 in station SDTL15 caused much high-voltage breakdown, and it was therefore replaced with SN1101 (a new klystron) in June 2014.

A further 2 klystrons were replaced for other reasons: (v) In station RFQ, SN9902, with operating cathode voltage ~80 kV, was replaced with SN0214, a new klystron of operating cathode voltage greater than 100 kV, because of a change in high-voltage transformer (HVTR) (described in the subsection "High-voltage Transformers") in April 2012. (vi) SN9901 was replaced with SN0210, because the station was changed from station DeBuncher01 (which required lower power) to station SDTL16 (which required higher power) (October 2013).

High-Voltage Transformers (HVTRs)

In the 324-MHz RF source, 5 HVTRs are in operation. A HVTR is a device comprised of transformers and rectifiers (diodes) in an oil tank. The HVTR converts the input 600 V AC power (from an AVR (automatic voltage regulator)) into output high-voltage DC power of 110kV maximum, which is then transferred to the anode modulators.

A total of 3 HVTRs failed: HVTR01 in March 2012 (the total operating hour was 28,400h(hours)), HVTR02 in December 2013 (30,200h), and HVTR05 in June 2014 (36,000h), respectively [12]. HVTR01 was replaced with HVTR11 and HVTR02 with HVTR14, respectively. HVTR05 has not been replaced yet, and will be replaced with repaired HVTR02.

The problematic components were identical in both HVTR01 and HVTR02 transformers, i.e., the ceramic condensers in the diode-stacks (120 kV, 4 A), and are thought identical in HVTR05. A HVTR is composed of 6 diode-stacks (3 parallel x 2 series) and an old-style diode-stack is composed of 12 (series) diode-modules. (The term "old-style" is used here as this design has since been revised, as explained below.) In turn, a diode-module comprises 11 (series) diodes, and a diode and a ceramic condenser (2200 pF, 3 kV) are connected in parallel. The diodes and the ceramic condensers are fixed in the diode-modules using mold resin. After the disassembly examination, creeping discharges were confirmed in many

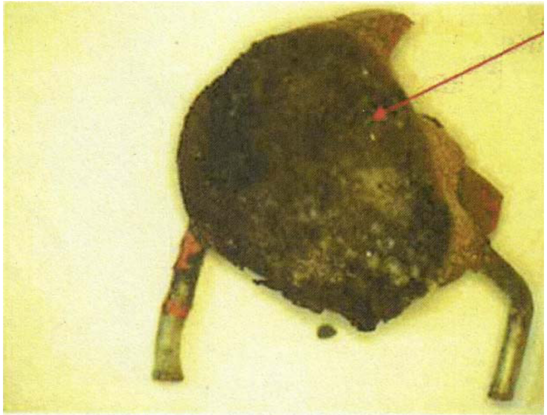

Figure 3: A carbonized ceramic condenser in the HVTR diode-stack.

condensers and it was found that some had carbonized (Figure 3). The result of the investigation showed that unexpectedly high voltages had been impressed on the condensers, but a systematic understanding of the source of these high voltages and the precautionary steps necessary for the protection of the remaining HVTRs (HVTR03, 04, and HVTR06, 12 in the 972-MHz RF source), have not yet been determined. HVTR01 had unique specifications in that it had two outputs of 80 kV and 110 kV Max., and therefore it was discarded. Its successor, HVTR11, is standard with one output of 110 kV Max., and therefore the klystron in station RFQ was replaced (as described in the subsection "324-MHz Klystrons"). HVTR02 was repaired by manufacturer. New-style diode-stacks, which have been installed in HVTR07-10, 13 (in the 972-MHz RF source) and HVTR11, 14, and which have been installed in repaired HVTR02, do not make use of the mold resin in the diode-modules.

Anode-Modulators

Regarding the anode-modulators, much electric discharge had occurred since the start of operations in 2006 [4,13]. Before new anode-modulators for the recent energy upgrade were manufactured, thorough steps to prevent electric discharge had been taken: (i) the arrangements of the machine parts, and the shapes of the parts, had been changed, (ii) the isolation transformers, around which much discharge had occurred during removal from the oil tank, had dipped into the tank [13].

The 25 new, improved anode-modulators for the 400-MeV upgrade had been manufactured and delivered to the J-PARC linac building before the Great East Japan Earthquake Disaster. However, when the earthquake occurred, the 15 anode-modulators of the 324-MHz RF source had not been upgraded. During the period between the termination of overnight operations in July 2012 to the resumption of operations in September 2012, the 15 original anode-modulators were replaced with the revised designs. At that time, the cranes in the linac building could not function, so the anode-modulators were moved overground. The 15 original devices were returned to the manufacturer, where they were recalibrated and returned to the linac building until February 2013[14]. All 45 anode-modulators were re-arranged in July 2013 using cranes.

The overnight operation of the 324-MHz RF source resumed in November 2013, and no fatal electric discharges involving revised components occurred.

SUMMARY

Since 2006, the 324-MHz RF Source in the J-PARC linac has been in operation for over 35,000 hours. It has experienced many kinds of malfunction, including electric failures, earthquake disasters, and so on, and has undergone a number of resultant design modifications and repairs. In addition, a linac energy upgrade to 400 MeV was achieved in January 2014.

Going forward, a quick response to malfunctions followed by efficient repair will be of increasing importance. After longer operations, quite a few components will most likely require replacement. As these components are expensive and require considerable manufacturing time, an appropriate plan for efficient future operation and maintenance for the 324 MHz RF source will be essential.

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