PERFORMANCE OF J-PARC LINAC RF SYSTEM

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Abstract

High power operation of all the RF systems of J-PARC linac was started for the cavity conditioning in October 2006. Twenty 324-MHz klystrons have supplied the power to the accelerating cavities successfully, and the beam commissioning was started in November 2006. The RF drive and control systems are working well, and required stability is satisfied.

INTRODUCTION

J-PARC Linac provides 181-MeV proton beam to the 3-GeV rapid-cycling synchrotron (RCS) at the first phase (Phase I) [1]. This linac consists of 20 accelerating cavity modules (an RFQ, 3 DTLs and 16 SDTL modules), which are driven by klystrons. The operation frequency is 324 MHz. The maximum RF pulse width is 620 μs, including cavity build-up time, and the repetition is 25 pps in the Phase I.

We should keep the cavity field stability within ±1% in amplitude and ±1 degree in phase against the external disturbance. The main factors of the instability are the voltage sag and the pulse-to-pulse fluctuation of the klystron DC power supply, the temperature drift and the beam loading.

High power operation of all the RF systems was started for the cavity conditioning in October 2006. Twenty 324-MHz klystrons have supplied power to the accelerating cavities successfully, and the cavity conditioning processed well. The beam commissioning was started in November 2006 then the 181-MeV acceleration was succeeded. The RF feedback/feed-forward control system is working well. The performance of the RF system will be reported in this paper.

RF SYSTEM

Figure 1 shows the overview of the J-PARC Linac RF system. We have 6 high voltage DC power supplies (HVDCPS) and 20 klystrons and 4 Solid-State amplifiers. Therefore 24 low level RF (LLRF) systems are required.

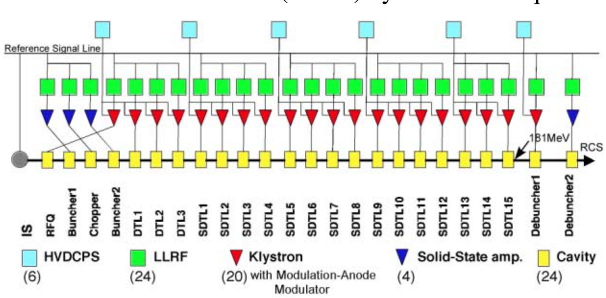

Figure 1: Overview of the RF system.

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Table 1: Main parameters of the HVDCPS

DC voltage output	110 kV (incl. sag drop voltage)
Pulse width	700 μsec
Pulse repetition rate	50 Hz (Max)
Voltage sag	< 5%

Table 2: Main parameters of the 324-MHz klystron

Peak Power	2.5 (max. 3.0) MW
Pulse Width	650 μs
Repetition	50 Hz (25 Hz)
m-Perveance	1.37 A/V $^{3/2}$
Gain	50 dB
Efficiency	55 %
Beam Voltage	105 (max. 110) kV
Beam Current	45 (max. 50) A
Mounting Position	Horizontal

One HVDCPS drives 4 klystrons [2]. Table 1 and 2 shows the main parameters of the 324-MHz klystron and the HVDCPS, respectively.

KLYSTRON PERFOMANCE

We have 23 klystrons including 3 spares in total. Performance study of the klystron was done for the all klystrons. The important characteristics, for instance, frequency characteristics, perveance, gain and efficiency, were evaluated, and it is found that they satisfy the required specifications. Figure 2 shows the typical one of the input-output characteristics. As shown in the figure,

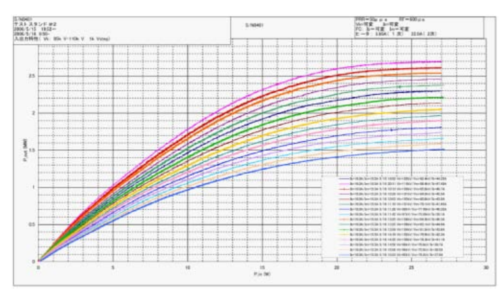

Figure 2: Input-Output characteristics of the klystron.

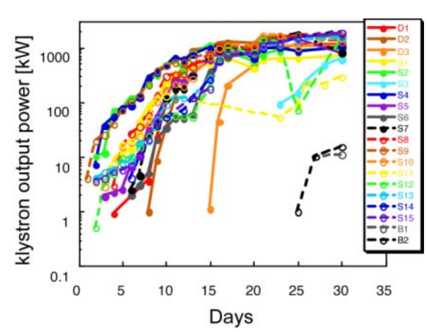

Figure 3: Conditioning history of the cavities.

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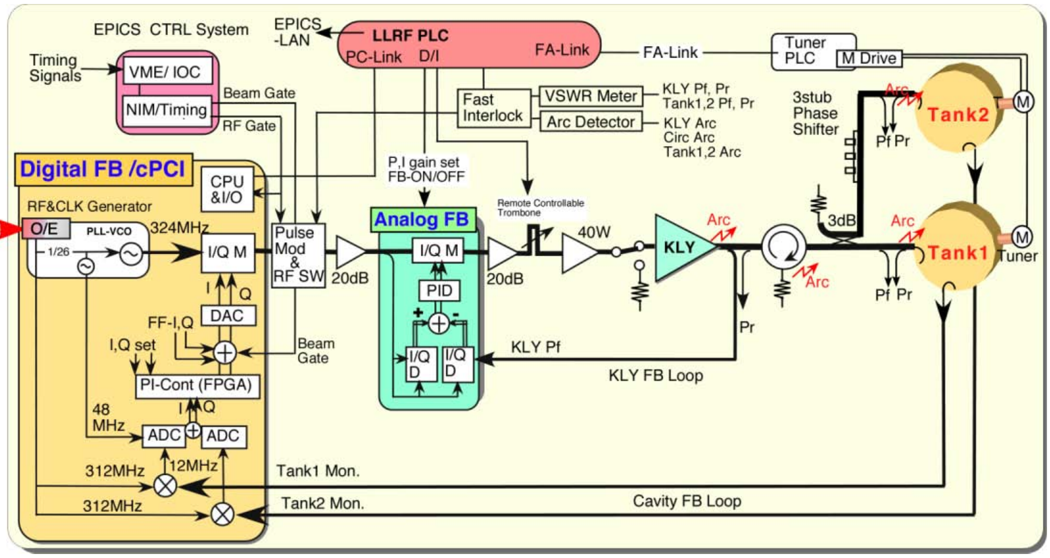

Figure 4: Schematic draw of the LLRF System.

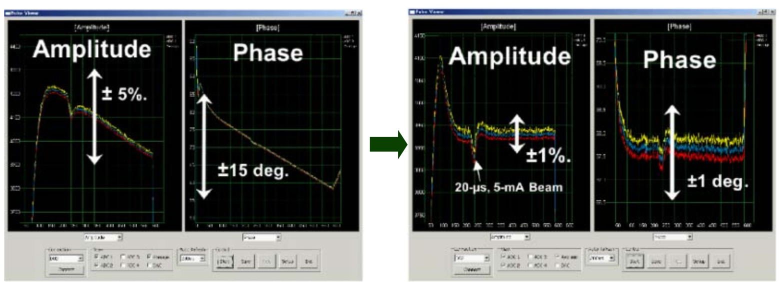

Figure 5: Pulse waveform of the DTL cavity field. The left is without feedback control, and the right is feedback control result.

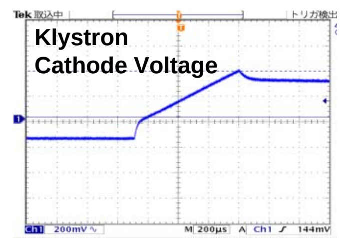

Figure 6: Klystron cathode voltage with 3.4 % sag in a 700-μs pulse modulation.

smooth curves were obtained for various cathode voltage of the DC supply. This property is important for the stable feedback control. The detail of this performance study is reported in [3].

The conditioning history of the cavities is shown in Figure 3. The designed power was achieved in about a month. We have no fatal troubles in the klystron operation for the beam commissioning.

LOW LEVEL RF CONTROL SYSTEM

Figure 4 shows an illustration of the LLRF system. For stabilization of cavity field, a digital feedback (FB) & feed-forward (FF) control system, which acts on a cPCI crate system, was developed [4]. It generates the standard signals and it also controls the resonant frequency of the cavity. The 312-MHz optical signal is received by an O/E in the cPCI as the phase reference [5].

One klystron feeds power to 2 cavities in the SDTL section as shown in Figure 4. The FB system controls the vector sum of the I/Q components of two cavity fields. The amplitude and the phase of the two input ports were matched with each other in accuracy of ±1% and ±1 degree, respectively, by adjusting the hybrid power divider and the three-stub phase shifter in the waveguide system.

An analogue fast FB control system is optionally installed for the klystron-FB loop in order to make the klystron to act an ideal linear amplifier for the cavity FB control. The analogue FB control is not used in the present operation because only the digital FB control sufficiently satisfies the required stability.

Cavity-tuners are controlled from the cPCI by way of a program logic controller (PLC) [6], and the auto-recover sequence from the fault down is processed by the PLC.

The details about the high-power protection system and the remote control from EPICS are described in Reference [7].

PERFORMANCE OF RF CONTROL

Stabilization by FB control

Performance of the stabilization of the cavity fields will be described below. Figure 5 shows the pulse waveform of the DTL cavity field. The left figure is without FB control. 25-degree phase sag is due to DC voltage sag of about 3.4% as shown in Figure 6. FB control result is shown in the right of Figure 5. The amplitude and phase are stabilized to be ±0.15% and ±0.15 degrees, respectively, during the flat top and for the pulse-to-pulse fluctuation. The ripple in the pulse is caused by beam

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loading (5 mA, 20 μs). It must be completely compensated with feed-forward control.

Beam Loading Compensation by FF control

Figure 7 (above) shows the beam-loading ripple caused by a beam of 26-mA peak current and 50-μs duration in the DTL cavity field with only FB control. The amplitude and phase are changed by ±2.7% and ±1.5 degrees, respectively, at the rise/fall of the beam. By using the FF control with FB, this field change due to the beam loading was vanished almost perfectly as shown in Figure 7 (below), however, it is necessary to adjust a timing of a beam-synchronized control gate by 0.1-μs step. Furthermore, optimum values of the FF amplitude and phase depend on beam current.

The beam current decay of about 3% was observed in 181-MeV acceleration without the FF control. By applying the FF control to all cavities, then the current decay disappears obviously.

Long Term Stability

A trend of the amplitude and phase of the DTL cavity field under the FB control was measured by external monitor for 2 days during beam study. The result is shown in Figure 8. The amplitude drift is ±0.15% and the phase drift is ±0.15 degrees during 2 days. This result is also including the characteristics of measurement components such as the detector, mixer and so on. Thus, cavity field is maybe more stable than observed values.

The phase stability between different cavities also satisfies requirements, considering that the phase stability of the RF reference is within ±0.1 degrees [5].

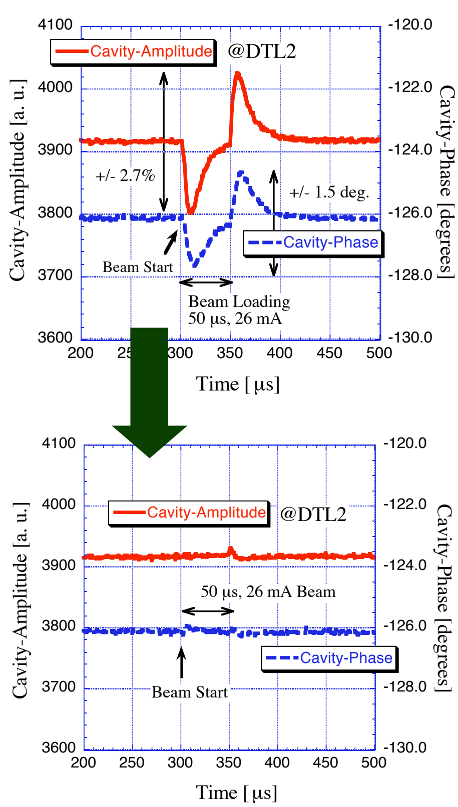

Figure 7: The above is the beam loading (26 mA, 50 μs) in the DTL2 cavity amplitude and the phase with only feedback control. The below is the feed-forward compensation result.

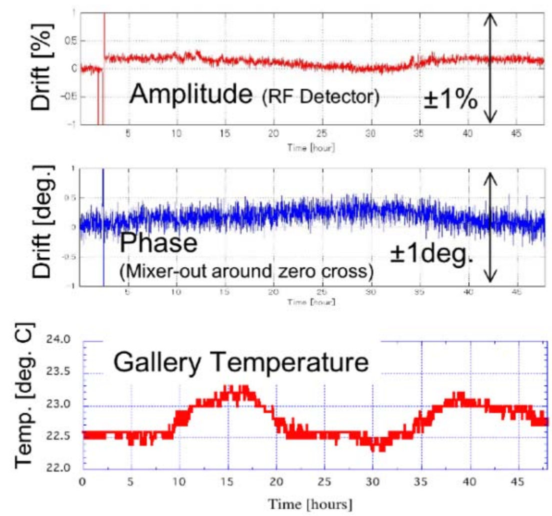

Figure 8: Trend of the amplitude and the phase of the DTL cavity field with FB control measured by external monitor for 2 days.

SUMMARY

Most machines of the RF system are working well without fatal problem and have supplied the powered to the accelerating cavities successfully then the 181-MeV acceleration was succeeded. The digital FB control system is performing according to the expectation and then required field stability is achieved. The validity of the beam loading compensation by the FF control was observed.

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