Upgradation of 82.6GHz ECRH system for SST-1 and Aditya-U

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Abstract. In SST-1 and Aditya-U Tokamaks, two ECRH systems (42GHz-500kW and 82.6GHz-200k) are used to carry out various experiments related to ECRH assisted plasma start-up and heating at fundamental and second harmonic. The SST-1 tokamak is operated at 1.5T magnetic field and 42GHz ECRH system has been extensively for plasma start-up and heating. The 82.6GHz ECRH could not be used thoroughly due limitation in power as 200kW power is not enough for breakdown in SST-1 at second harmonic. The original 82.6GHz-200kW ECRH system is being upgraded in terms of ECRH power to carry out experiment at higher power. The 82.6GHz-200kW Gyrotron has been upgraded to 400kW power. The Gyrotron has been tested successfully at factory and delivers 400kW power at 48kV cathode voltage and draw around 20A cathode current, the efficiency of Gyrotron is around 42%. The 82.6GHz Gyrotron will be commissioned at IPR and the total ECRH power 0.9MW (0.5MW at 42GHz and 0.4MW at 82.6GHz) will facilitate to carry out ECR heating experiments simultaneously at fundamental and second harmonic. The paper presents the recent test results of 82.6GHz-400kW Gyrotron and discusses the experimental plan with upgraded ECRH system.

1 Introduction

The SST-1 and Aditya-U are medium size tokamaks. The SST-1 is superconducting tokamak while Aditya-U tokamak has normal copper magnets. The SST-1 has been operated up to 2.0T magnetic field but plasma experiments are carried out at 1.5T operation. It is due to the availability of 42GHz ECRH system which facilitates plasma start-up at 1.5T magnetic field. The Aditya-U tokamak is normal tokamak and it operates for short pulse duration and has been operated for maximum 400 ms duration. The major parameters of both the tokamaks are shown in table 1.

Table 1. Main Parameters of SST-1 and Aditya-U

Parameters	SST-1	Aditya-U
Major Radius	1.1m	0.75m
Minor Radius	0.2m	0.25m
Magnetic field	0.75 – 2.5T	0.75 – 1.5T
Plasma Current	~100kA	~150kA
Achieved Plasma Duration	0.65s	0.4s

The electron cyclotron resonance heating (ECRH) has been emerged as an important and most demanding heating system for many tokamaks, it has shown many interested results in various tokamaks [1-4]. In SST-1, 42GHz electron cyclotron resonance heating (ECRH) system has emerged as main heating system and responsible for plasma start-up in tokamak, the same system has shown many interesting results in tokamak Aditya-U also [5-8]. In SST-1, two ECRH systems 42GHz-500kW and 82.6GHz-200k are used to carry out ECRH experiments at 1.5T and 3.0T operation. The SST-1 and Aditya tokamaks are mainly operated at 1.5T magnetic field and the 42GHz ECRH system has been used extensively for plasma breakdown, current ramp-up, reliable start-up and plasma heating.

The 82.6GHz ECRH could not be used extensively due limitation in its power as the system could deliver maximum 200kW power. The transmission line consists of a matching optic unit, 63.5mm corrugated waveguide, several miter-bends, two DC breaks and a polarizer. The Total transmission loss in the line is around 20%. After this transmission loss, the maximum ECH power that could be launched to tokamak was around 160kW. While operating at 1.5T magnetic field which corresponds to second harmonic demands higher ECRH power for plasma breakdown.

The originally commissioned 82.6GHz-200kW ECRH system is being upgraded in terms of ECRH power to carry out experiments at higher ECRH power for tokamaks SST-1 and Aditya-U. The 82.6GHz Gyrotron has been upgraded to 400kW power and has been tested successfully at factory. The Gyrotron delivers 400kW power at 48kV cathode voltage and it

draws around 20A cathode current, the efficiency of Gyrotron is around 42%. The Gyrotron will be commissioned first on Aditya-U tokamak. After the commissioning of this 82.6GHz ECRH system, the total ECRH power would be 0.9MW (0.5MW at 42GHz and 0.4MW at 82.6GHz) and it will facilitate to carry out ECRH experiments at higher power and at fundamental and second harmonic simultaneously.

2 Upgradation of 82.6GHz ECRH system

The old 82.6GHz ECRH system was commissioned on dummy load in 2009 and integrated with SST-1 in 2010. This 82.6GHz Gyrotron tested for 200kW CW power (1000s duration on dummy load). Since this power was not enough for plasma breakdown in tokamak at second harmonic, so it could not be exploited fully on SST-1 and in 2013, another 42GHz ECRH system commissioned for plasma breakdown. This old 82.6GHz Gyrotron started degradation with time (More than 12 years old), ion-pump current high, so it was decided to upgrade it as per the need of higher Power even for short pulse duration.

The main aim to upgrade this Gyrotron is to upgrade it in terms of power so that it can be used for 2nd harmonic breakdown and plasma heating at higher ECRH power. Since it is not a new Gyrotron, it is a refurbishment of existing old 82.6GHz-200kW Gyrotron, due to limitation in the cavity, Gyrotron manufacturer suggested for maximum 400kW power for 500ms duration. The duration 500ms is enough for the breakdown and heating for both the tokamaks. The efficiency of this refurbished Gyrotron is around 42%, the power supplies available at IPR can suffice this demand for full power operation. The old and upgraded parameters of Gyrotron are shown in Table 2.

Table 2. Parameters of Upgraded ECRH system

ECRH Parameters	Old Parameters	Upgraded Parameters
Power	200kW	400kW
Pulse Duration	1000s	500ms
Gyrotron output	Gaussian TEM00	Gaussian TEM00
Mode Purity	>95%	>95%
Operating Voltage	40kV-10A	40kV-20A
Efficiency of Gyrotron	Better than 45%	Better than 40%
Transmission line	Corrugated waveguide	Same line 63.5mm ID

3 Initial testing of 82.6GHz Gyrotron

The 82.6GHz Gyrotron (Figure 1) is refurbished at M/s. Gycom Russia, the OEM (Original Equipment Manufacturer) of Gyrotron. The Gyrotron was sent back to factory for necessary repair and upgrade. The Gyrotron was repaired with new window so that it can be operated for longer time and withstand the warranty of two years. The factory tests of 82.6GHz Gyrotron are carried out successfully.

Fig. 1. 82.6GHz-400kW Gyrotron

The burn pattern at the exit of Gyotron is shown in Figure 2. We see the power is centralized and the size of thermal image compare with the window ensures the good Gaussian output of the Gyrotron. The burn pattern was achieved at 44.5kV cathode voltage, 16kV anode voltage and pulse duration is 40ms.

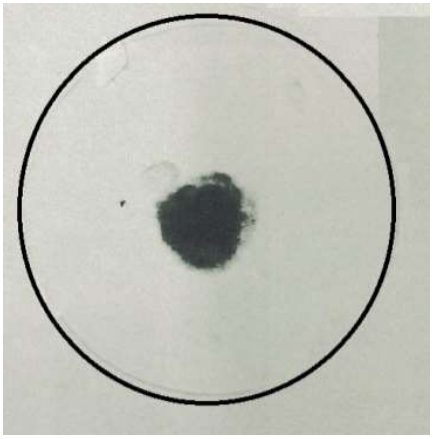

Fig. 2. Burn Pattern at the exit of Gyrotron

Fig. 3. Frequency of Gyrotron

The frequency of Gyrotron (Figure 3) was also measured at factory and monitored 82.689GHz. The mode purity test separately carried out at factory, the IR images of thermal paper are recorded at distances shown in figure 4, later it was matched with the simulation. As shown in the figure, the mode purity of this upgraded 82.6GHz Gyrotron is better than 99%.

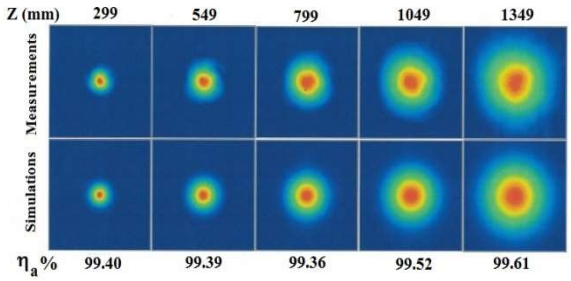

Fig. 4. Mode Purity test of gyrotron

The full power test of Gyrotron has also been carried out at the factory. The Gyrotron delivers 400kW power at cathode voltage around - 48.5kV, anode voltage + 25kV. As shown in figure 5, the Gyrotron draws 20A of cathode current, the efficiency of this Gyrotron is around 42%.

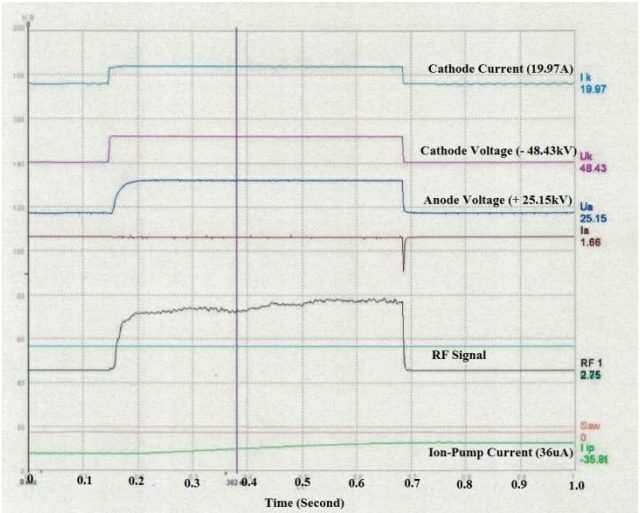

Fig. 5. Full Parameter test of gyrotron

4 Conclusion

The 82.6GHz Gyrotron has been upgraded for ECRH systems on tokamaks SST-1 and Aditya-U. The Gyrotron has been tested at factory for its rated parameters, It delivers 400kW power at around 48kV cathode voltage and draws cathode current around 20A. The efficiency of gyrotron is ~42%. The 42GHz-500kW ECRH system is already operational on both the tokamaks. For 1.5T operation, 42GHz would be used at fundamental harmonic while 82.6GHz would be used at second harmonic. The total ECRH power of 900kW would facilitate to carry out several ECRH experiments on SST-1 and Aditya-U at higher ECH power.

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