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A Study on the High Power RF Components for PEFP 20MeV Proton Accelerator

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Abstract

A study on the high power RF components for PEFP (Proton Engineering Frontier Project) 20MeV proton accelerator was carried out. The operating frequency is 350MHz, and the required RF power for 3MeV RFQ and 20MeV DTL are 417kW, 895kW respectively. The high power components include 1MW klystron, 1.3MW circulator, 1MW dummy load, WR2300 waveguide components and input couplers with window. The tests of each component have been done, which reveals the characteristics of each component and overall system performances. In this paper, the characteristics of high power RF components were discussed on the basis of the test results.

1. Introduction

The PEFP 20MeV proton accelerator consists of 3MeV RFQ and 20MeV DTL. The high power RF for 20MeV accelerator is summarized in Table 1. The operating frequency is 350MHz and the required RF power for RFQ and DTL are 418kW, 895kW respectively [1][2]. The structure power of the RFQ is the calculation result of the SUPERFISH code. The structure power of the DTL takes into account 20% margin of the SUPERFISH code result, which includes the power loss at the DTL tank wall (including end wall), drift tubes, stems. The 20% margin may cover the additional loss originated from Q-degradation and other structure loss such as post couplers, slug tuners and so on. A 350MHz, 1MW klystron is used as a RF source for RFQ and DTL respectively. A 3MeV RFQ has two RF input ports and the RF power from a 1MW klystron is divided into two legs to drive a cavity because of the power limitation of the RF window. A DTL up to 20 MeV consists of 4 independent tanks. The RF power from a 1 MW klystron is split into 4 legs to drive 4 tanks of the 20 MeV DTL – that is one RF port per one tank – by magic tees. Each leg has a phase shifter to adjust the phase of the RF field in each tank.

Table 1. PEFP 20MeV accelerator high power RF summary

	RFQ	DTL	
Energy (MeV)	0.05-3	3-20	tank1 : 3-7.18
			tank 2 : 7.18-11.5
			tank 3 : 11.5-15.8
			tank 4 : 15.8-20
Frequency (MHz)	350	350	
Beam power (kW)	68	339.2	tank1 : 83.4
			tank1 : 86.2
			tank1 : 85.7
			tank1 : 83.9
Structure power (kW)	350	555.8	tank1 : 141.6
			tank1 : 138.8
			tank1 : 138.3
			tank1 : 137.1
Total RF power (kW)	418	895.0	tank1 : 225.0
			tank1 : 225.0
			tank1 : 224.0
			tank1 : 221.0
No. of klystron (ea.)	1	1	
No. RF port (ea.)	2	4 (1ea./tank)	

2. Klystron

The klystron was manufactured by TED(THALES Electron Devices, Model no. TH2089F). The specification of the klystron is shown in Table 2. It is a slightly modified version of the 352 MHz, 1.1 MW CW klystron for CERN. The klystron has a triode type electron gun to control the electron beam current from the cathode of the klystron and is capable of dissipating the full beam power up to 1800 kW. The result of the acceptance test showed that the klystron could deliver RF power up to 1.1MW into the load of VSWR 1.2:1 at 350MHz. One klystron for RFQ was installed at PEFP as shown in Figure 1 and the other klystron for DTL will be delivered to PEFP site at the end of 2003. In order to protect personnel from X-ray, additional 2mm thick lead shield - besides the lead shield in the collector - around the klystron was installed. The klystron for RFQ was tested up to 100kW at PEFP. The RF power was measured by using both calorimetric method with RF dummy load and power meter with directional coupler. The measured data showed good agreement. During the test, the gun perveance was maintained same value to that used during acceptance test [3]. The klystron for RFQ is scheduled to be tested up to 600kW until the end of 2003.

Table 2. Specification of the klystron

Parameter	Value
Frequency	350 MHz
RF average output power	> 1.1 MW
RF drive power	< 110W
Gain	> 40 dB
Efficiency	> 60 %
Bandwidth (-1dB)	> 0.6MHz
VSWR load	> 1.2 : 1

Figure 1. TH2089F Klystron

3. Circulator

A 350MHz Y-junction type circulator, which can deliver 1.3MW RF power for forward direction and permit 1.3MW reverse power at any phase, was used. The circulator was manufactured by AFT (Advanced Ferrite Technology). It uses temperature compensating system to compensate the temperature dependent ferrite saturation magnetization. One circulator for RFQ was installed at PEFP and the other circulator for DTL will be delivered at the end of 2003. The circulator for RFQ was tested up to 100kW and will be tested up to 600kW during the test period of klystron for RFQ.

4. Waveguide components

The WR2300 waveguide components were used. The waveguide components include straight, E-plane, H-plane sweep bend, mitre bend, flexible section, full height to half height transition, RF dummy load, magic tee, phase shifter, harmonic filter and so on. The major components were purchased from DIELECTRIC Communications and some components such as straight, sweep and mitre bend were also manufactured by domestics company. To check the characteristics of the components manufactured by domestic company, the VSWR were measured using the Network analyzer(Agilent 8753ES), N-w/g transition, quarter wavelength straight section, and waveguide termination as shown in Figure 2. The Network analyzer was 1-port calibrated and the straight section of quarter wavelength eliminated the effects of the N-w/g transition and waveguide termination. The VSWRs of the straight, sweep bend, mitre bend which were manufactured by domestic company were all below 1.02 at 350MHz.

A RF dummy load located at one of the arms of the circulator was manufactured by DIELECTRIC Communication. It is a 350MHz, 1MW load which is used as a dummy load not only for absorbing the reflected RF power from the accelerator but also for full power test of the klystron. It is about 4m long and uses mixture of water and MEG (volume ratio 50:50) as a coolant. The load was tested up to 100kW. During the test, it showed VSWR value of 1.2 that is higher value than original specification - below 1.05. The possibility for high VSWR and method to reduce the VSWR value were reviewed and recently the improvement of the VSWR is being carried out.

Figure 2. Measurement of the VSWR

5. Input coupler & window

The requirements of the input coupler for RFQ and DTL are summarized in Table 3 respectively.

The input coupler of the RFQ is a ridge loaded waveguide type with iris coupling structure [4][5]. A taper will transform the half height WR2300 into smaller dimension that is suited to the RFQ input port. The dimension of the ridge was determined to maintain a constant cutoff frequency at each cross section of the taper. The end of the taper becomes part of the cavity wall, and the RF power is coupled into the cavity through the slot. The coupling factor can be adjusted by varying the hole size at the end of the slot. To check the RF properties of the coupler, cold model coupler was manufactured using aluminum. The cold model coupler are shown in Figure 3.

The RF window for RFQ was manufactured by TED (Model no.: TH20548B). It is a plannar type window with half height WR2300 flange at both sides. It can transmit RF power of 750kW at 350MHz on a load with a VSWR < 1.3:1.

The input coupler for the DTL is a loop type coaxial coupler. Among several types of coaxial loop coupler, the one with cylindrical window and half height waveguide to quarter wavelength coaxial transition is used, because of the relatively easy fabrication method. This type of coupler is very similar to the input coupler of the spoke cavity considered in Accelerator Driven Test Facility at LANL and slightly modified version of the coupler that was used at TRISTAN APS cavity which transmitted up to 300kW [6][7]. The coupler consists of a half height WR2300 waveguide section merged with a shorted coaxial conductor as shown in Figure 4. At the coaxial to waveguide transition, a cylindrical ceramic window is installed to create the air/vacuum barrier. The impedance of the coaxial line is 75ohm. The coaxial line extends from the short through the waveguide and terminates with coupling loop in the cavity. A pumping port is located in the quarter wave stub to facilitate good vacuum. The optimum positions of the waveguide short and the coaxial short are obtained from the MWS code. As a start up for the development of the input coupler, a cylindrical window was fabricated to verify the fabrication processes including material selection, machining, brazing, coating. The inner diameter of the alumina ceramic (purity : 95%) is 130.1mm and the thickness 4.8mm. The ceramic was brazed into 1.5mm thick copper sheet, which was e-beam welded into the copper-stainless steel flange. Vacuum tight sealing was proved to be good through leak test. The window will be TiN coated and installed in the coupler section to check the low power RF properties.

Table 3. Requirements for RF input coupler

	RFQ	DTL
Parameter	Value	Value
Frequency	350MHz	350MHz
No. of coupler	2ea.	4ea. (1ea./tank)
RF power	210kW/coupler	225kW/coupler
Coupling beta	0.6/coupler	1.6

Figure 3. Cold model RF input coupler for RFQ

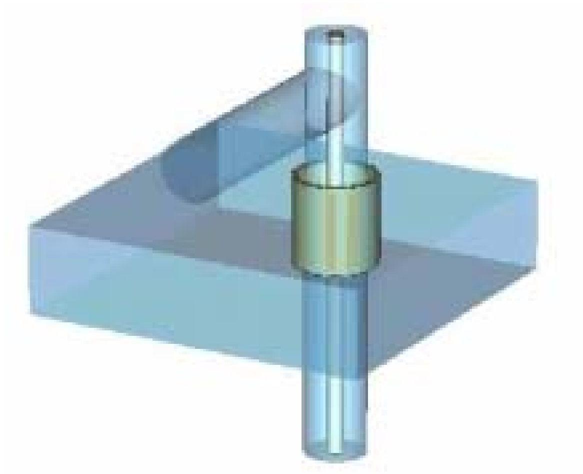

Figure 4. RF input coupler for DTL

6. Conclusion

The high power RF components have been developed and tested at PEFP. The klystron and circulator was tested up to 100kW and scheduled to be tested up to 600kW until the end of 2003 to drive the 3MeV RFQ The waveguide components were tested to verify the RF performances and the test results showed that the all of the components have satisfied the requirement at 350MHz. The RF dummy load need more tuning of the post to reduce the VSWR in the operating temperature of the coolant. The major components of input couplers for RFQ and DTL have been developed. But they need more studies on the coupling factor adjustment, thermal and mechanical analysis.

7. Acknowledgement

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8. References

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