OVERVIEW OF THE RF SYSTEM FOR THE JAERI/KEK HIGH-INTENSITY PROTON LINAC

S. Yamaguchi†, S. Anami, S. Fukuda, T. Kato, M. Kawamura, C. Kubota, S. Michizono, H. Nakanishi, M. Ono, KEK, Tsukuba, Ibaraki, 305-0801, Japan
E. Chishiro, K. Suganuma, T. Kobayashi, JAERI, Tokai, Ibaraki, 319-1195, Japan

Abstract

The construction of a high-intensity proton linear accelerator has started as the JAERI/KEK joint project. The injector linac provides 400-MeV proton beams for the following 3-GeV rapid-cycling synchrotron. The rf system for the linac is composed of high-power klystrons, high- voltage DC power supplies, a waveguide system, an rf drive and control system and a buncher, chopper driving system. An overview of the rf system is presented.

1 INTRODUCTION

The construction of a high-intensity proton accelerator complex has started as a joint project of JAERI and KEK at the JAERI site in Tokai [1]. This accelerator complex is composed of a 400-MeV proton linac, a 3-GeV rapid cycling synchrotron (RCS) and a 50-GeV synchrotron. The linac provides proton beams to ADS (Accelerator Driven Transmutation System) as well as RCS. The role of the rf source for the linac is to provide rf power to twenty low-energy accelerating structure modules (an RFQ, 3 DTLs and 16 SDTLs) operating at 324 MHz and twenty-three high-energy accelerating structure modules (ACS) operating at 972 MHz. The maximum pulse width and the repetition rate are 650μs and 50 Hz, respectively. The layout of the rf system is shown in Figure 1. The required accuracy of the field stability is ± 1% in amplitude and ± 1degree in phase.

2 RF DRIVE AND CONTROL SYSTEM

The drive system [2] distributes a 12-MHz master clock signal to each station (4 solid state amplifiers and 46 klystrons), which will be installed in the klystron gallery with a total length of 350 m. Accelerating frequencies of 324 MHz and 972 MHz are generated at the front end of each power station by a voltage-controlled crystal oscillator (VCXO), which is phase-locked with the distributed 12-MHz signals. For distributing the 12-MHz signals, phase-stabilized optical fibers will be used, which have a phase stability of 1 ppm per °C in order to satisfy the phase- stability requirement of ± 1degree for a room-temperature fluctuation of 2 °C.

In order to stabilize the amplitude and phase of the field in the accelerating cavity, the feedback and feed-forward control is used in the low-level rf controller [3]. The feedback and feed-forward control is performed by a combination of FPGAs for fast and simple processing and DSPs for slow and complicated processing. A prototype of the low-level rf controller is now under testing using an SDTL cavity in high-power operation with preliminary results of the required field stability.

The feasibility of the feedback control of the amplitude and phase was demonstrated for a DTL test cavity using analogue modules with two feedback loops: a major loop for the DTL cavity and a minor loop for the klystron (see Fig.2). Proportional and integral (PI) control using an I/Q modulator and a demodulator was adopted. The input power of the cavity was 400 kW.

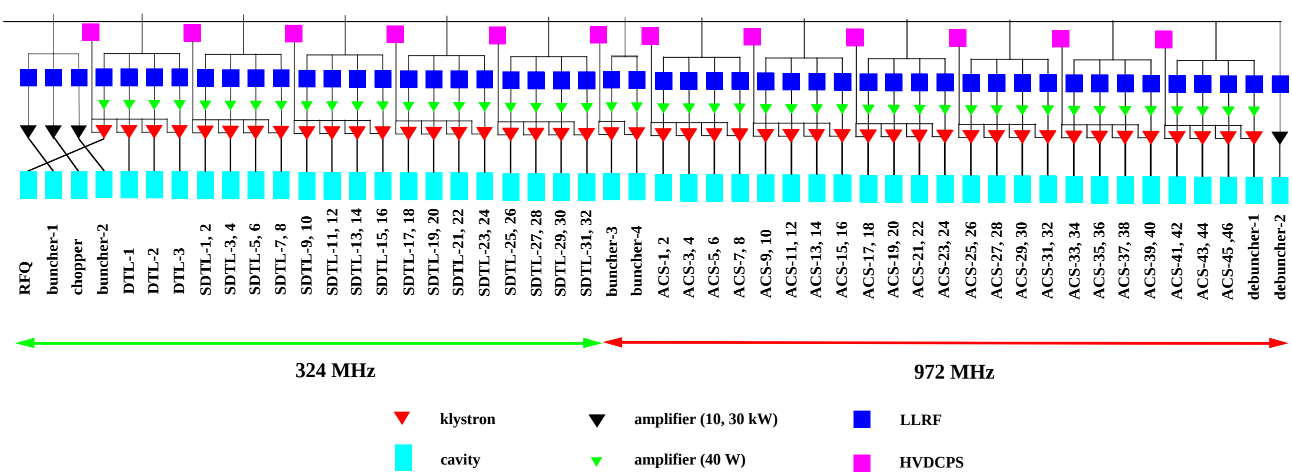

Figure 1: Layout of the RF system.

†seiya.yamaguchi@kek.jp

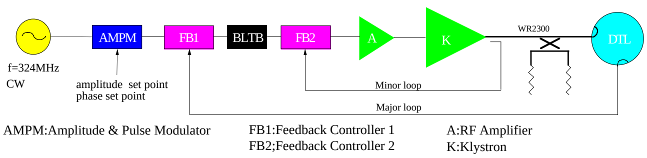

Figure 2: Block diagram for the test of feedback control.

The measured stability in a pulse was 0.38% rms and 0.95% peak in amplitude and 0.24° rms and 0.71° peak in phase. The long-term stability was 0.03% rms (0.18% peak) for the amplitude and 0.24° rms (0.71° peak) for the phase. The pulse response with electrically simulated "beam- loading" was measured using a "beam loading test box" [4]. The test results are shown in Fig 3. Except for the parts for the rise and fall of the pulse and the start and stop of the beam loading, almost a flat shape was obtained for both the amplitude and phase. Residual ripples at the start and stop of beam loading are to be rejected with the feed- forward control. The bandwidths of the feedback loop were measured for the drive amplifier, the klystron and the DTL tank by measuring the frequency response for an amplitude-modulated input signal. The measured bandwidths were 53 MHz, 1.2 MHz and 18 kHz, respectively.

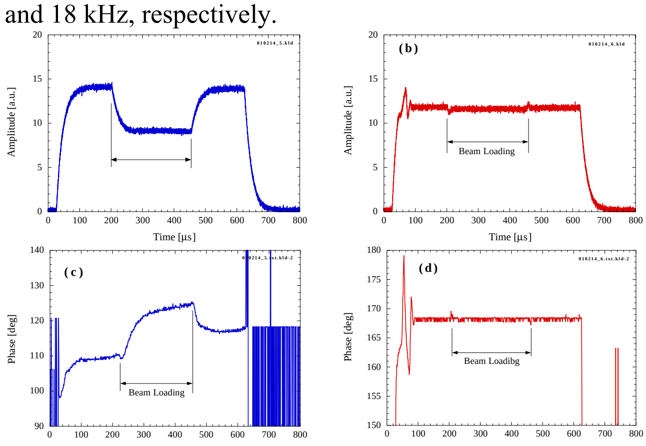

Figure 3:Pulse response with electrically simulated beam loading: (a) amplitude without feedback, (b) amplitude with feedback, (c) phase without feedback, and (d) phase with feedback.

3 KLYSTRON AND POWER SUPPLY

As for the 324-MHz klystron [5], an oscillation problem at the prototype klystron in the development stage was observed under high-voltage operation without rf input power. From an experimental investigation and simulation, it was revealed that the back-streaming electrons scattered from the collector induced these strong oscillations. By using a large-radius and long-length collector, the oscillation problem was eliminated.

Gun oscillations were observed for a prototype of a 972-MHz klystron [6]. The mechanism is under investigation.

Since one DC power supply drives four klystrons, a large sag (5% in amplitude and 50 degrees in phase) is expected due to the capacitance of the condenser bank. This sag will be compensated by feedback control in a minor loop.

4 WAVEGUIDE SYSTEM

The elements of the waveguide system include circulators (see Fig. 4 (a)), power dividers (b), phase shifters (c), coaxial-waveguide transformers, E and H corners and dummy loads (d). All of these elements were developed specially for this project use.

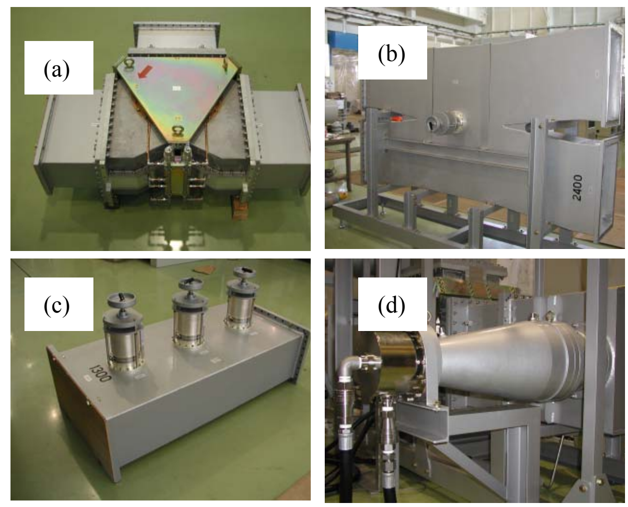

Figure 4: Prototype of the waveguide components: (a) circulator, (b) power divider, (c) phase shifter, and (d) dummy load.

The power transmission capability is a 3- MW peak, a 750-µs pulse width and a 50-Hz repetition rate (average power is 105 kW) for both 324 MHz and 972 MHz. The waveguide used are WR2300 (full size and half-height size) for the 324-MHz system and WR975 for the 972 MHz system. In the 324-MHz system, where the power from one klystron is fed to two cavities, it is required the errors of the amplitude and phase at two cavity inputs must be below ±1% and ±1 degree, respectively. The amplitude and phase errors can be adjusted almost independently by tuning a power divider and a phase shifter. Cooling of the waveguide is not necessary for the 324 MHz system because the temperature rise is only 1.4°C, even for full power and full duty. On the other hand, water-cooling is necessary for the 972-MHz system because of its high temperature rise (15°C).

5 CHOPPER DRIVING SYSTEM

The chopper driving system is composed of a high-power (30 kW peak) solid-state amplifier and a low-level rf control system. The time structure generated by the low-level rf control system is shown in Fig. 5. Specifications of the solid-state amplifier are shown in Table 1.

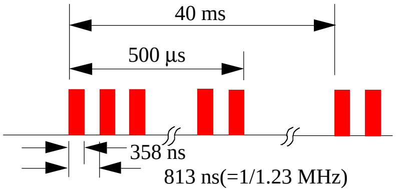

Figure 5: Time structure of the chopper- driving RF.

Table 1: Specifications of the 30 kW solid-state amplifier for the chopper.

Frequency	324 MHz
Output peak power	30 kW
Rise-fall time	< 20 ns
Phase flatness in a pulse	< ±1.5 °
Overshoot/undershoot	< 5 %
Pulse-to-pulse fluctuation amplitude phase	< ±1.5 % < ± 1.5 °
Harmonics	<-60 dB
Circumference temperature	27 ± 2 °C
Cooling	forced air cooling

In order to minimize the amount of an incompletely kicked beam, a very fast rise and fall time (less than 20ns) of the output pulse is required. The measured rise and fall time of the output pulse was 15 ns (see Fig.6).

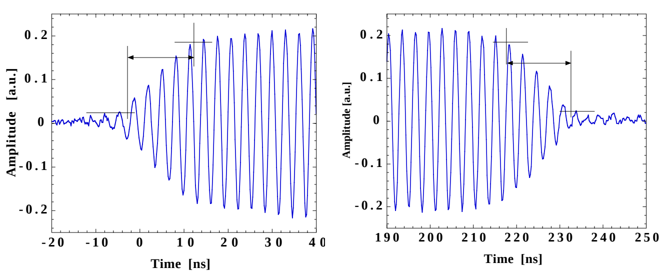

Figure 6: Pulse shape of the output amplitude: (a) rise time, (b) fall time.

6 RF SOURCE FOR THE 60-MEV LINAC

The beam commissioning has started for low-energy front 60-MeV proton linac that is being assembled at the KEK Tsukuba site [7,8]. The rf source (klystrons and solid-state amplifiers) for an RFQ, two bunchers and the chopper is already installed, and that for the DTL1 will soon be connected to the DTL tank (see Fig.7). We have an RF test bench in the gallery, which is used for high-power test of the klystron and waveguide components.

Figure 7: Klystron gallery viewed from the upstream.

7 REFERENCES

[1] F. Naito, et al.,"The JAERI/KEK Joint Project and its Performance," LINAC'02, Kyongju, August 2002.

[2] T. Kobayashi, et al., , "RF Reference Distribution System for the 400-MeV Proton Linac of the KEK/JAERI Joint Project," LINAC'02, Kyongju, August 2002.

[3] S. Michizono, et al, "Digital RF Control System for 400-MeV Proton Linac of JAERI/KEK Joint Project"," " LINAC'02, Kyongju, August 2002.

[4] R. J. Pasquinelli and B. Chase, "Linac Low Level RF Operating Procedure", Internal memo, Fermi National Laboratory, (1994).

[5] S. Fukuda, et al.," "Performance of 324MHz Klystron for High Intensity Proton Accelerator Facility," LINAC'02, Kyongju, August 2002.

[6] E. Chishiro, T. Kobayashi, M. Yamazaki, H. Suzuki, T. Hori, M. Sakamoto, H. Urakata, S. Miyake, S. Fukuda, S. Amani, "Development of 972MHz Klystron for High Intensity Proton Accelerator Facility," LINAC'02, Kyongju, August 2002.

[7] A. Ueno, et al.,"Beam Test of a Front-end System for the JAERI-KEK Joint (JKJ)," LINAC'02, Kyongju, August 2002.

[8] F. Naito, et al.,"High-Power Test of the SDTL for the JAERI/KEK Joint Project," LINAC'02, Kyongju, August 2002.