PERFORMANCE OF 6MW PEAK, 25 KW AVERAGE POWER MICROWAVE SYSTEM FOR 10MEV, 10KW ELECTRON LINAC

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Abstract

An S-Band microwave system with peak power capability of 6MW and average power capability of 25 kW was designed, constructed and commissioned at RRCAT. The in-house development of various microwave technologies and pulse modulator technologies was successfully achieved and the microwave system was interfaced to the 10MeV, 10kW electron LINAC. The electron LINAC could be tested to full rated energy and power using the present microwave system. The present paper highlights the details of the performance results.

INTRODUCTION

The microwave system for 10MeV, 10kW average beam power LINAC was designed and developed indigenously.

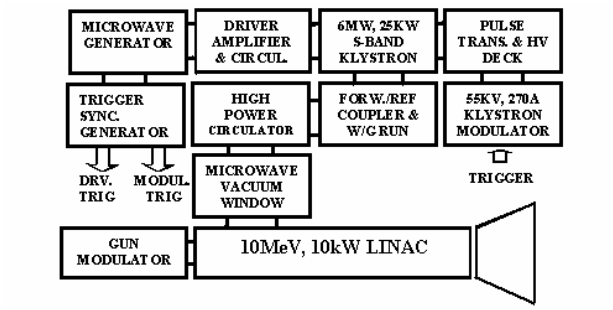

Figure 1: Schematic of 6MW S-band microwave system.

Table (1) shows the specifications of the Microwave system. The klystron needs 50-55kV, 270-300Amp beam voltage pulse to achieve the rated output power. The klystron modulator has been designed to give output pulse voltage of 15 microsec duration see fig 2.The specifications of the klystron modulator are listed in table (2). The klystron modulator and pulse transformer are designed to supply also the gun voltage up to 50kV. Challenging work on the technologies like droop compensation hyperboloidal tuneable pulse forming network, fast rise time long pulse high average power pulse transformer, pulse voltage and current measurement systems, short circuit protection, optically triggered command charging system, solid state trigger drives for thyratron, high voltage power supplies with fault protection systems which were developed in-house have performed to expectations.

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Table 1: Microwave System Specifications Achieved

Peak o/p power	MW	6
Average o/p power	kW	25
Operating frequency	MHz	2856
Pulse duration	microsec	13/7
Pulse repetition rate	Hz	1-300
Pulse rise time	microsec	<2
Pulse top variation	%	<1
Pulse-pulse stability	%	<1
Frequency stability	/day / °C	$1X10^{-8}$ $1X10^{-8}$

Table 2: Modulator Specifications Achieved

Pulse output power	MW	15
Pulse voltage output	kV	50
Output impedance	Ω	180
Pulse duration	microsec	15
Rise time	microsec	~2
Fall time	microsec	<2
Flat top variation	%	< ±1
Mean output power	kW	70

SYSTEM DETAILS

The microwave system consists of a stabilized signal generator, circulator, 200W solid state microwave amplifier driver, circulator, directional coupler, 6MW klystron amplifier and waveguide system. The power from the signal generator is amplified up to 200W by the driver amplifier, which in turn is fed to a 6MW klystron. The power from the klystron is fed to the accelerator by means of a dual directional coupler, flexible waveguide, waveguide pressurizing system, circulator, dual directional coupler and vacuum ceramic window see fig. (1). The klystron modulator is line type construction see fig. 2. A high voltage regulated dc power supply rated for 16kV, 6 amp continuous duty with regulation better than 0.5% has been built for charging the pulse-forming network. An air core charging inductor with RC damping for high frequency ringing, occurring due to parasitic components, has been used. A command charging thyratron placed on a floating deck is triggered by an optical isolated triggering system. The necessary power to the trigger supplies, filament and reservoir is supplied by means of a high voltage isolation transformer. Pulse forming line consists of 16 sections Gullemin E type network in which the number of cells can be selected for desired pulse width from the modulator.

A shunt diode fault circuit protects the components from mismatched loads or load short circuit/arcing. The pulse-forming network is discharged through a high voltage high power thyratron, which is triggered by

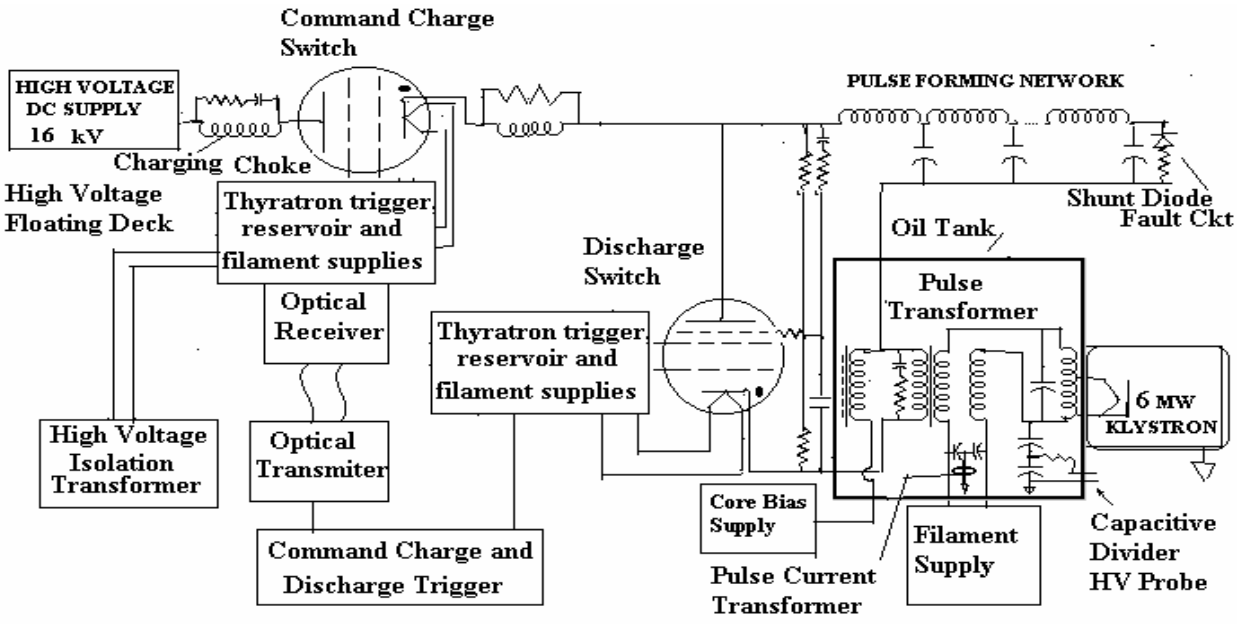

Figure 2: Schematic of the high power long pulse klystron modulator with command charging and pulse parameter measurement system.

means of a solid-state trigger drive. Cooling module as well as the gradient grid circuit for the discharge thyratron has been developed in-house. Sufficient care has been taken for reducing the parasitic components as well EMI, which is proven by the final test results of the modulator. Pulse transformer is oil insulated provided with water-cooling for high average power and thermal considerations. It is a 1:4 turns ratio, 2 mil CRGO ribbon core based transformer and has provision to provide the filament power to the klystron as well as the electron gun. Innovative design and fabrication techniques have been incorporated based on the previous experience to retain the good pulse characteristics. Separate windings on the secondary have been included to provide the gun voltage to the LINAC gun. The grid voltage for LINAC gun is tapped from the beam voltage pulse of the klystron.

Figure 3: Left - Klystron modulator showing discharge thyratron with associated supplies, command charge thyratron above the main thyratron. Middle- Tuneable Pulse Forming network Right up- klystron assembly on high voltage deck. Right lower- waveguide system connected to LINAC input.

PERFORMANCE DESCRIPTION

Operation Details

The Microwave system has been satisfactorily operating since more than 2 years with the rated specifications to deliver power to 10MeV Linac. During the period the system has been operated at different power levels up to 10kW for commissioning, qualification & radiation experiments for a total of 800 hrs. The Linac operation hours are over of ~600hrs. The microwave system has been operated for ~20 hrs. at max. Output power of 25kW and with Linac its recorded time is 15 hrs. for Linac mean beam power output of 9-10 kW.

Output performance

The beam pulse shape obtained is good & stability is within 1%. Initially the rise time of the cathode pulse was less than 1us. Later the gun cathode voltage at 50 kV was also supplied from the klystron along with grid voltage

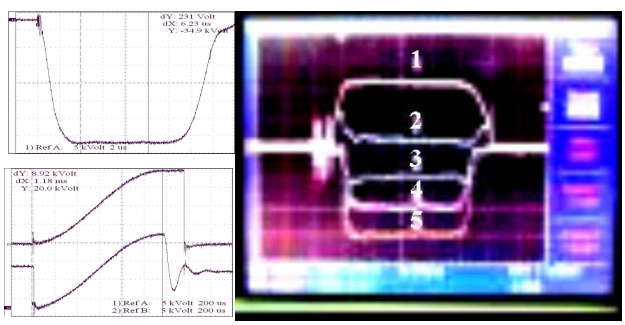

Figure 4: Left upper: Output of the klystron beam voltage @50kV, 2.5 µs/div loaded with LINAC gun and klystron, probe ratio is 1:1.47. Left lower: waveforms with command charging before and after charging diodes. Right- Traces from top 1) Forward power Pulse at 6MW peak. 2) Reflected power Pulse at 100kW in flat region. 3) & 4) Beam currents at first and second collecting electrodes 5) Total beam current @ 300mA. Horizontal scale @2.5 µs/div.

from a divider network. With this load the rise time has increased to 2us after tuning of the modulator for pulse top. The pulse top variations including the droop are less than ±1%. Fig (4) shows the cathode Pulse of klystron as measured from divider circuit, the measured microwave Forward/reflected power & Beam current pulses are shown.

Table 3: Interlocks & Limits Provided in the System

Interlock/Limit	Protection/value
Over voltage, overload, Transformer oil level/temperature, & Output short circuit Interlocks	To protect High voltage DC supply
Cooling water, vacuum, Waveguide gas pressure & Arcing interlocks / Pulse repetition & high voltage DC limit	For protection of Klystron / PRR 275Hz & High voltage limit 12kVDC
Air/water Cooling interlock	For protection of Thyratron/ klystron
Air changer, Door timer & Search 'N' Scram interlocks & Emergency stop switches	For personnel safety
Vacuum & beam scanner interlock	For Linac protection

Solid-state microwave driver amplifier

The solid-state microwave driver amplifier with capability upto 200 W output power was developed and interfaced with the klystron. At maximum gain of klystron with 50kV anode voltage the drive needed was only upto 30 W but at reduced anode voltages higher power from driver was required to be fed. The driver has worked satisfactorily.

Difficulties & Modifications

During the High Power operations of 10 MeV Linac with 6MW Peak power Microwave system a few of difficulties & breakdowns were faced. Initially during the time of arcing in Linac Gun, Pulse Forming Network capacitors leaked. These Capacitors are subjected to high mechanical stress during high power discharge and being plastic cased, they leaked during breakdown in Gun. All the capacitors were replaced & Pulse forming network was retuned. To overcome this loading problem of Pulse Forming Capacitors during any arcing inside the Gun, necessary circuit modifications were done to limit the short circuit current inside the Gun.

The connecting cable of Linac Gun was damaged partly during the time of arcing in Gun. Replacement of cable was difficult due to its narrow passage from Pulse transformer room to Linac room & requiring dismantling of waveguide line also. To overcome the problem Grid energising circuit was transferred near to Linac Gun.

The transformer to supply filament current to klystron Gun malfunctioned as its primary insulation failed during long heat run. The reason was found to be degradation of insulation over prolonged heat cycles. Filament transformer has been replaced with a taking into account the extra margins in and is kept dipped in oil inside the pulse transformer tank for with better cooling .

Besides these modifications extra interlocks & limits have been provided for protection of microwave system as well as Linac. Those include Beam Scanner & vacuum interlock to safeguard Linac, Pulse repetition & High voltage DC limit for Klystron safe operation. The complete list of Interlocks & Limits is shown in table (4) which stand for the safety of system & personnel.

CONCLUSION

The microwave system has been operated over long heat runs to produce 6MW peak and 25 kW mean power at 2856 MHz. Several modifications and upgrades resulted in higher reliability and reduced turn down time.

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