# TC-17 \* scaling of intrinsic torque

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| **TG priority:** High | **Start date:** 2012 | **Status:**  On-going | **Personnel exchange:**  Yes |
| **IO priority:**   | **End date:** 2017 | **Motivation:** Physics Basis |

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| **Device /****Association** | **Contact****Person** | **2016 TGRequest** | **Activity (from JEX/JA spreadsheet)** |
| **2012** | **2013** | **2014** | **2015** | **2016** |
| DIII-D  | C. Chrystal | Desirable | Considering | Analysis | Analysis | Analysis |   |
| JET | T. Tala | Desirable | Committed | Considering | Committed | Analysis |   |
| AUG | R. McDermott | Desirable | Committed | Committed | Committed | Committed |   |

**Purpose:** The ultimate aim of the experiment is to investigate the \* scaling of the intrinsic torque at the edge of the plasma, for the purpose of extrapolating the intrinsic rotation to ITER. A \* scan between JET and DIII-D/AUG (and perhaps C-Mod) is to be performed, at matched βN, q and \*. As this remains a new experimental measurement for most devices, the initial phase of this joint experiment will be broader in scope, trying to more carefully validate the simplified measurement technique required for devices that cannot null out the intrinsic rotation like DIII-D.

**Results for 2015**

**JET:** JET executed two sessions on intrinsic torque experiment in autumn 2014. The main goal of this experiment was to perform a dimensionless identity experiment JET and AUG and single-machine ρ\* scaling experiment in JET. The main motivation for both them was to clarify whether the intrinsic torque scales with ρ\* or not.

The match between JET and AUG was excellent, including both the shape and the dimensionless profiles. JET high ρ\* shot (#87309) matches the AUG ρ\* within 10% and this is a very good result. The q, β and υ\* profiles are matched more or less within 10%, the volume averaged values being off by less than 10%.

Shots #87309 (Bt=1.3T), #87320 (Bt=2.3T) and #87322 (Bt=2.9T) form a successful 3-point ρ\* scan in JET (ρ\* scanned by a factor slightly less than 2). Within the 3-point JET ρ\* scan, q, β and υ\* are matched very well, the volume averaged values being typically within 10% between the 3 JET shots.

Currently two discharges have been analysed with TRANSP calculated time dependent torque (Shots #87309, Bt=1.3T; #87320, Bt=2.3T). Intrinsic torque was found to increase with decreasing ρ\* and agree qualitatively with Solomon edge intrinsic torque scaling from DIII-D data published in 2010. New TRANSP runs are requested and expected to be finished before the end of the year.

 **AUG:** New experiment was planned and prepared in 2015 to be executed in 2016 so that the identity match with JET would be successful without the large mode that ruined us to use the good identity pulse from the 2014 campaign. New TRANSP runs have been made for the ECRH shots and the analysis of those is just about to start.

**DIII-D:** Experiments at DIII-D have investigated the scaling of intrinsic torque with the normalized gyroradius, ρ\*, by performing a dimensionless parameter scan. High- and low-ρ\* versions of a plasma have been created such that the scan can be combined with similar scans on other tokamaks. The identity match with JET is fairly good in terms of q, β and υ\* profiles very similar, difference being 10-20%. Intrinsic torque and momentum transport coefficients are measured by applying repeated torque steps at constant power with co- and counter-current neutral beam injection. The intrinsic torque was also measured by determining the neutral beam torque required to null the toroidal rotation profile. These results show that the density of intrinsic torque in the core of these plasmas more than doubles while ρ\* decreases by approximately 23%. Independent measurements of intrinsic torque are consistent and show that the dependence of intrinsic torque on the Mach number is minimal.

**Plans for 2016**

**JET:** A detailed analysis of the successful ρ\* scan and identity with AUG should be finished once the new TRANSP runs will come. The 3-tokamak, wider range of ρ\* scan, comparison is to be carried out.

Concerning further experiment, the originally planned lowest ρ\* point at Bt=3.4T could not be matched due to the available NBI power of 25MW. If JET succeeds to go to a stationary plasma with more than 30MW of NBI power so that the 3.4T match point can be performed, this could be pushed forward.

**AUG:** The ρ\* identity experiment with JET will be re-executed in January 2016 with the main goal to get rid of the large mode. This should be a relatively straightforward task, but still absolutely critical to pin down the main objective of TC-17, i.e. ρ\* scaling of the intrinsic torque.

To conclude the role of different turbulence regimes and different heating schemes in influencing the magnitude of the intrinsic torque, further and hopefully cleaner experiment will be still needed and those will be executed in February 2015.

The analysis of both 2013 and 2014 intrinsic torque experiment (ρ\* identity, q-scan, turbulence regime scan) will continue extensively, with the aim to get the first results published in 2016. In particular, the effect of possibly a little time-depending plasma background (momentum confinement time) on the inferred intrinsic torque profile should be quantified.

**DIII-D:** The analysis will continue based on the APS talk by Colin Chrystal. Results and intrinsic torque profiles from different analysis and experimental methods will be compared to minimize the error bars of individual shots. New experiments on the scaling of momentum transport on ρ\* will be executed and this experiment may contribute also to experiment by giving new and additional data in different plasma regime.

**Background:** Previous ITPA work has amassed a substantial database of intrinsic rotation measurements in various tokamak devices. Initial estimates from this database project to a large intrinsic velocity (~300 km/s) for ITER. However, more recent data, particularly from JET, have shown very small intrinsic velocities, which can even go counter depending on the level of ripple. As our understanding of momentum transport has evolved, it has become clear that although a velocity prediction is ultimately what is desired for ITER, other torques on the plasma, as well as the need to distinguish between velocity and angular momentum, makes it difficult to make further progress on understanding intrinsic rotation generation without looking at the underlying drive mechanisms. Therefore, the necessary extension of the work on intrinsic rotation is to begin to characterize the “intrinsic torque” associated with its generation.

A limitation of the simplest approach used to obtain the intrinsic torque is that it can only be applied to plasmas that can be successfully slowed to zero rotation. Because of this fairly significant restriction, a new technique has been devised for measuring the intrinsic torque. The idea is relatively straightforward, and operationally, one only needs to make a (calculable) step in the applied external (eg neutral beam) torque. From a simple 0D angular momentum balance equation, one can relate the angular momentum evolution to the NBI torque, the intrinsic torque, and some effective damping associated with the momentum confinement time. At each radius, one measures the angular momentum evolution, and must solve for two unknowns, the intrinsic torque and momentum confinement time, from the time history of data. Although it is not *a priori* clear that this simple model is able to capture the physics of the complete angular momentum balance equation and accurately reproduce the intrinsic torque profile, the technique has been successfully benchmarked in plasmas where the rotation profile was successfully brought to zero. This opens the door for making these measurements in multiple devices.

However, analysis in the last year from AUG has shown that this approach may have some limitations in its applicability. In particular, AUG discharges have found situations where the intrinsic torque and momentum confinement time are not well decoupled, leading to large uncertainties in these solved quantities. More work is required to understand the conditions where the approach breaks down.