PROGRESS IN DEVELOPMENT OF HIGH POWER PULSED MICROWAVE SYSTEMS, HIGH VOLTAGE MODULATORS AND ASSOCIATED TECHNOLOGIES FOR PARTICLE ACCELERATORS

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Abstract

The characteristics and quality of the beam delivered by a particle accelerator largely depends on the characteristics of the high power pulsed RF/Microwave fed to the accelerating cavities for creating the accelerating gradient. Various considerations on the rise time/fall time, flat top, ripple on pulse top, stored energy, as well as reliability and safety are the key factors in designing these high power systems. Faults or failures in the RF/microwave system or any of its constituent components can severely affect the operation of the accelerator and need careful system design for eliminating or minimising accelerator turn down time. At RRCAT high power microwave systems for several electron accelerators like 20MeV Microtron injector for Booster Synchrotron for Indus 1 and Indus 2, 8MeV Variable energy microtron, 10MeV electron LINAC were designed, developed and commissioned. Test facilities were developed and supplied to microwave tube R & D lab, CEERI, Pilani, for ageing and evaluation of microwave tubes developed under collaborative efforts. RRCAT has also taken up development of key technologies for advanced accelerators. A 1.3 MW pulsed test stand at 352.2 MHz was successfully designed and developed to qualify devices, subsystems and components developed in-house for Indian as well as International collaboration projects. Development of RF systems at 1.3 GHz as well as test set ups are in progress for SCRF technology development. A solid state bouncer modulator operating at 100kV, 20A was successfully designed, developed and supplied to CERN under Novel Accelerator Technology, (NAT) collaboration in LINAC 4 project. Further efforts on other advanced modulator design and construction are also underway. Design and development of 45 MW peak power S Band test facility as well as energy doubler scheme is underway. The present paper describes the recent progress, performance review of high power pulsed RF/Microwave systems, test facilities and components..

INTRODUCTION

A typical microwave system consists of a microwave tube, drive electronics & microwave control for tube, pulse modulator for the microwave tube, waveguide transmissions line feeding microwave to the one or a group of accelerating cavities. We had constructed 5MW klystron based microwave system for 20MeV Microtron RRCAT and 2MW magnetron based microwave systems for 8MeV Microtron which was installed in Mangalore University in 1995. Table 1 lists some of the microwave systems developed at RRCAT for various applications [1][2]. In this paper klystron based microwave systems are mainly described along with other key technology components [1]. Fig 1 shows main components of a microwave system for accelerator applications. The klystron is supplied microwave drive by means of solid state driver amplifier which in turn gets the stabilised microwave from a synthesized signal generator having stability better than 1 ppm.

MICROWAVE TECHNOLOGY DEVELOPMENT

Solid state microwave amplifiers

We had designed and developed solid state amplifiers upto 300W for driving the S Band klystrons. A 1kW solid state amplifier is under development.

Table 1: Various pulsed microwave systems

Pk Pwr MW	Freq MHz	Pulse Characteristics			Modulator type
		Anode kV/A	PW µsec /PRR Hz	Device	
5	2856	110/90	3/1	Klystron	PFN
2	2856	41/100	2.5/200	Magnetron	PFN
6.5	2856	55/280	14/300	Klystron	PFN
1.3	352.2	100/20	800/2	Klystron	Solid state
45	2856	300/335	4.5/10	Klystron	PFN

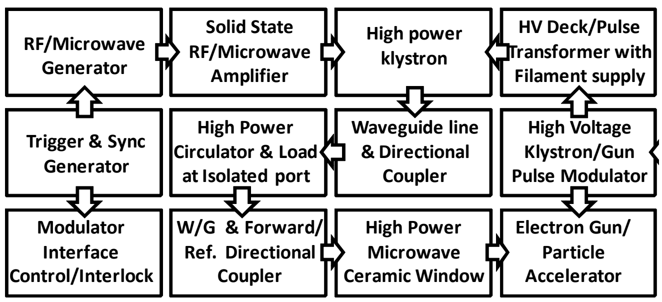

Figure 1: A typical klystron based microwave system

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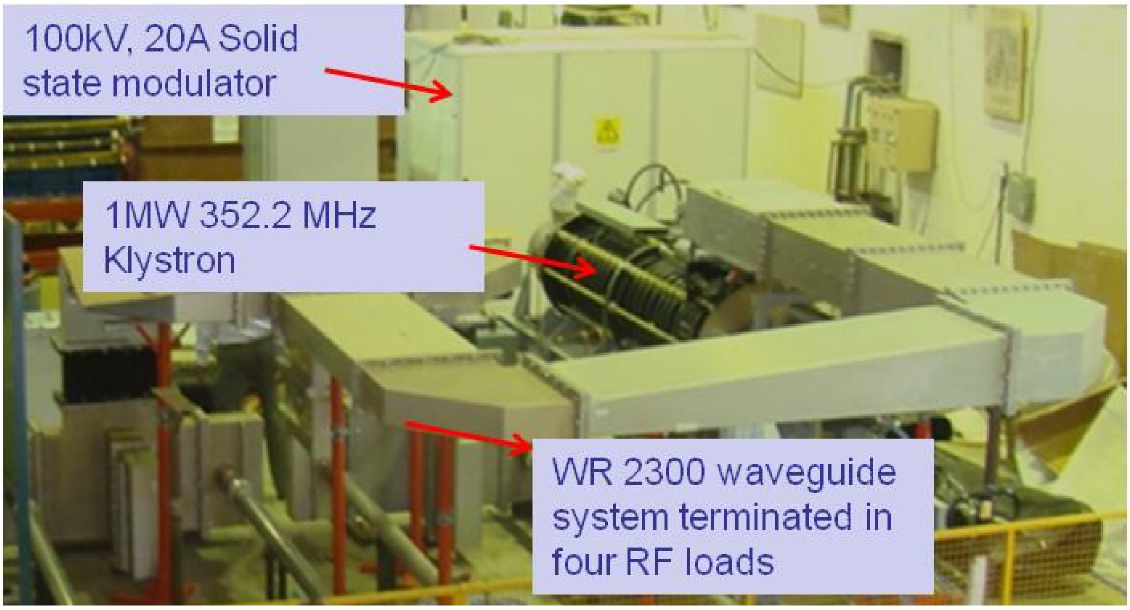

Figure 2: Photograph of the 1.3 MW, 352.2 MHz test stand built around CERN LEP 1.3 MW klystron with the 100kV solid state bouncer modulator connected to the klystron. The output of the klystron feeds to a WR 2300 waveguide transmission line terminated into dummy loads for klystrons tests.

For the development and tests for 1.3 GHz SCRF cavities design and development of solid state amplifiers upto 500W is under progress. The driver stages upto 2W have been developed and design of 500W stages has been done and devices are ordered. The developments are reported in this conference.

Waveguide components

WR 284 waveguide components

WR 284 waveguide components were designed and fabricated in-house for use in the microtron and electron LINAC at RRCAT [1][2]. We have developed straight and bent waveguide sections, dual directional couplers, high power microwave loads. In-house set ups were prepared and used to qualify the waveguide components to rated high power microwave input [5].

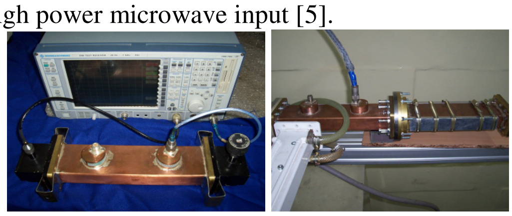

Figure 3: Left ,loop type dual directional coupler, right SiC load under high power tests on test stand.

WR 2300 waveguide components

For the development of pulsed high power RF systems for 3MeV RFQ a in-house development of WR 2300 waveguide components was launched. This was also necessary to prepare necessary test set ups and test facilities to test the high power klystrons received from CERN under NAT collaboration project. The waveguide components were designed using CST MWS and fabricated in RRCAT workshop using aluminium allow 6061 T6. Dual directional couplers, full height to half height transitions, waveguide to coaxial transitions, straight sections and bends were developed and tested.

Figure4: Left 352.2 MHz circulator under tests. Right WR 2300 waveguide transitions and sections.

SCRF Cavity characterization test set ups

For tests on the prototype half cell, dumbbell as well as single cell, cavity characterization and test set ups were designed and fabricated at 1.3 GHz. After qualifying the initial prototypes made in aluminium and copper, finally two niobium single cell cavities were constructed by RRCAT and tested. These have undergone final tests at FNAL. See Fig. 5.

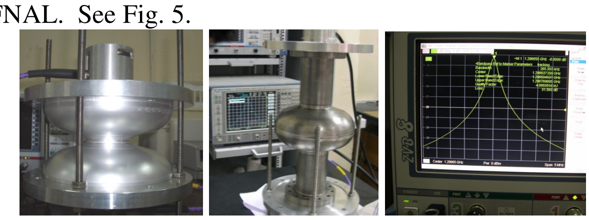

Figure5: From left dumb bell prototype tests. Middle niobium single cell cavity with resonant frequency trace shown on right.

High voltage pulse modulators

Line type pulse modulators

The initial designs of line pulsers were based on the pulse forming network (PFN) based modulators switched by hydrogen thyratron. All the components for these modulators were developed in-house. Low inductance energy storage capacitors were used along with inductors developed in-house to construct the pulse forming networks. The pulse transformers were made with 4 & 2 mil ribbon wound CRGO cores. These systems were used in 5MW microwave system for 20MeV microtron and 2MW microwave system for 8MeV microtron[2]. Test stations for developing S Band 5MW klystrons and 2MW magnetrons were designed, developed and installed at CEERI, Pilani. A continuous upgrade effort resulted in high reliability and low turn down time for these modulators. Pulse transformers for magnetron were constructed with special care taken in design for the correct mode free operation of the magnetrons. Later more advanced modulator design was done for powering multi-beam klystrons for 10MeV electron LINAC [1].

Solid state pulse modulators

A effort was launched to start development of solid state modulators in the country. Initially an all solid state modulator was developed using series stacked MOSFET switches for output of 5kV at 10microsecs, 10Hz. Later a bigger switch upto 5kV was developed and with the help of a 1:10 pulse transformer it reliably produced output upto 55kV, 15 μsec with PRR upto 200Hz. This is in use as an electron gun modulator for testing the indigenous electron guns, Fig. 6.

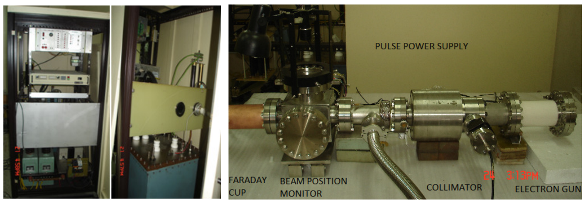

Figure 6: 55kV solid state modulator on left and high voltage electron gun test set up at right.

A solid state bouncer modulator with output 110kV was successfully designed and developed. This has been supplied to CERN under NAT Collaboration in LINAC4 [3]. See Fig. 7.

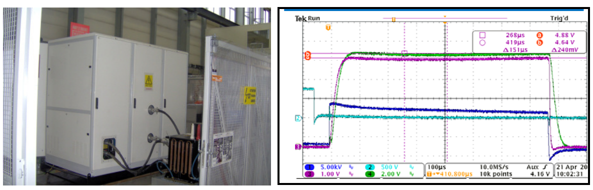

Fig. 7: Bouncer modulator delivered to CERN and commissioned. Waveforms from top indicate output voltage 104kV@20kV/div, output current@5A/div, primary voltage referred to ground, and bouncer switch voltage respectively.

Efforts are under way to design and develop advanced modulators based on Marx Modulator as well as Inverter Modulator designs keeping in view the future requriments of 1.3 msec, 50 Hz requirements for proton accelerator projects. A 1.3 MW 352.2 MHz test stand was developed to test and qualify high power klystrons, circulators and waveguide components under DAE CERN Collaboration. Two klystrons received from CERN under NAT collaboration were successfully tested up to 1.3 MW pulsed operation at 800microsecs/2Hz operation on these tests stands. Fig 2 shows the photograph of the test stand at RRCAT and Fig 8 shows the results of these tests.

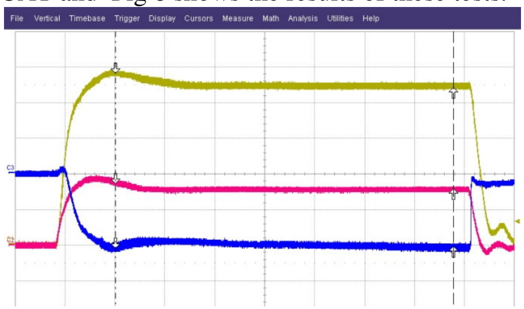

Figure 8: Klystron beam voltage, beam current and output RF power @1.3 MW, 352.2 MHz.

CONCLUSION

A large reservoir of experience in design, development and commissioning of pulsed high power microwave systems, high voltage pulse modulators, waveguide components, solid state amplifiers and cavity characterization set ups exists at RRCAT. The systems developed have been tested for very long durations in the accelerator environment and have worked satisfactorily.

ACKNOWLEDGEMENTS

We thank Shri V. Phadnis, Shri P.K. Bajapai and Shri J.Y. Parate for electrical and mechanical assembly and fitting of various systems. Continuous encouragement and guidance from Dr. P.D. Gupta, Director, RRCAT is gratefully acknowledged.

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