ECRH experiments on Tokamaks SST-1 & Aditya-U and ECRH upgradation plan for SST-1

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Abstract. A 42GHz-500kW ECRH system [1-6] is used to carry out various experiments related to plasma breakdown and ECR heating on tokamaks SST-1 and Aditya-U. The system has been upgraded with new anode modulator power supply to launch two ECRH pulses to carry out breakdown and heating simultaneously. In SST-1, ECRH system is used routinely for plasma breakdown at fundamental harmonic, approximately 150kW power is launched for 70ms to 150ms duration and consistent plasma start-up is achieved in SST-1. In the recent experiments, second EC pulse is also launched at the plasma flat-top to heat the plasma, some heating signatures are seen but more experiments will be carried out to confirm the plasma heating with ECRH. In Aditya-U tokamak, simultaneous plasma breakdown and heating experiments are carried out successfully [2]. In the first pulse around 100kW power in fundamental O-mode is launched for 70ms duration for the breakdown at low-loop voltage and around 150kW ECRH power for 50ms duration is launched in second EC pulse to heat the plasma. In case of Aditya-U, plasma heating is observed clearly as soft X-ray signal increases sharply with ECRH. In Aditya-U tokamak, deuterium plasma experiments have been carried out and ECRH launched at the flat-top of deuterium plasma current. In deuterium plasma also ECR heating is observed as soft X-ray signal increases with ECH power. For SST-1, ECRH system is being upgraded with another 82.6GHz system, this system would be used to carry out plasma heating and start-up at second harmonic. The 82.6GHz system is already connected with the SST-1 tokamak, the old 82.6GHz-200kW Gyrotron will be upgraded to 400kW system to carry out effective heating experiments on SST-1 at higher ECRH power. The paper discusses the recent results of ECRH experiments carried out on tokamaks SST-1 & Aditya-U and presents the upgradation plan of EC system for SST-1.

1 Introduction

The 42GHz ECRH system has shown many interesting results towards low-loop voltage start-up and ECR heating in SST-1 and Aditya-U. Till now we have carried out experiments with single EC pulse and experiments were limited for either breakdown or heating. It is mainly due to limitation in power supply system. Recently the power supply system of 42GHz Gyrotron is upgraded and a new advance anode power supply is commissioned with the system. The rise and fall time of this power supply is ~1ms, which allow to operate the Gyrotron for more than one pulse. The data acquisition software is modified accordingly and interfaced with power supply as per the demand of the experiment. The pulse duration and ECRH power can be varied as per the experimental requirement. For the breakdown at fundamental harmonic, less ECH power is needed for breakdown while for heating higher power is recommended. The ECH power in both the pulses can be adjusted as per the need of experiment by selecting the suitable parameters of anode power supply. The ECRH two pulse experiments (breakdown and heating simultaneously) have been carried out on both the tokamaks

2 ECRH experiments in SST-1

In the SST-1, various experiments have been carried out related to low-loop voltage start-up and two EC pulse experiments. The recent ECRH results in SST-1 are shown in figure 1. Two pulse experiments are carried out for plasma breakdown and heating. The toroidal magnetic field of SST-1 tokamak is 1.5T and ECRH power in fundamental O-mode is launched from low field side. The first pulse of 150kW power for 50ms duration is launched for start-up and after a gap of 25ms another pulse is launched for 75ms.

The breakdown is achieved successfully with first pulse as H_alpha appears with ECRH. The appearance of Hα with ECRH confirms the breakdown but variation of Hα throughout the plasma shot indicates that burn-through may not be completed fully. It could be due to presence of impurity in the plasma as carbon increases during the plasma shot. The other reason of Hα could be the emission from the edge. In the (Figure 1), there is increase in soft X-ray signal with the second pulse of ECRH but it is not conclusive for plasma heating with ECRH and more experiments are scheduled in next plasma campaigns. In SST-1, ECRH is mandatory for plasma start-up, so first pulse is needed for every plasma shots and second pulse would be applied when heating experiments would be carried out, these experiments would be carried out systematically in forthcoming campaign of SST-1.

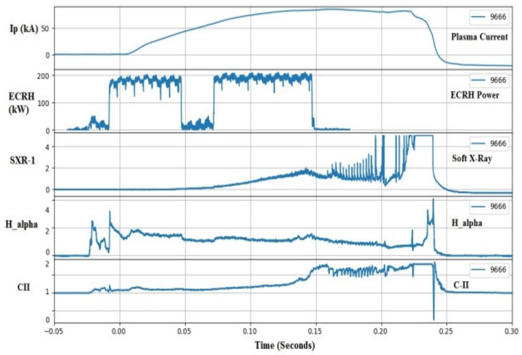

Fig. 1. SST-1 plasma shot with two ECRH pulses

3 ECRH experiments in Aditya-U

In Aditya-U tokamak, EC-assisted breakdown and heating experiments are carried out simultaneously. Two ECRH pulses launched in Aditya-U plasma, first pulse of ECRH is launched before the loop voltage and after a gap of 30ms another pulse is launched for plasma heating. The power in first pulse is 100kW and duration is 50ms while in second pulse 150kW power launched is launched for 100ms.

In Aditya-U tokamak, the operating toroidal magnetic field is 1.35T, so ECR layer lies inboard side the plasma. The standard Aditya-U plasma discharge is shown in figure 2. The loop voltage is around 13V and successful discharge of more than 200ms is achieved with plasma current close to 150kA.

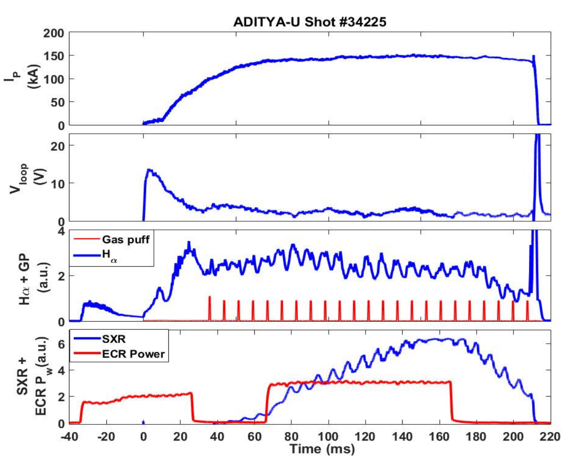

Fig. 2. ECRH two pulse in Aditya-U

In Aditya-U, the effect of plasma heating can be observed as soft X-ray (SXR) signal follow the ECH power (Figure 3). Although the soft X-ray signal starts increasing before the ECRH pulse so ECR heating effect may not be conclusive but reduction in soft X-ray signal immediate after ECRH pulse indicates the effect of ECRH. The soft X-ray (SXR) radiation is generated mainly by bremsstrahlung, which depends on both electron density n_e and temperature T_e:

$$P_{brem} \sim Z_{eff}\, n_e^2 \sqrt{Te}$$

The contribution of impurity can be considered as constant in the plasma for both the cases (with and without ECRH) as tokamak conditions are maintained, so the increase in SXR flux at the detector due to ECRH power could be either due to increase in density or due to increase in electron temperature. Considering the Aditya-U plasma is fully ionized, the increase in soft X-ray could be due to increase in electron temperature. These ECR heating experiments are not yet completed on tokamak Aditya-U, it will be carried out again systematically with supporting diagnostics and systematic variation in the parameters like ECRH power and durations etc.

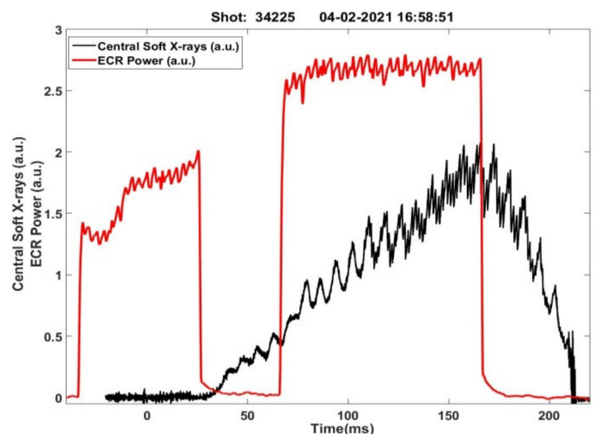

Fig. 3. Soft X-ray signal and ECRH in Aditya-U Plasma

4 ECR heating in Deuterium Plasma in Aditya-U

In Aditya-U, deuterium plasma experiments are carried and during this plasma campaign, ECR heating is also tried in deuterium plasma. The ECH power is launched at the flat top of plasma current. The ECRH power in fundamental O-mode is launched from the radial port (low field side of tokamak). The 200kW ECRH power for 50 ms duration is launched in deuterium plasma from 160ms to 210ms. The total plasma discharge length in this shot is around 245ms and plasma current close to 150kA (Figure 4). The effect of plasma heating with ECRH power is also seen with the increasing trend of soft X-ray with ECRH power, which indicates the EC wave coupling with deuterium plasma. The exact ECR heating cannot be explained as other diagnostics like ECE were not available during this shot, but decrease in soft X-ray after ECRH pulse indicates the ECR heating effect of deuterium plasma.

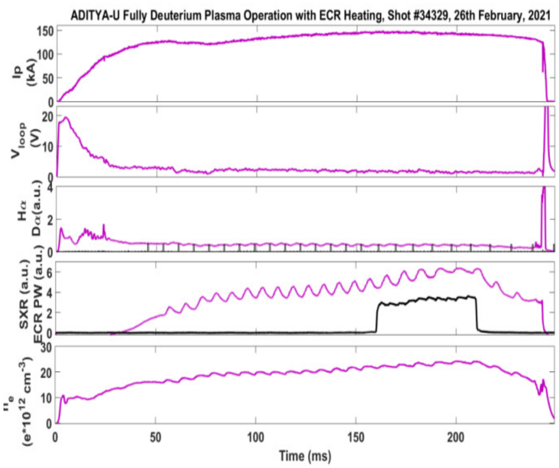

Fig. 4. ECR Heating in deuterium plasma in Aditya-U

5 Upgradation plan of ECRH system on SST-1

In the SST-1, 42GHz-500kW ECRH system is used to carry out breakdown and heating at fundamental harmonic (1.5T operating toroidal magnetic field). In 2010, another 82.6GHz-200kW ECRH system commissioned on SST-1 to carry out breakdown and heating at 3.0T operation (fundamental harmonic) and 1.5T operation (second harmonic). This system can deliver maximum 200kW ECRH power and considering 20% transmission loss, only 160kW ECRH will be available for ECRH experiments and this power is not sufficient for plasma start-up at second harmonic (1.5T) and ECR heating also demands higher power. This has been experimentally observed in SST-1 with 42GHz ECRH system [7]. At fundamental harmonic (1.5T operation) 150kW ECRH power is sufficient for plasma breakdown while for second harmonic breakdown (0.75T operation), more than 250kW ECRH power was required for reliable breakdown and plasma start-up.

In order to carry out plasma experiments at higher ECRH power, this old 82.6GHz is being upgraded in terms of power. The 82.6GHz ECRH system is planned to achieve double power (400kW) for 500 ms duration. This 82.6GHz ECRH system is already connected with the SST-1 tokamak, transmission line is laid and launcher mirrors are installed inside the tokamak. The Gyrotron will be repaired and upgraded in terms of power. With this upgradation, the entire ECRH system will be upgraded for SST-1 and total ECRH power (42GHz and 82.6GHz system) in SST-1 will be increased to 900kW which will facilitate to carry out several experiments related to plasma start-up and heating at both the harmonics.

6 Conclusion:

The 42GHz ECRH system for SST-1 and Aditya-U has been upgraded for multi ECRH pulse operation. The experiments related to ECRH assisted breakdown and ECR heating experiments can be carried out simultaneously in both the tokamaks. Depending on the experimental demand, the ECRH power and duration can be varied in both the ECRH pulses.

Initial experiments with two ECRH pulses have been carried on both the tokamaks SST-1 and Aditya-U both. The breakdown is consistent in both the tokamaks while ECR heating needs more experiments for its confirmation.

The 82.6GHz ECRH system which would be useful to carry out second harmonic ECR heating experiments on SST-1 at 1.5T magnetic field will be upgraded to double the power. The Gyrotron is under process of upgradation while transmission line is already connected with Gyrotron. This system will facilitate to carry out several ECRH experiments in SST-1 at higher EC power.

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