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Operation and control of high power Gyrotrons for ECRH systems in SST-1 and Aditya

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HIGHLIGHTS

- Operation and control of high power Gyrotrons.
- Data acquisition and control (DAQ) for Gyrotron system.
- Ignitron based crowbar protection.
- VME and PXI based systems.

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ABSTRACT

The Electron Cyclotron Resonance Heating (ECRH) system is an important heating system for the reliable start-up of tokamak. The 42 GHz and 82.6 GHz ECRH systems are used in tokamaks SST-1 and Aditya to carry out ECRH related experiments. The Gyrotrons are high power microwave tubes used as a source for ECRH systems. The Gyrotron is a delicate microwave tube, which deliver megawatt level power at very high voltage ~40–50 kV with the current requirement ~10 A–50 A. The Gyrotrons are associated with the subsystems like: High voltage power supplies (Beam voltage and anode voltage), dedicated crowbar system, magnet, filament and ion pump power supplies, cooling, interlocks and a dedicated data acquisition & control (DAC) system. There are two levels of interlocks used for the protection of Gyrotron: fast interlocks (arcing, beam over current, dI/dt, anode voltage and anode over current etc.) operate within 10 μs and slow interlocks (cooling, filament, silence of Gyrotron, ion pump and magnet currents) operate within 100 ms.

Two Gyrotrons (42 GHz/500 kW/500 ms and 82.6 GHz/200 kW/1000 s) have been commissioned on dummy load for full parameters. The 42 GHz ECRH system has been integrated with SST-1 & Aditya tokamak and various experiments have been carried out related to ECRH assisted breakdown and start-up of tokamak at fundamental and second harmonic. These Gyrotrons are operated with VME based data acquisition and control (DAC) system. The DAC system is capable to acquire 64 digital and 32 analog signals. The system is used to monitor & acquire the data and also used for slow interlocks for the protection of Gyrotron. The data acquired from the system are stored online on VME system and after the shot stored in a file in binary format. The MDSPlus, a set of software tools has been used for data visualization & management for after shot analysis.

1. Introduction

The Electron Cyclotron Resonance Heating (ECRH) is an important heating system for tokamaks widely used to carry out several experiments from breakdown to plasma control [1–8]. A standard ECRH system consists of a high power microwave source (Gyrotron), corrugated waveguide based transmission line and quasi-optical mirror based launcher. The Gyrotron is a delicate high power microwave tubes associated with high voltage system, dedicated protection system and reliable data acquisition and control (DAC) system. The schematic of 42 GHz ECRH system in tokamak SST-1 and Aditya are shown in Fig. 1.

In SST-1, two ECRH systems (42 GHz/500 kW and 82.6 GHz/200 kW) [9–11] are used to carry out various exper-

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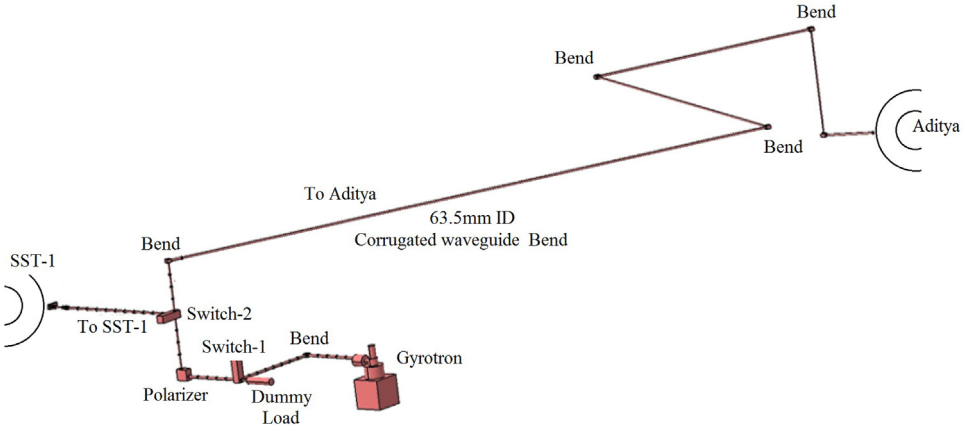

Fig. 1. (Schematic of ECRH system in a tokamak).

iments on plasma breakdown, heating and current drive over wide range of magnetic field (0.75 T to 3.0 T) in tokamaks. The 42 GHz is used in Aditya tokamak also, in this system transmission line consists of two switches to transmit power either in SST-1 or in Aditya tokamak.

The 82.6 GHz Gyrotron delivers output power of 200 kW for 1000 s at ~−45 kV beam voltage and ~10 A beam current with 17% duty cycle, while the 42 GHz Gyrotron delivers output power of 500 kW for 500 ms at ~−50 kV beam voltage and ~20 A beam current with ~50% duty cycle.

These Gyrotron systems are associated with dedicated subsystems like Regulated High Voltage Power supply (RHVPS −80 kV/80A & 15 A), Anode modulator Power Supply (AMPS +30 kV, 100 mA), Filament power supply (~35 V, 30 A), Cryomagnet (+5 V, 100 A), Ion Pump (+3 kv, 100 uA), the crowbar unit and the water cooling system. As the Gyrotron is a delicate tube, it requires dedicated protection system in an event of fault. There are two levels of interlock systems used for the protection of a Gyrotron: Fast interlock operate within 10 μs and slow interlocks operate in 100 ms. A dedicated VME based data acquisition and control (DAC) system is used to operate the Gyrotron. The VME based DAC is used for the monitoring, acquisition and control of Gyrotron operation. The DAC system is being upgraded with PXI based system for system reliability and safety. The operation and control of Gyrotron are discussed in detail in following sections.

2. High power Gyrotrons and its protection system

2.1. High power Gyrotrons

The Gyrotron is a high power microwave vacuum electron tube device, which delivers megawatt level CW power at frequency varied from 28 GHz to 170 GHz. These Gyrotron delivers high power at very high voltage (~−50 kV) with high current (~10–50A). These Gyrotrons are very sensitive device need to be operated with optimum care. In SST-1, two Gyrotrons (82.6 GHz/200 kW & 42 GHz/500 kW) are used to carry out various experiments related plasma breakdown heating and current drive. The 42 GHz/500 kW Gyrotron is shown in Fig. 2.1 .

2.2. Protection of high power Gyrotrons

Since the Gyrotrons are very sensitive high power microwave tube, it requires very reliable and dedicated protection system. In an event of any fault, the energy deposited to the Gyrotron should not exceed to its critical fault energy, which is order of 10J. Thus in order to make safe operation of Gyrotron, the high voltages should

Fig. 2.1. (42 GHz Gyrotron for ECRH in SST-1).

be removed fast enough (less than 10 μs) so that energy deposited should be less than 10J. There are following two levels of interlocks used for the safe and reliable operation of Gyrotron:

1) Slow interlocks: The slow interlocks are operated in case of cooling failure, filament, vac-ion, magnets current, these interlocks operate within 100 ms and removes the high voltage from the Gyrotron.
2) Fast Interlocks: The fast interlocks are operated in case of arc, beam over current, dI/dt, anode over current, body current, vac-ion etc. The fast interlocks are hardwired and a dedicated crowbar protection system (Ignitron based or solid state) is used to remove the high voltages within 10 μs.

2.3. Ignitron crowbar system

In order to operate the 82.6 GHz and 42 GHz Gyrotron with safety, ignitron based crowbar system is developed and commissioned with the real high voltage. Ignitron based crowbar system consists of two stages and each stage consists of 50 kV ignitron

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