HIGH POWER RF PERFORMANCE TEST OF AN IMPROVED SiC LOAD

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Abstract

Two prototypes of SiC loads sustaining a maximum peak power of 50 MW were fabricated by Nihon Koshuha Co. in Japan. The PAL conducted the high power RF performance tests of SiC loads to verify the operation characteristics for the application to the PLS Linac. The in-situ facility for the K12 module was used for the test, which consists of a modulator and klystron system, waveguide network, vacuum and cooling system, and RF analyzing equipment. As the test results, no breakdown appeared up to 50 MW peak power of 1 μs pulse width at a repetition rate of 50 Hz. However, as the peak power increased above 20 MW at 4 μs with 10 Hz, the breakdown phenomena has been observed. Analyzing the test results with the current operation power level of PLS Linac, it is confirmed that the SiC loads well satisfy the criteria of the PLS Linac operation.

1 INTRODUCTION

The high power RF loads of the tapered waveguide section with direct water cooling have been used for the PLS Linac. Although many of them are well functioning at a current power level of about 15 MW, we have been observing several occasions of RF breakdown problems resulting in water leak to the vacuum side, they tend to happen during the initial operation of the Linac after the long maintenance shutdowns. the RF loads with water-leak proof, as called dry load or its equivalent load, are required [1]. Furthermore, we are have been installing one more accelerating unit (K12 module) for the beam energy margin of about 200 MeV to upgrade the operation performance and to obtain more stable beam energy of 2 GeV. For this purpose, the RF loads should be able to handle 50 MW of peak power for about 1 μs, and 30 Hz repetition.

The SiC load developed by Dr. Matsumoto in KEK/ATF [2] was indirect cooling type, and it was designed in a length of 640 mm with a capacity of 50 MW of peak power with 1 μs at a repetition of 50 Hz. Recently, the NKC in Japan newly designed and fabricated a prototype SiC load with a length of 475 mm for the PLS Linac. After the vacuum and RF cold test from the NKS, the PAL carried out the high power test to verify the RF characteristics based on our Linac operation requirements. This article describes the high power RF test results and properties of the SiC loads.

2 DESIGN OF SiC LOAD

The SiC ceramic has large heat conductivity, good heat resistance and oxidation resistance, and high chemical stability. At 2,856 MHz, the dielectric constant of the SiC ceramic is 31, which is three times higher than the conventional Al_2O_3 ceramics, and the loss tangent is $5x10^{-1}$, which is two orders of magnitude higher than Al_2O_3 ceramics. And due to the characteristics of large attenuation, SiC ceramic is one of the best material for RF absorbing material.

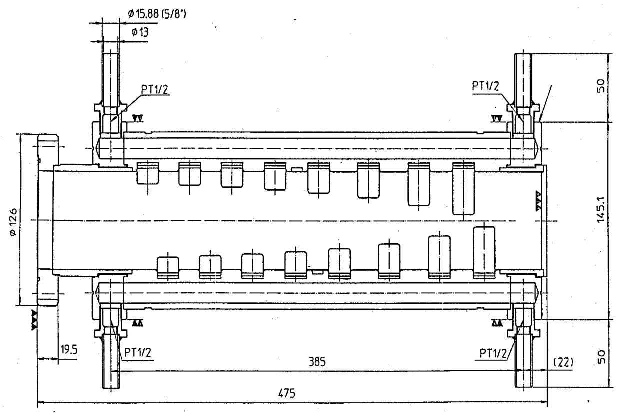

Figure 1: Cross sectional view of SiC load

Table 1. Specifications of SiC load

Parameters	Short Pulse	Long Pulse
Pulse Width (μs)	1.0	4.0
Peak Power (MW)	50	12
Operating Frequency (MHz)	2,856	
Bandwidth (MHz)	20	
Input vswr	< 1.1	
Repetition Rate (Hz)	50	
Average Power (kW)	2.5	
Cooling Temperature (^{o} C)	45	
Cooling Water Flow (m^3/hr)	1.2	
Cooling Pressure (kg/cm^2)	5.8	
Vacuum Leak Rate (Torr l/sec)	$2x10^{-10}$	
Length of load (mm)	475	

Figure 1 shows the cross sectional view of SiC load designed as a short length of 475 mm with ceramic rods brazed on the H-plane. The SiC rod has 20 mm diameter with varying length. The waveguide is standard WR-284, which has the inner height of 34 mm and the inner width of 72 mm, and made of 5 mm thick OFHC copper. The rectangular cooling tubes to circulate the water of 45 ^{o}C were mounted on the narrow walls of outer surface of the waveguide. This indirect cooling method will keep the structure from leaking the water into the waveguide, and thus the high vacuum is sustained. The design specification of SiC load for an application of short and long pulses is described in Table 1.

3 HIGH POWER RF TEST

3.1 Test facility

The high power test for the prototype of SiC load has been performed at PAL with a test facility which was composed of klystron (SLAC5045), waveguide, cold cathode gauge (CCG), radiation monitor, temperature sensor (TC/ RTD), residual gas analyzer (RGA), etc., as shown in Figure 2.

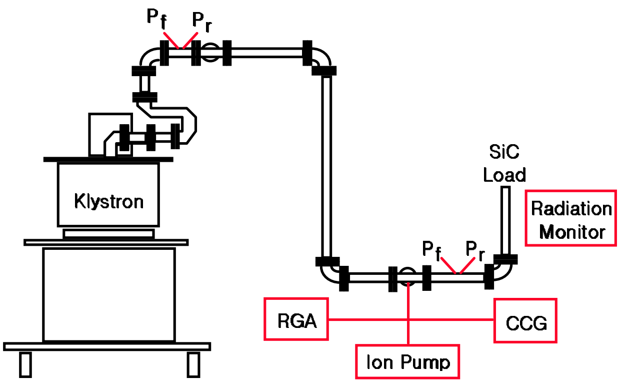

Figure 2: Layout of high power test for SiC load

3.2 Test Results and Performance

From the initial operation, the microwave power of 1 MW with 1 μs at the repetition of 10 Hz was applied to the SiC load. Then the vacuum was 5.3x10^{-8} Torr. The low power aging of the load was carried out within a few MW power levels with raising the repetition rate from 10 Hz to 50 Hz. After aging and stabilizing the vacuum within 2.5x10^{-8} Torr, RF performance tests of three steps were conducted according to test procedures for investigating the breakdown phenomena in the load and abnormal temperature rise on the surface of the load.

In Step I, we increased the input power in a slow rate from 1 MW to 50 MW with 1 μs at a repetition rate of 10 Hz. As the power level increases, the vacuum pressure and radiation counts increased and the waveform of reflected wave deformed. However, with a continual RF processing, the vacuum and radiation level were decreased, and the waveform of reflected wave was returned to normal waveform. At the operating power of 50 MW, the vacuum pressure was kept at 1.8x10^{-8} Torr, and the temperature on the wide surface of longitudinal center of load was 1.5 ^{o}C higher than that of no RF power. After that, we adjusted the repetition rate up to 50 Hz maintaining the same power level of 50 MW with a pulse width of 1 μs. After RF powering of 90 hours, the RF power level reached to 50 MW with 1 μs at a repetition rate of 50 Hz. Then, the vacuum pressure was 1.7x10^{-8} Torr and the temperature rise was 6.4 ^{o}C. The reflected waveform was the same profile as that of incident waveform. No breakdown occurred and radiation level was under 0.1 mR/hr. Outgassing of SiC ceramics was not produced.

In Step II, the power has been gradually adjusted for the case of 4 μs pulse width at a repetition rate of 10 Hz. At 20 MW of peak power, the breakdown initially occurred. Furthermore, the breakdown continuously appeared above 25 MW of peak power. The vacuum pressure increased abruptly, and the reflected waveform deformed severely, as shown in Figure 3. The average value of radiation for 1 minute was above 20 mR/hr, and the instantaneous maximum radiation level reached to 400 mR/hr.

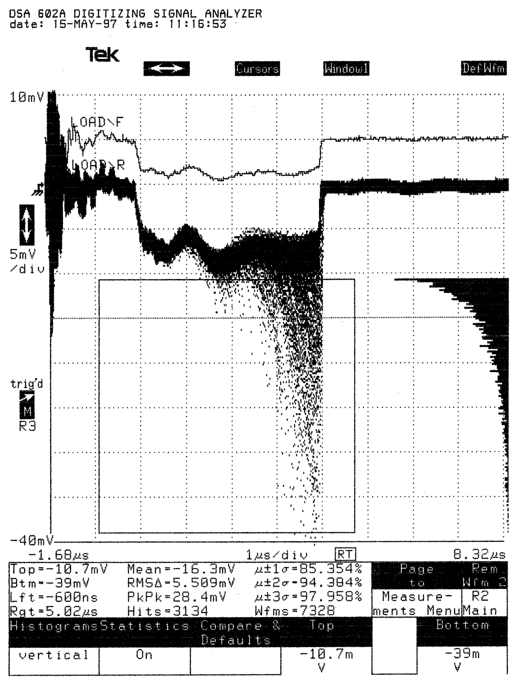

Figure 3: An example of forward and reflected waveform caused by RF breakdown

In Step III, the input power of 12 MW with 4 μs at a repetition rate of 50 Hz was applied. During the RF processing, no RF breakdown occurred. The vacuum pressure, temperature rise, and radiation level were about $1.5x10^{-8}$ Torr, 4.5 °C and 0.1 mR/hr, respectively.

Through the high power RF test, outgassing from SiC ceramics was not detected. Table 2 describes the high power test results for three step conditions. The test results indicate that the SiC load has an acceptable RF performance except Step II condition, as shown in Table 2 [3].

Table 2. High power test results of SiC load

Parameters	Step I	Step II	Step III
Pulse Width (μs)	1	4	4
Repetition Rate (Hz)	50	10	50
Peak Power (MW)	50	40	12
Temperature Rise (° C)	6.4	> 3.1	4.5
Radiation (mR/hr)	< 0.1	> 20	< 0.1
Vacuum (Torr)	$< 2.4 \times 10^{-8}$		

The peak power capability of SiC load with varying input pulse width has been investigated. Figure 4 shows breakdown region as a function of the input pulse width. The ordinate represents the power level at which the power can not be increased any further due to the breakdown and vacuum condition. The repetition rate was 10Hz during the test.

Figure 4: Breakdown region of SiC load

Another test was performed to investigate the effect of prior air exposure on RF conditioning. Two SiC loads (No RF processing applied) were mounted on the 3-dB power divider at the test facility. It took about 7 hours to reach 25MW of klystron output power (~12MW at each loads). The pulse width and repetition rate were 3.5μsec and 30Hz respectively. The two SiC loads and waveguide network were then vented to nitrogen gas and kept for 2.5 hours. After pumping out the system, RF processing was again performed. This time, it took about 10 minutes to reach the 25MW of klystron output power. Next the system was vented to air and re-conditioned. The humidity and temperature of the test environment were about 33% and 22 °C respectively. The processing time was not much different from that of the nitrogen venting. From those results, we may conclude that as far as the SiC loads are concerned, air or nitrogen venting will not deteriorate much the surface condition while we replace klystron tube.

4 SUMMARY

Through high power RF test for the prototype of SiC loads, we confirmed that the SiC load had a good performance both in 50 MW of peak power with 1 μs and 50 Hz and in 12 MW of peak power with 4 μs and 50 Hz. Furthermore, no RF breakdown occurred, and negligible radiation counts were produced in the SiC load. The vacuum pressure was kept well under $2x10^{-8}$ Torr. However, above 20 MW RF peak power with 4 μs and 10 Hz, the RF breakdown occurred. The test results indicate that the SiC loads will be well functioned for the operating power level of PLS Linac as in 15 MW of peak power. To prevent the breakdown trouble from the current loads and to upgrade the operating performance of Linac, the two SiC loads were installed in K12 Module, and four SiC loads in K5 module. Up to now, the loads have been well functioned.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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