RF PROPERTIES OF A 175MHz HIGH-Q LOAD CIRCUIT

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Abstract

For an RF input coupler test, a 175MHz high-Q load circuit based on a 6 1/8 in. co-axial waveguide was developed. This circuit consists of the RF input coupler, a trombone-type phase shifter and a stub tuner. The coupler with a loop antenna and the stub tuner are located in end of the circuit, the loop antenna and the tuner work for a short circuit. When RF input power is transmitted into the circuit, a high-voltage standing wave is excited by adjusting the tuner and the phase shifter. Rf input power can be also accumulated due to its low resistive loss. The rf power of 200 kW could be accumulated by rf input power of 740W, the 14-18 sec CW operation by 200kW could be performed after sufficient RF aging.

INTRODUCTION

International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based neutron irradiation facility to develop materials for a demonstration fusion reactor next to ITER [1]. For providing materials to make a decision of IFMIF construction, Engineering Validation and Engineering Design Activities (EVEDA) under the Broader Approach agreement have been started. IFMIF/EVEDA prototype accelerator consists of Injector (output energy;100keV), a 175MHz RFQ linac (0.1-5.0MeV), a matching section, the first section of Superconducting RF linac (5.0-9.0MeV), a high energy beam transport line and a beam dump(9MeV-125mA CW), and the acceleration tests by employing the deuteron beam of 125mA are planning in Rokkasho, Aomori, Japan [2].

In the design of prototype RFQ linac [3,4], a four-vane integrated cavity type of RFQ, which has a longitudinal length of 9.78m, was proposed to accelerate deuteron beam up to 5MeV. The operation frequency of 175MHz was selected to accelerate a large current of 125mA in CW mode. The driving RF power of 1.28 MW has to be injected to the RFQ cavity. In the RFQ design, the 8 couplers are used to share the required driving power and located at 4 different longitudinal positions. Each two couplers are arranged to have the same longitudinal position. For each coupler, nominal RF power of 160kW for CW mode and maximum transmitted power of 200kW for full reflection to be withstood up to 100µsec are required, and it also withstands maximum reflected power of 20kW during RFQ operation with no beam.

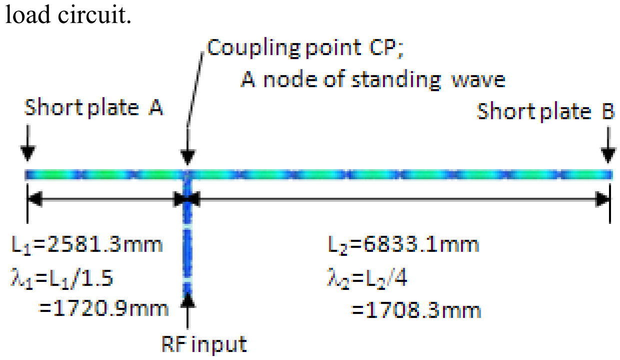
A RF input coupler with water cooling port including an RF window, based on a 6 1/8 inch co-axial waveguide, was designed and fabricated [5]. For a high RF power test, a 175MHz high-Q load circuit based on a 6 1/8 in. co-axial waveguide was developed. This article presents the high-Q load circuit in details.

HIGH-Q LOAD CIRCUIT

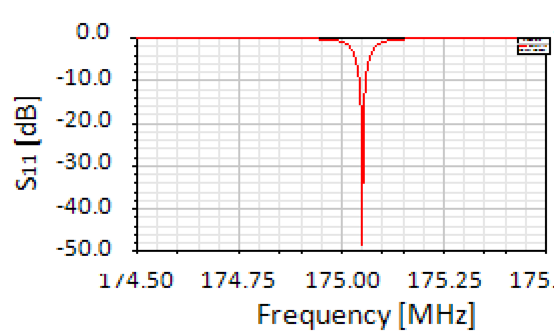
This high-Q load circuit is a resonant system using a co-axial waveguide, of which end parts are closed by a loop antenna of RF input coupler and a short plate of stub tuner, respectively. A standing wave is excited in this circuit and the resonant system property was investigated by using both simple model and realistic model.

Simple Model

For a simple mode using a 6 1/8 in. co-axial waveguide, analysis results by HFSS code are indicated in Fig.1. Short plates of A and B are equipped with waveguide end parts (Fig. 1 (a)). In order to obtain the resonant frequency, a node of standing wave has to be positioned at coupling point CP. In this case, lengths between short plate A and CP, and between short plate B and CP have to be n times of λ/2, here λ is standing wavelength. The S_{11} parameter at the rf input position is as shown in Fig.1 (b), the bandwidth for resonant frequency is evaluated to be ±5kHz at S_{11}=-20dB. Therefore, fine tuners to adjust lengths between A and CP, and between B and CP, are indispensable. A stub tuner for adjustment of the position A and a trombone-type phase shifter for adjustment of the waveguide between CP and B are applied for the High-Q load circuit.



(a) Electric field distribution for a simple mode



(b) S_{11} parameter at RF input port

Figure 1: Analysis results by HFSS code for the simple model using a 6 1/8 inch co-axial waveguide.

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High-Q Load Circuit

A 175MHz high-Q load circuit consists of a RF input coupler, a phase shifter of 9 3/16 in co-axial waveguide and a stub tuner of 6 1/8 in co-axial waveguide. For this realistic model, electric field distribution is analysed by HFSS code. Fig. 2 shows the electrical distribution at the resonant frequency of 175.0MHz. This result also shows that a node of standing wave is positioned at coupling point CP same as simple mode case (Fig.1 (a)).

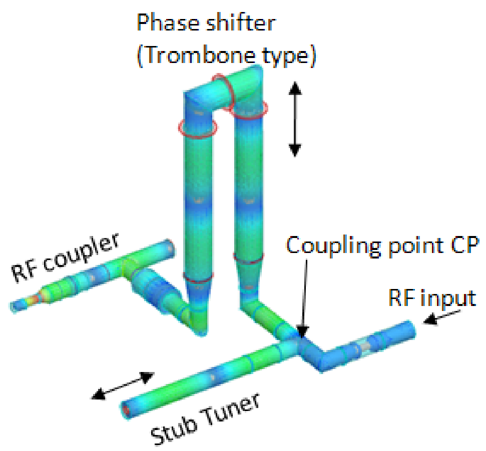

Figure 2: Electric field distribution for realistic model.

Figure 3 shows the measured S_{11} parameter by Network analyser, the peak value of -35dB and the bandwidth of ±5kHz are measured. For the measured bandwidth, it is quite good agreement with analysis result.

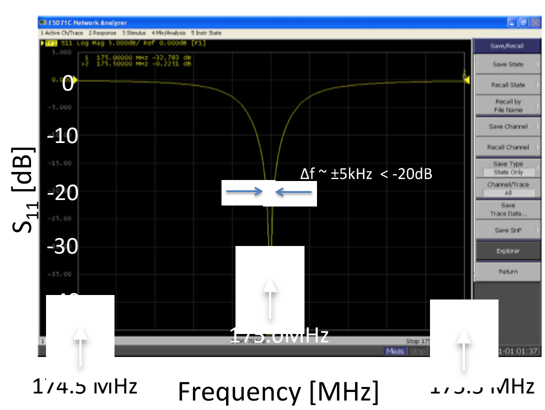

Figure 3: Measured S_{11} parameter at RF input port.

RF PROPERTIES

Accumulated RF Power

Accumulated RF power vs. RF input power is indicated in Fig. 4. The accumulated power by experiments is evaluated by $P_{in}(1+\gamma)^2$, where P_{in} and γ are incident RF power and reflection coefficient, respectively. The incident and reflected powers are detected by DC couplers at the coupler. Accumulated power is about four times of incident RF power, since incident RF power is fully reflected (γ~1). As shown in Fig.4, experimental power is slightly lower than analysis results. This difference is caused by resonant frequency shift due to temperature rise of waveguide components. The accumulated power of 200kW could be achieved by the input power of 740W. For the power gain, it is evaluated to be 24.32dB. By this result, the resistive RF loss while the high-Q load circuit is evaluated to be 0.046Ω by the equation of $P_a=Z_0P_{in}/(4R_c)$, where P_a is accumulated power, Z_0 is 50Ω, P_{in} is RF input power and R_c is resistive RF loss.

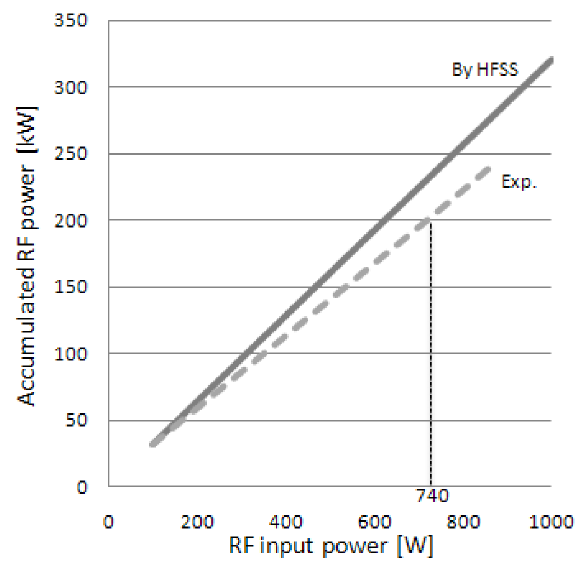

Figure 4: Accumulated RF power vs. RF input power by HFSS code and experiment result.

Electrical Fields at RF Coupler

In Fig. 5, internal structure of RF coupler is illustrated. For the part L=0 to 0.14m, inside diameter of outer-conductor is specified as ϕ70mm, where the maximum electric field is applied. For the part L=0.14 to 0.23m, it is a tapered waveguide part with transition to 6 1/8in.co-axial waveguide. RF window part is positioned at middle of L=0.42 to 0.50m.

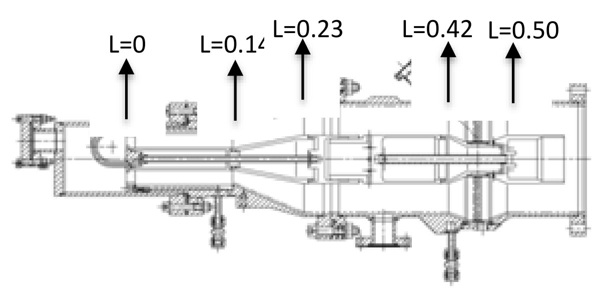

Figure 5: Internal structure of RF coupler tip part.

Figure 6 shows complex electric field distribution on inner conductor along the straight section including RF input coupler obtained by HFSS code. The analysis was carried out under the condition: no reflected power due to fully coupling on beam loading with the transmitted power of 200kW. The maximum and average field strengths at the tip part L=0 to 0.14m are evaluated to be 3.61 [kV/cm] and 3.26 [kV/cm], respectively. The average field at the 6 1/8in. waveguide part L=0.23 to 0.42m is evaluated to be 1.59 [kV/cm].

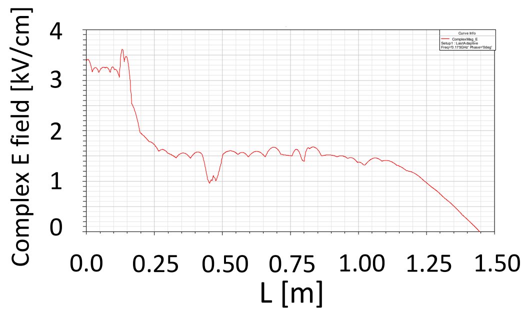

Figure 6: Complex electric field by RF power of 200kW with no reflected power, full RF coupling on beam loading.

Figure 7 indicates complex electric field distribution by the accumulated power on the 175MHz High-Q load circuit. Due to standing wave nature in this case, electric field strength at L=0 is decreased to 2 [kW/cm], but the maximum field strength of 3.08 [kV/cm] is achieved at L=0.14m. This field strength corresponds to 85.3% of fully RF coupling case (Fig. 6). The average electric field at 6 1/8 in waveguide part nearby RF window at L=0.3 to 0.4m (vacuum side) is 1.67 [kV/cm], which is to be 5% higher than that of fully RF coupling case. From these results, it is found that a withstanding voltage test is possible for taper design and RF window in vacuum side by this High-Q load circuit.

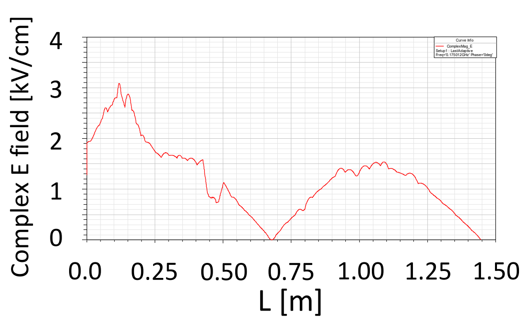

Figure 7: Complex electric field by the accumulated RF power of 200kW on the High-Q load circuit.

Using the high-Q load circuit, the CW operation up to 14-18 sec at 200kW could be performed after sufficient RF aging. For more than 20 sec-CW operation, it was faced to difficulties to keep the constant accumulated power of 200kW without no water cooling system, since the resonant frequency is shifted by temperature rise for support disks and waveguides. The CW operation up to 14-18 sec, however, is enough to test for a withstanding voltage, RF contact defects, unnecessary low-Q value and extraordinary outgassing of RF input coupler.

CONCLUSION

For the 175MHz High-Q load circuit, three characteristics are indicated by analyses results and experimental results. Firstly, the accumulated power of 200kW can be achieved by the input power of 740W. Secondary, the electric field strength due to standing wave is almost large enough for withstanding voltage tests of the coupler in vacuum side. Finally, the CW operation up to 14-18sec at 200kW is possible. From these results, it is concluded that the 175MHz High-Q load circuit is quite good system to test for a withstanding voltage, RF contact defects, unnecessary low-Q value and extraordinary outgassing of RF input coupler.

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