RECENT STATUS OF RF SOURCE IN J-PARC LINAC

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Abstract

RF sources for the low beta linac section use 324-MHz klystrons. After the evaluation of prototype tubes, mass production of 21 tubes are completed. These are installed in the linac building from April 2005. Performances of the 324 MHz klystrons are described in this paper. A prototype klystron of 972-MHz klystron, which is planed to be installed in high beta linac section, oscillated strongly without any drive rf power, and it had been investigated to solve it. Though it was suspected to be a gun oscillation at first, it was showed to be a drift-tube oscillation in recent experiment. After this experiment, we built a new tube and started to test it. This experimental result is written in this paper. Other status of construction related to the klystron power supply also shows in this paper.

INTRODUCTION

Japan Proton Accelerator Research Complex (J-PARC) is provided a high power proton beam for nuclear physics, material science, life science and nuclear technology [1].The accelerator complex consists of a 400 MeV linac, a 3 GeV rapid cycle synchrotron and a 50 GeV synchrotron. The linac building was completed in April 2005. Figure 1 shows the klystron gallery. The installation of rf apparatuses has started. High power rf sources of the linac consist of 20 unit 324-MHz klystron stations for low-beta linac and 23 unit 972-MHz klystron stations for high-beta linac. In first phase of J-PARC project, the 324MHz rf sources are operated to drive the low-beta linac. The high beta linac that consists of ACS cavities is under manufactured and is evaluated by the 972-MHz rf source. The specification of the 324-MHz klystron and 972MHz-klystron shows Table 1. In order to make the common design of klystron power supply, the same operating parameter is chosen.

Table 1: Specification of J-PARC Klystrons.

Frequency (MHz)	324	972
Number for operation	20	23
Output Power (MW)	3.0	3.0
Beam Voltage (kV)	110	110
Anode Voltage (kV)	94	94
RF Pulse width (μs)	650	650
Repetition Rate (Hz)	50	50
Efficiency (%)	55	55
Gain (dB)	50	50
Perveance ($\mu A/V^{1.5}$)	1.37	1.37

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324-MHZ KLYSTRON

A 324-MHz klystron (tube #1) was evaluated at the KEK test bench. Strong spurious oscillations occurred at beam voltage range of 63-71kV and 90kV or more. The oscillation originated in the backstreaming electron form the collector as results of the experimental and simulative investigation [2]. In order to suppress the backsreaming electron, the klystrons (tube #1A and tube #2) with the different collector shape varying the length and the radius were manufactured. These klystrons were observed the oscillation at the beam voltage that is higher than the tube #1. These klystrons were proved that suppression the backstreaming electron needed to eliminate these oscillations [3]. At the beam voltage of 106.6kV, these klystrons were obtained the rf power of nearly 3MW.

In newly designed klystron (tube #3), reconsideration of the diameter of a drift tube and a collector was performed at Toshiba Corporation [4]. The tube #3 was adapted a constant drift tube diameter. In the tube #3, the oscillation was not observed up to the beam voltage of 110kV and a maximum rf power of 3.01MW was achieved.

Twenty-one klystrons were mass-produced from Dec. 2001 to Mar. 2005. High power test of these klystrons (from tube #3 to tube #23) was performed in the Toshiba. The test result is summarized in Table 2. In the table, the value shows the average of 21 units the klystrons, and deviation shows the standard deviation. Requirement specification is satisfied and the individual difference is

Figure 1: Klystron gallery (before installation).

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small. The desirable performance such as input-output and bandwidth characteristic was obtained in all the klystrons. Now, these klystrons are kept in KEK and J-PARC site.

A minor modification was added on the cooling system of the klystron output structure. At the first, the internal parts that were ceramic window and inner conductor were cooled by forced-air. To reduce the cost of initial equipment and maintenance, and to exclude the fan-noise, the cooling system using a heat pipe was adopted. The cooling ability was confirmed by the high power test (3MW, full duty).

Table 2: Statistical Test Result of 21 Klystrons.

	Average	Deviation
Output Power (MW)	3.01	0.03
Beam Voltage (kV)	110.1	0.9
Anode Voltage (kV)	91.9	1.3
Heater Current (A)	23.2	0.6
Beam Current (A)	48.0	0.6
Efficiency (%)	56.9	1.0
Gain (dB)	55.3	1.5
Perveance ($\mu A/V^{1.5}$)	1.31	0.01

972-MHZ KLYSTRON

A 972-MHz klystron (tube #1) was evaluated in in 2001 [5]. In the klystron, strong oscillations were observed. We identified by three modes with the frequency and its occurrence voltage. Table 3 lists the oscillation modes.

Table 3: Oscillation Frequency and Occurrence Voltage.

Mode	Frequency	Beam Voltage
A	1300MHz	100 kV
B	3210MHz	90 kV
C	1460MHz	70 kV

Though it was suspected to be a gun oscillation at first, it was showed to be a drift-tube oscillation in recent experiment. We found that the oscillation frequency changed by detuning the intermediate cavities. Figure 2 shows the dependence of the frequency of the mode C on a deformation length in the 2nd cavity. In the figure, these lines show each frequency and range of occurrence voltage when the cavity is screwed up to the deformation length. There is an obvious correlation of the oscillation and resonance.

The tube #1 was assembled in the intermediate cavities that had long gap length and had symmetrical structure to the gap center. Table 4 shows the simulated resonant frequency of the 2nd cavity. These resonant frequencies correspond with the oscillation frequencies. We considered that these cavities caused the oscillation.

A new klystron (tube #2) with the asymmetric structure and shot gap length in the 2nd and 3rd cavities was designed and was tested in March 2005. Although any oscillations were not observed to the beam voltage of 106kV, another oscillation that is frequency of 4093MHz occurred at above 106kV. In this oscillation, the frequency also changed by detuning of 2nd and 3rd cavities. We are considering measures to eliminate the oscillation that will be affected by the high order resonance.

Table 4: Resonant Frequency of the 2nd Cavity.

Resonant Mode	Frequency	Corresponding Mode
TM011	1474MHz	C
TM021	3289MHz	B

By weakening the focusing field to 95% of the regulation, the klystron (#2) could be operated up to the voltage of 110kV without the oscillation. Figure 3 shows the input-output curves. At the first evaluation, the klystron was achieved the saturated output power of 3.0MW, the efficiency of 59% at the beam voltage of 108kV. The gun perveance was calculated to be 1.28 $mA/V^{1.5}$. These results satisfied the specification.

KLYSTRON POWER SUPPLY

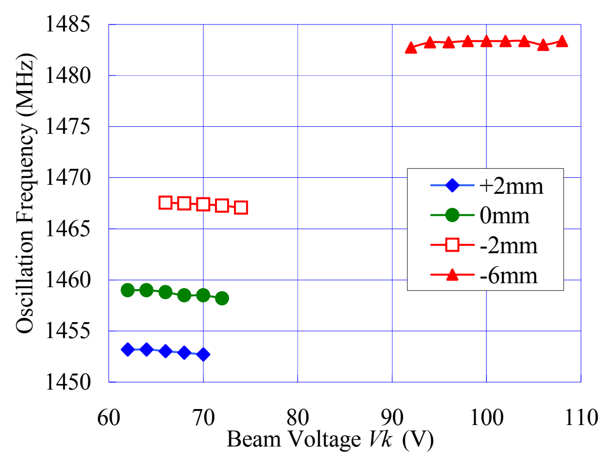

Figure 2: Dependence of oscillation frequency of mode C on deformation length in the 2nd cavity.

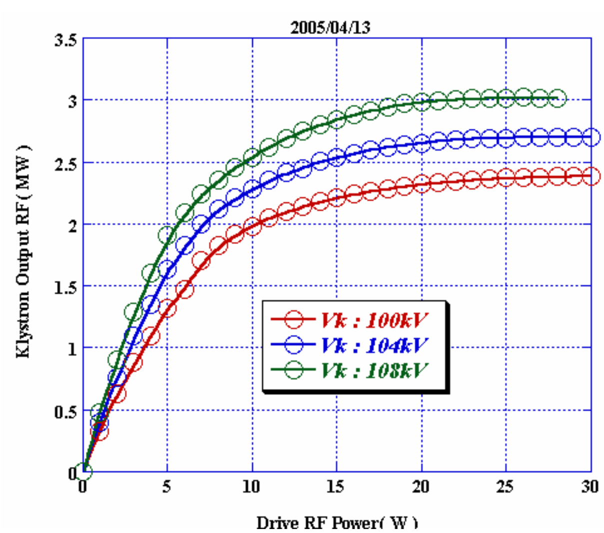

Figure 3: Characteristics of the 972MHz klystron.

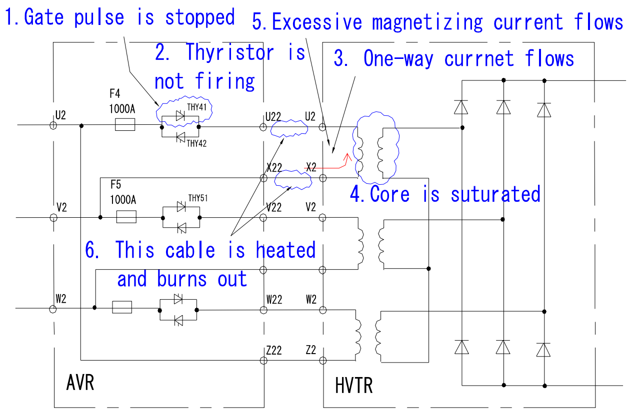

Figure 4: Illustration of the burned cable process.

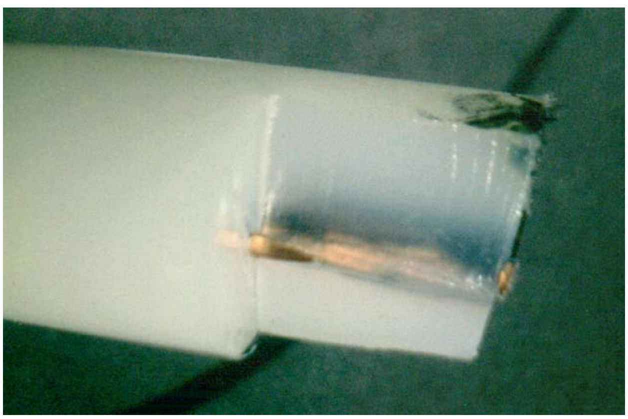

Figure 5: Damage of breakdown cable.

A klystron power supply (KPS) drives four klystrons. The KPS consists of a high voltage DC power supply (DCPS), four anode modulators and 4 sets accessory power supply [1]. At the first stage of the J-PARC project, five DCPS's feed the electric power to 20 klystrons. The DCPS has the capability to generate the DC voltage of 110kV and the pulsed current of 185A. Each KPS was installed in KEK and JAERI test site and was evaluated the reliability.

In the JAERI site, the cable burnout happened in March 2004. Figure 4 illustrates the process. Breakdown of one transistor in a gate circuit of the AVR caused the accident. Finally, by the excessive magnetizing current of several kA the cable was overheated, and the outer jacket of cable burned out. When the burned cable became the shot-circuit, the KPS was stopped by the protection of short-circuit fault. In order to prevent the accident at an early stage, The DCPS was equipped with circuit breakers and zero-phase-sequence current transformers at secondary line of the AVR.

The anode modulator and the klystron were connected with the RG-220/U coaxial cable. The cable head (model D-117-BA) manufactured in the Isolation Products, Inc was adopted in these apparatus. The cable and the head have been used for a long time for test of the klystron. The coaxial cable connected to the modulating anode often caused the breakdown. Three cables were observed a serious damage and were replaced. Figure 5 shows the cable damage. The tree grew up at carbonized spot on the conductor. Those damages were found out only the terminal portion. We think that intensively bending stress in this portion takes place the breakdown. The stress forms a void on the boundary of the conductor and the insulator. The pulsed anode voltage generates the corona discharge in the void. The corona discharge degrades the insulator. The coaxial cable with semi-conductor layer in both the outer and the inner conductor will be tested to obtain the long-life.

CONCLUSION

After the evaluation of prototype 324-MHz klystrons, mass-production of 21 tubes was completed. These klystrons are satisfied the specification and achieve desirable performance. In prototype 972-MHz klystron (tube #1), strong oscillations were observed. A new klystron (tube #2) with the asymmetric structure and shot gap length in the intermediate cavities was designed and was tested. Although any oscillations were not observed to the beam voltage of 106kV, another oscillation occurred at above 106kV. By weakening the focusing field, the klystron was achieved the saturated output power of 3.0MW, the efficiency of 59% at the voltage of 108kV. The KPS was evaluated the reliability in both KEK and JAERI site. The cable-burnout happened by breaking a transistor in the AVR. Several protections add on the KPS. An RG-220/U coaxial cable is used to connect the modulator and klystron. The cable using at the modulating anode often caused the breakdown obtain the long-life.

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