HIGH POWER RF SYSTEMS OF LEHIPA FOR ADS

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Abstract. As a part of ADS program, a proton accelerator (20 MeV, 30 mA) and its high power RF (HPRF) systems are being developed in BARC. This paper explains design details of this klystron based HPRF systems.

Keywords: accelerator; klystron; bias supplies; HPRF system; protections
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INTRODUCTION

As a part of accelerator driven sub-critical system (ADS) program [1], a normal conducting, low energy high intensity proton accelerator (LEHIPA) of energy 20 MeV and beam current of 30 mA is being developed in Bhabha Atomic Research Center (BARC). LEHIPA comprises of Electron Cyclotron Resonance (ECR) ion source (50 KeV), Radio Frequency Quadrupole (RFQ) accelerator (3 MeV) and Drift tube Linac (DTL) 1 and 2 (10 MeV and 20 MeV respectively). As per the accelerator physics design, RFQ requires about 530 kW of radio frequency (RF) power, DTL-1 requires around 665kW and DTL-2 requires around 677 kW. Each accelerating cavity will be driven by a one- megawatt (CW) klystron based high power RF (HPRF) system at 352.21 MHz. This paper describes overall system description, each subsystem design & status details that adds to overall RF system details.

BRIEF DESCRIPTION

A) RF System

The RF system has been designed around five cavity klystron tube TH2089 (Thales make) [2] capable of delivering 1 MW continuous wave power at 352.21 MHz. Each RF system comprises of a low power solid state driver (~ 150 W), klystron tube, associated high voltage (HV) and low voltage (LV) bias supplies, harmonic filter, directional coupler, Y-junction circulator (AFT make) [3], RF load and WR2300 wave guide based RF transmission line. It also includes other subsystems like interlock and protection circuits, dedicated low conductivity water-cooling, pulsing mechanisms etc. Klystron will be housed in a lead (3 mm) based shielded hutch for X-ray shielding. Detail description of some of these high power RF components used in the RF system is elsewhere [4].

The proton accelerator will be operated initially in pulsed mode and then will be gradually switched to CW mode. The required pulse repetition rate (PRR) (Hz) is 1, 10, 100 and Pulse width (PW) is 20 microseconds. Hence, all three RF systems are designed to operate in both modes. Synchronization & response capabilities between cathode and anode supplies and RF input are being studied.

B) Bias Power Supplies

Klystron is a very sensitive device. Its performance and reliability depends on performance of the bias power supplies connected to it, specially its DC bias supplies. Some of the crucial performance requirements to the power supplies are; tight voltage regulation, low ripple, better voltage stability, high efficiency, built in effective protection circuits and effective technical mechanisms to bypass the stored energy. These features are included in all the bias supplies. Description of vacuum ion pump supply, filament and solenoid supplies is described elsewhere [4].

Klystron operates its cathode bias at 87 KV and 18 Amp for one MW of RF power. So a regulated high voltage power supply (RHVPS) of maximum rating 120 kV/ 24 A, is being developed. It uses two dry type transformers with forty secondaries each and the solid-state modular converter configuration with IGBT based switched power modules (SPM). The output voltage is variable from 0 to120 KV DC with overall efficiency of more than 96 %, ripple of 0.3 % and line and load regulation of 0.2 %.

At 1 MW RF power, the modulating anode of klystron operates at 57 KV, 02 mA floating at (- 100 KV) cathode voltage while its maximum rating is 65 KV, 20 mA. The supply uses a number of MOSFET based modules, connected in series. The overall circuit topology eliminates the possibility of having stored energy inside the supply and gives the supply the ability to obtain both, pulsed and CW operation. Voltage regulation is 0.5 % over entire range. As a protection in case of arcing across the klystron, a crowbar based HV interface system is designed. Bias voltages for cathode, anode and filament are also provided via this system. This crowbar comprises of a fast acting, gas pressured spark gap based system.

C) Interlock and Protection Scheme

HPRF system requires a very reliable and fast acting interlock and protection for its safe operation. A detail investigation of data sheets and specifications of high power RF devices, RF transmission line components was done and a detail sequence control scheme including all the interlock and fault parameters were evolved. The entire operation sequence of the klystron based RF system has been divided into five modes such as start, heater, standby, high voltage and RF. All these modes have taken into account appropriate time delays for switching, settling, and protection, based on fast and slow timing requirements. The sequence starts with the start mode by monitoring the vacuum conditions, predefined safety parameters like door interlocks, X-ray shielded cage interlocks etc. and water cooling parameters. Then, it proceeds to heater mode that starts with ramping up of filament supply and then electromagnet supplies are switched ON. Next is standby mode where all status parameters like vacuum, filament current, electromagnet current, cooling water flows and water temperature of RF system are reviewed. Then HV mode starts with switching on of cathode bias in a smooth ramping mode and then similarly anode bias is established. Throughout this entire sequence, vacuum parameters and water flow parameters are continuously monitored. Final mode is RF mode where low level RF drive is switched on. In addition to interlocking sequence, the protections parameters included are, faults or trips generated because of low water flows, outlet water temperature trip, over voltage and over current in all the bias supplies, arc detection across various RF windows, vacuum deterioration etc. Additionally active and fast monitoring of VSWR and arcs is being done electronically and use of these parameters as a feedback, to ensure the safe shutdown of the RF systems is incorporated.

D) Waveguide System RF Power Distribution

The RF power for acceleration of protons inside the accelerating structure, supplied from high-power klystrons, is taken up to the desired ports by means of wave-guide lines. There are three waveguide power distribution systems from three klystron RF systems. The factors of primary importance for a wave-guide system are: power handling capacity, insertion loss, impedance uniformity, band width, physical dimensions/tolerances, economic considerations and self strength. For 1MW, CW RF transmission, WR 2300 based waveguide is used at 352.2 MHz and is made from aluminum alloy 6061 plates. WR 2300 based RF transmission line starts from second port of the circulator, and consists of straight sections, half height sections, magic Tee, termination loads, directional couplers and RF windows. RFQ will be fed the power at two ports (of around 250^+ kW power) whereas, 10 MeV and 20 MeV DTL is having four ports each (of around 250 kW power), for RF power coupling. The general specifications of WR 2300 are as in Table1.

TABLE 1. Rectangular wave-guide specifications

Specifications	
Type	WR2300
Frequency (MHz)	320-490
Attenuation (dB/m)	0.002% /100 m
Dimensions broad (mm)	584.2
Dimensions broad (mm)	292.1
Peak Power Capacity (MW)	1.5
Average Power (MW)	1.0

Magic Tee Power Dividers

It is intended to divide 1MW power channel to four equal power channels. The isolated port is terminated with RF loads of corresponding rating. All magic TEEs are intended to be made for the maximum rating to have standardization, as it does not lead to major variations in their dimensions. Its other important parameters are insertion loss (dB) of less than 0.05, isolation 35 dB and power division 3 dB.

High Power RF Loads, Dual Directional Couplers and Vacuum windows

RF dummy loads are required in large number for terminating the circulators as well as at magic TEEs. 1MW RF load uses ferrite based absorbing material. It uses equal splitter arrangements to divide 1MW power into smaller amount of power and this power is then dissipated in the loads attached to respective splitter ports. Its other major specifications are VSWR of 1.05 and coupling ratio of an in built coupler of 60.4 dB.

Dual directional couplers with coupling loops attached on the respective wave guides are provided for measurement of power going into the accelerator as well as that reflected. Its directivity is 25 dB and forward coupling is 60 dB.

Vacuum windows are used between end side of wave guide line and RF coupler. In this case, it uses wave guide to a coaxial conversion and the alumina ceramic barrier placed for vacuum isolation. Its important parameters are vacuum of 1×10^{-7} Torr, VSWR of 1:1.04, insertion loss of 0.05 dB and 2.5 % bandwidth.

E) RF Grounding

A special grounding scheme has been designed. It comprises of two numbers of RF ground pits for each klystron, grid type mesh structure beneath each of the klystron based RF system, and interconnecting copper strips between the mesh and two RF ground pits This ground system has been simulated in software 'CST microwave studio [5]' for optimizing its overall impedance as seen by the RF system.

CONCLUSION

All the three high power (one MW) RF systems for accelerator have been designed. Installation of first HPRF will start soon. Here, we have tried to bring out the salient features and design information of the HPRF systems.

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