CONTROLLING PLASMA ROTATION USING PERIODIC GAS-PUFF IN ADITYA-U TOKAMAK

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Abstract

Plasma rotation and its shear in the edge and scrape-off-layer (SOL) region plays an important role in determining overall confinement of tokamak plasmas. The sources of spontaneous generation of these rotations are still not fully understood. Furthermore, to answer the questions like whether they modify the electric field profile or electric field profile modifies the rotation and its shear, the radial profiles of toroidal and poloidal plasma rotation have been measured in ADITYA-U [1-2] in presence and absence of multiple periodic fuel and neon gas-puffs. Further in typical ADITYA-U discharges, effects of plasma density and different MHD modes on plasma rotation are studied. The results are compared with neo-classical estimations. Plasma rotation velocity is deduced from Doppler shift of the observed line emissions in Visible wavelength range. The collection optics, installed on a tangential view port of the tokamak, contains five line-of-sights giving radial profile of rotation velocity. The details on the development of the diagnostics with emphasis on the results obtained from ADITYA-U plasma rotation profile will be discussed.

1. INTRODUCTION

Plasma rotation is known to play an important role in improving plasma confinement and stability by suppressing turbulence and MHD mode instability [1]. High rotation velocities are achieved by imparting external momentum through injection of Neutral beam, this may not be the case for large fusion devices like ITER having large plasma volume [2]. In scenarios where external momentum will not be sufficient to drive plasma, intrinsic rotation will play an important role. Mechanisms leading to generation of momentum thus leading to intrinsic rotation are also not known [3-5]. Plasma rotation can be measured by Doppler shift spectroscopy by implementing active or passive spectroscopy. For the measurement of plasma rotation, a high resolution visible spectroscopic diagnostic has been developed and implemented on ADITYA-U tokamak, for the measurements of passive charge exchange spectral line of C^{5+} at 529 nm is used.

ADITYA-U [6] is a medium sized tokamak having a minor radius of a=25cm with a major radius of R = 75cm and having diverter configuration. Toroidal limiter and diverter plate is made of graphite material thus providing the carbon impurity as a good candidate for the study. ADITYA-U parameters for limiter configuration are: Plasma current ~ 150 -250 kA, Discharge duration ~ 250 -300 ms, Electron density of ~ 3 -5 x 10^{19} m^3 and electron temperature of 500 eV – 1keV . In diverter configuration, shaped discharges with ~ 100 – 150 kA, elongation of ~ 1.1 – 1.2 with triangularity of ~ 0.45 can be produced.

The report is divided into following headings: Section 2 gives diagnostic detail and experimental set up. Section 3 presents preliminary results obtained from Aditya-U followed by Section 4 with conclusion and details about future work.

2. EXPERIMENTAL SETUP

The measurement of toroidal rotation on ADITYA-U tokamak is performed using a high resolution 1m *f/8.7* Czerny-Turner configuration spectrometer from Princeton Instruments AM 510 equipped with a 1800g/mm grating. The fibers are imaged onto an iDUS CCD from ANDOR DV – 420 OE having 1024 x 256 pixels with 26 µm pixel size. The spectrometer-CCD system gives a dispersion of 0.0144nm/pixel. Two experimental setups were used in the experiment, for measurements without gas puff setup in [7] was used. For the experiments in shots having gas puff, diagnostic with upgraded collection optics was used. In the upgraded collection optics five lines of sights were viewing the plasma tangentially from ~ - 2 cm in high field side to ~ 17 cm of plasma minor radius towards low field side. The radial coverage of the plasma is limited by the port dimension which limits the number of fiber to be accommodated. The front end collection optics comprises of a miniature collimator having an aperture of ~ 0.43 cm coupled with a 400 µm core diameter fiber with a N.A. of

0.22, a spot size of ~ 3cm is obtained in the plasma where the line of sights are tangent to the flux surfaces. Figure 1 shows line of sight geometry inside the plasma along with the layout of experimental setup.

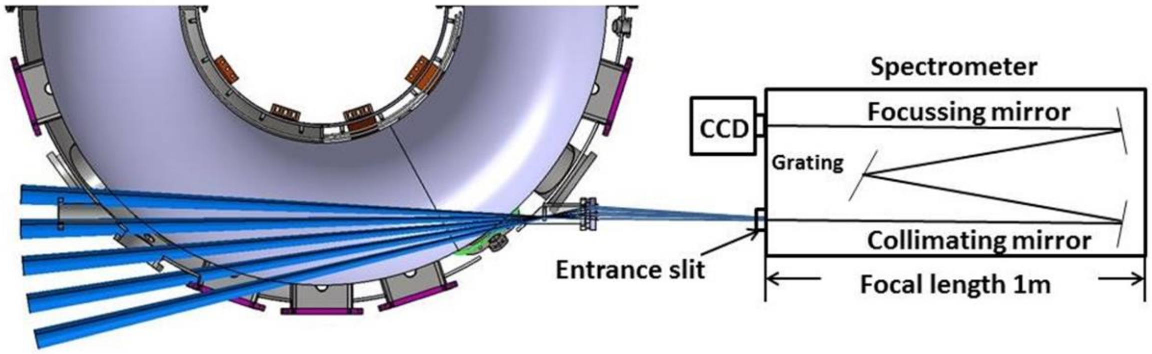

FIG. 1. Experimental set up showing arrangment of line of sights for toroidal rotation measurment .

3. PRELIMINARY RESULTS

Preliminary results obtained for the measurement of toroidal rotation velocity during the presence of gas puffs are presented. Fig 2 shows typical ADTIYA-U discharge without gas puff with duration of ~ 140 ms with maximum plasma current of ~ 94.78 kA. The loop voltage during flat top is around 2V, temporal evolution of H_α and soft X-ray signal are also shown in Fig 2. The measurement for the shot was performed with setup in [7] and CCD exposure was set to 20ms.

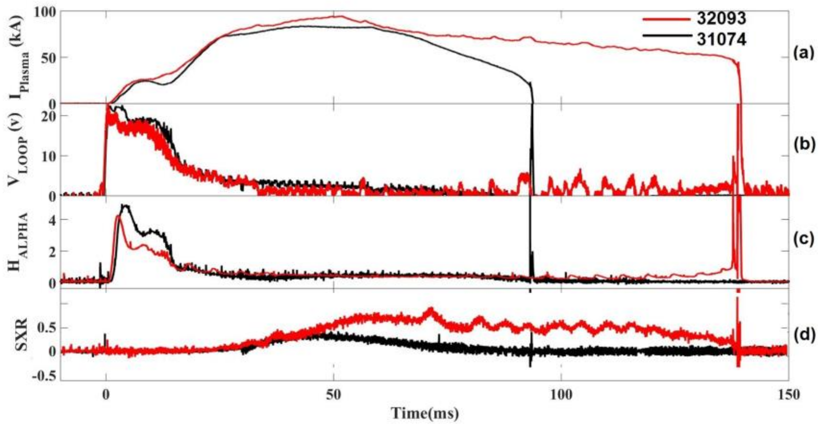

FIG. 2. Typical ADITYA-U discharge of shot #32093 along with CCD exposure duration.(a) Plasma current, (b) loop voltage (V), (c)Ha emission and (d) soft X-ray emission(SXR)

Fig 3 shows a ADITYA-U discharge with gas puff at ~ 42 ms, the discharge had a maximum plasma current of ~ 93.71 kA with a plasma duration of ~ 75 ms. The loop voltage during flat top was ~ 3V. The temporal evolution of H_α and soft X-ray signal are also shown in Fig 3. The effect of gas puff can be seen in SXR signal. The CCD exposure was set to 30ms for shot # 32140.

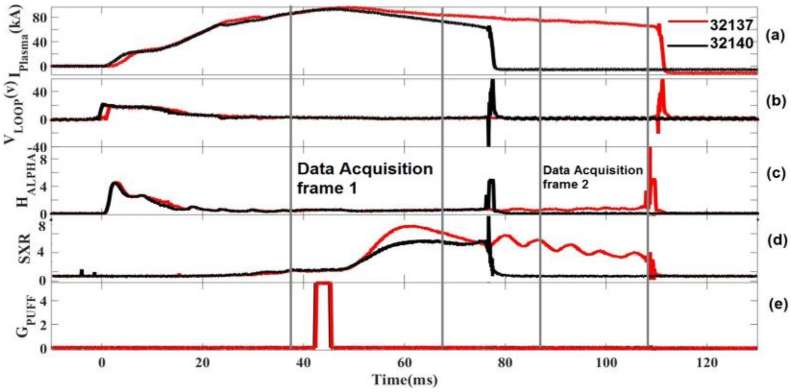

FIG. 3. Typical ADITYA-U discharge of shot #32140 along with CCD exposure duration.(a) Plasma current, (b) loop voltage (V), (c)Ha emission (d) soft X-ray emission(SXR) and (e)Gas puff pulse.

Rotation velocity measurements are obtained from Doppler shift, the unshifted wavelength was obtained from tokamak plasma. The method of determining the wavelength calibration is described in [7]. The measurement of C^{5+} presented are passive and line integrated. In order to obtain local rotation velocity from line integrated measurements, inversion technique is applied [8,9,10]. Fig 4 shows spatial profile of rotation velocity along with ion temperature for shot # 32093 without gas puff after inversion.

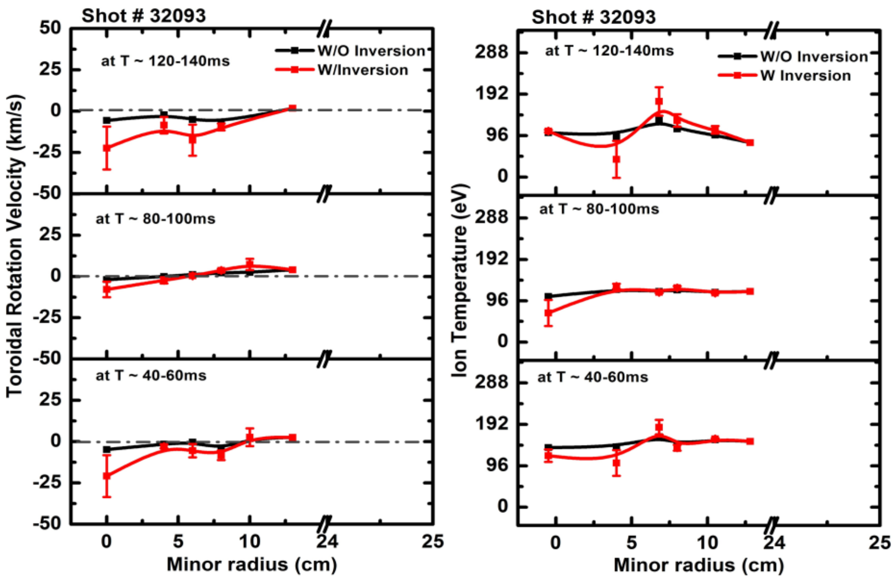

FIG. 4. Temporal evolution of toroidal rotation velocity and ion temperature profile along with error bars are shown for shot # 32093

The maximum rotation velocity obtained after inversion is – 24 km/s and ion temperature of ~ 150 eV in the core. The direction of the rotation is found to be in the counter-current direction. Gas puffing during the experiments was done from bottom port. During gas puffing experiment Neon gas was puffed using a piezoelectric valve. The time of gas puff was synchronized to flat top period starting at ~ 42ms, gas was puffed for ~ 5ms duration. The CCD exposure was set to ~ 30ms with delay in trigger of ~ 40 ms in order to capture effect on rotation velocity during gas puff. For measurements without gas puff, reproducible shots were used having similar plasma parameters. In long plasma discharge duration where more than one frame is captured, temporal evolution of rotation velocity can be studied. In shot 31074 and 32140 single frames were captured due to small plasma discharge of ~ 90 ms.

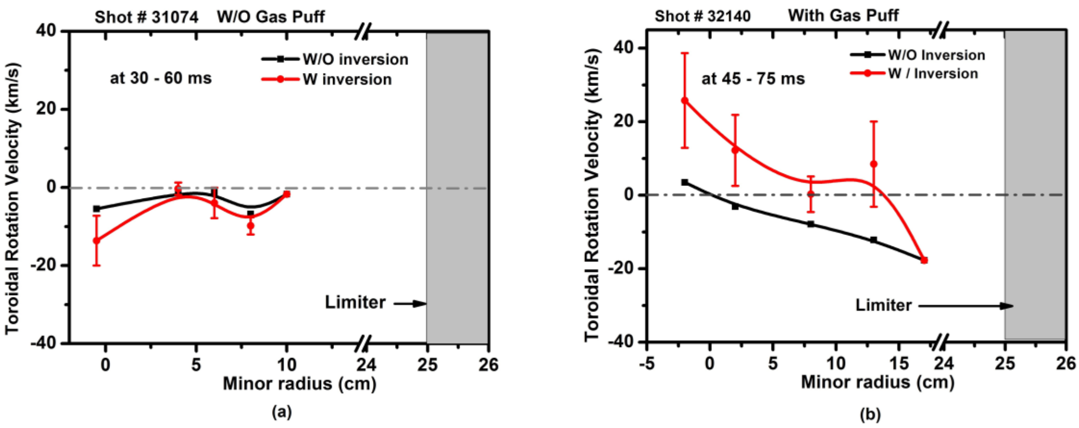

FIG. 5. Shows toroidal rotation velocity profile along with error bars are shown for shot # 31074 without gas puff and shot # 32140 with gas puff

It is observed that rotation velocity direction is in counter direction to the plasma current while the direction of rotation is observed to have changed to co-current direction during gas puff; this is shown in Fig 5. Further in shot # 32093 and shot # 32137, the same trend is observed.

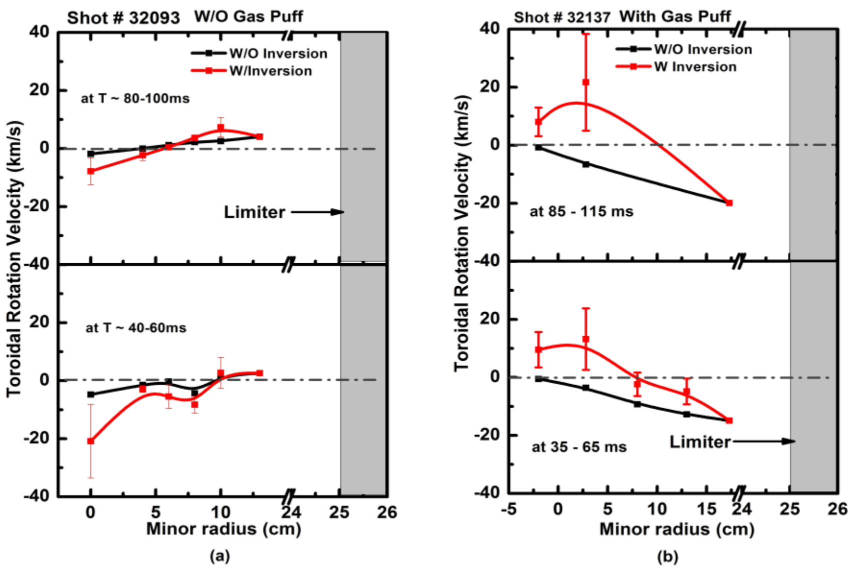

FIG. 6. Shows toroidal rotation velocity profile along with error bars are shown for (a) shot # 32093 without gas puff and (b) shot # 32137 with gas puff

4. CONCLUSION AND FUTURE WORK

Preliminary results of toroidal plasma rotation velocity are presented. The measurements were done to observe effect of gas puff on rotation velocity. To measure the rotation velocity spectral lines from C^{5+} at 529 nm are used. Preliminary results suggest that ADITYA-U tokamak has a counter-current rotation direction; however, it is observed that direction of rotation changes to co-current with gas puff. To measure gas puff effect Ne gas was puffed for ~ 5ms during the flat top.

The diagnostic collection optics will be upgraded with a re-entrant viewport to cover complete plasma radius. With the upgraded collection optics and coverage of complete plasma minor radius upto limiter will enable a better understanding of edge rotation.

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REFERENCES

[1] STOLTZFUS-DUECK, T., “Transport driven Toroidal rotation in the Tokamak edge” Phys. Rev. Lett. 108(6), 065002 (2012).

[2] DOYLE, E., *et al.*, Ch-2 : Plasma confinement and transport, Nuclear Fusion. 47, S18 (2007).

[3] RICE, J.E., *et al.*, “Edge Temperature Gradient as Intrinsic Rotation Drive in Alcator C-Mod Tokamak Plasmas” Phys. Rev. Lett. 106, 215001 (2011).

[4] RICE, J. E., *et al.*, “Inter-machine comparison of intrinsic toroidal rotation in tokamaks” Nuclear Fusion. 47, 1618 (2007).

[5] NAVE, M. F. F., *et al.*, “Influence of Magnetic Field Ripple on the Intrinsic Rotation of Tokamak Plasmas” Phys. Rev. Lett. 105, 105005 (2010).

[6] TANNA, R. L., et al., “Plasma production and preliminary results from the ADITYA Upgrade tokamak” Plasma Sci. Technol. 20, 074002 (2018).

[7] SHUKLA, G., *et al.*, "Plasma rotation measurement using UV and visible spectroscopy on ADITYA-U tokamak" accepted for publication in Rev. of Scientific Instruments (2018).
[8] CONDREA, I., *et al*., " Local poloidal and toroidal plasma rotation velocities and ion temperature in a tokamk plasma obtained with a matrix inversion method considering asymmetries" Phys. Plasmas 7, 3641 (2000).
[9] BELL, R. E., "Inversion technique to obtain an emissivity profile from tangential line-integrated hard x-ray measurements" Rev. Sci. Instrum. 66, 558 (1995).
[10] GHOSH, J., *et al*., "Radially resolved measurements of plasma rotation and flow-velocity shear in the Maryland Centrifugal Experiment" Phys. Plasmas 13 (2006).