Simulation study of NBI-driven torque and toroidal plasma rotation in KSTAR tokamak

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The KSTAR (Korea Superconducting Tokamak Advanced Research) device [1], which entered its real operation phase in 2009, after its successful first-plasma generation in 2008, aims eventually to demonstrate the steady-state operation of high performance AT (Advanced Tokamak) modes. For this research goal, KSTAR will use several heating and current systems including a NBI (Neutral Beam Injection) device.

Here, we present a simulation study of NBI heating and current drive with a planned KSTAR NBI system. Particularly, we calculate the NBI driven torque and the resulting toroidal plasma rotation, which is known to play an important role in the performance of a fusion device [2]. For this study we use NUBEAM [3], a Monte Carlo simulation code for NBI modelling in tokamak. The toroidal rotation velocity is calculated by combining NUBEAM with the 1D transport code ASTRA [4]. In a first part, we will talk about the plasma rotation driven by NBI torque. Then, we will show the results of our simulations.

1. Plasma rotation driven by NBI torque

In this study, we want to observe the influence of the NBI torque on the rotation of the plasma. For this, we coupled the transport code ASTRA with NUBEAM. The plasma toroidal velocity calculated by ASTRA is approximatively given by [5]:

$$u_\phi = \frac{T_\phi}{m_i n_i R}\tau_\phi \qquad (1)$$

The torque, T_ϕ, is given by NUBEAM, whereas the ion mass, m_i, ion density, n_i, and the plasma radius, R, are given by ASTRA.

The angular momentum time τ_ϕ, given by [6], can be calculated with ASTRA:

$$\left(\frac{\tau_\phi}{I_\phi}\right)_{MMM08} = 0.068\left(\frac{T}{N}\right)^{-0.78} \qquad (2)$$

where I_ϕ is the toroidal plasma current, T the total torque and N the density of ions.

This power law scaling comes from the MMM08 [7] transport model. Later, this formulation can be adapted to fit with KSTAR experimental results.

2. Results

The plasma configuration used in this study is described in the Table 1.

B (T)	I (MA)	R (m)	a (m)	χ	δ	q(0)	q95	Te(0) (keV)	Ti(0) (keV)	ne(0) (1/m3)
3.5	2	1.8	0.5	2	0.8	1.19	4.19	5.8	8.4	$2.04\ 10^{20}$

Table 1: Plasma configuration

We used only one beam source placed in different positions (R=1.721m, 1.483m, 1.246m, 1m, 0.5m, -0.5m, -1m, -1.246m, -1.483m and -1.721m), shown in the Figure 1-a. When the position R is positive (respectively negative), it means that the neutral beam is injected in the same (respectively opposite) direction as the plasma. The power of the beam is 2MW and its energy is 100 keV. The beam footprint is shown in the 1-b.

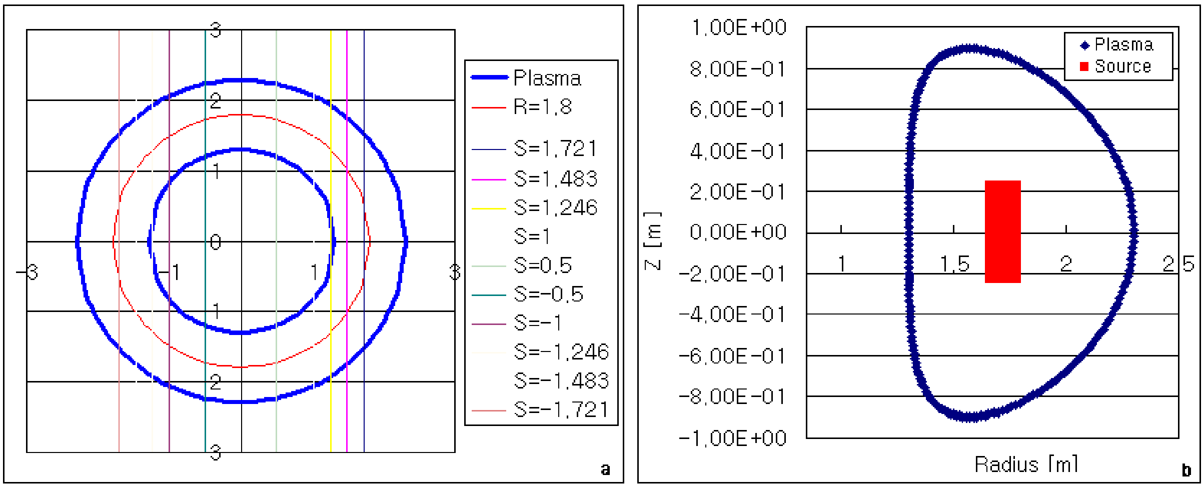

Figure 1: a- Different positions of the source (plasma view from above) b- Footprint of the source (side view)

We can see, in Figure 1-a, that the beam (colored lines) is tangential to the plasma (in blue). The source is vertical and on-axis (1-b).

The figure 2-a shows the total current (in MA) obtained for the different positions of the source. The figure 2-b shows the total power given to ions (PBI - pink dots), electrons (PBE - blue dots) and the bad orbit losses power (Orbit - green dots) for the different positions of the source (in MW).

As expected, the current shows symmetry between the NB launched in two opposite directions.

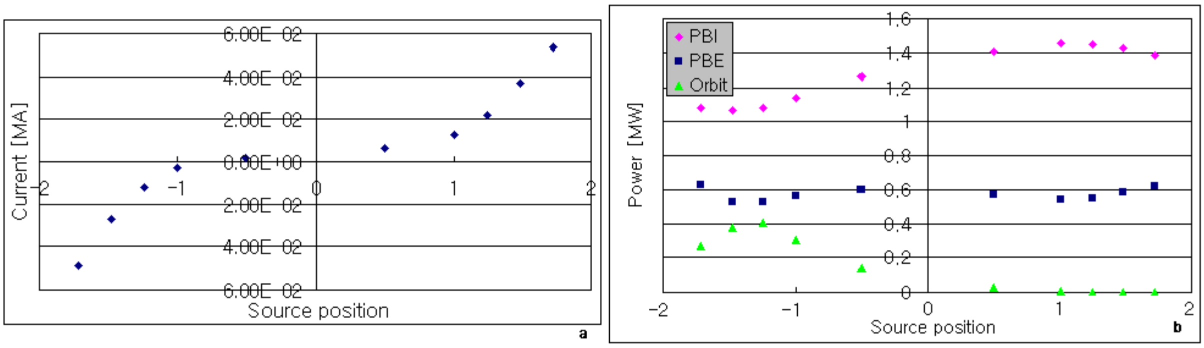

Figure 2: Total current (a-) and total power (b-) depending on the source position

The position of the source does not seem to influence the portion of power given to electrons, whereas the quantity of power given to ions is less when the source is positioned against the plasma rotation direction.

In fact, the decreasing of PBI is due to orbit losses. The phenomena has been studied in [8] for MAST tokamak. In our case, the power given to electron is unaffected and only the power given to ions suffers the orbit losses.

The figure 3 shows different torques obtained with NUBEAM: the beam collisional torque to electrons (TQBE - pink), the beam collisional torque to ions (TQBI - blue) and the beam JxB torque to thermal plasma (TQBJXB - green) in N.m.

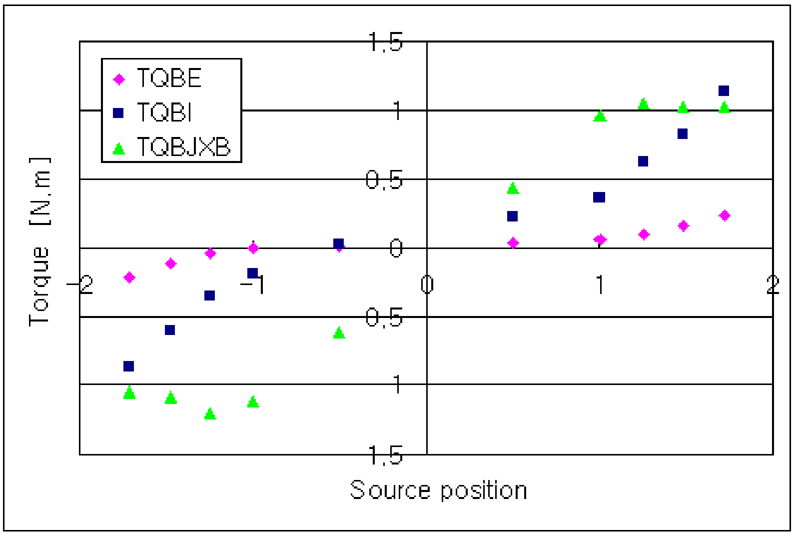

Figure 3: Torque depending on the source position

As expected, we observe symmetry for the different torques. We can see that the torque comes mainly from JxB phenomena, as noticed in [9].

Finally, the Figure 4 shows the plasma toroidal velocity generated by the NBI source.

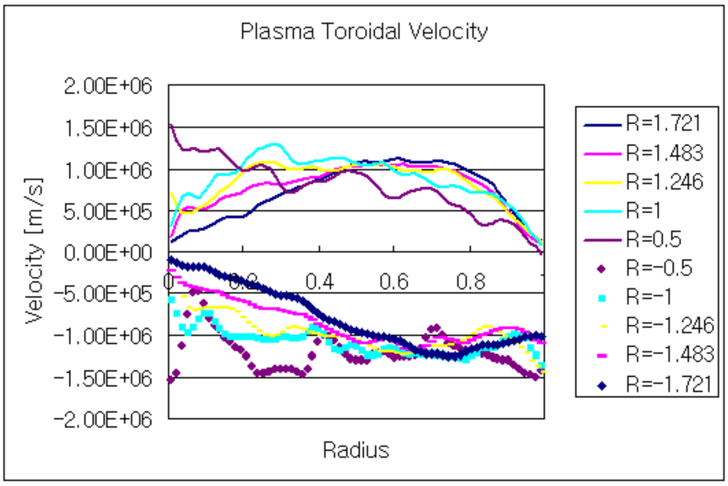

Figure 4: Plasma toroidal velocity depending on the source position

We can notice that the plasma rotation direction depends on the position of the NB source. Without torque, there is no rotation, because our model does not take into account plasma intrinsic rotations due to local pressure gradient [10] or magnetic field ripple [11].

3. Summary

The coupling of NUBEAM and ASTRA has been performed in order to investigate the plasma rotation driven by NBI torque. When the source is positioned against the plasma rotation direction, an increasing of bad orbit losses has been observed. And the JxB dominancy has been confirmed. The results obtained on the plasma velocity can be used to design the future NBI device, in order to increase KSTAR performance.

Later, the scaling used to calculate the plasma rotation will be adapted to fit the experimental results, not yet available. Then, the next step will be to solve the momentum transport in Astra, so that we can find the toroidal plasma rotation without using a scalinglaw. NUBEAM will be coupled with the global gyrokinetic code gKPSP for kinetic calculation.

References

[1] J.S. Bak and al., Fusion Engineering and Design 81, 20-22 (2006)
[2] D. J. Schlossberg and al., Physics of Plasmas 16, 080701 (2009)
[3] A. Pakin and al., Computer Physics Communications 159, 3 (2004)
[4] G.V. Pereverzev and P.N. Yushmanov, IPP 5/98, (2002)
[5] F.L. Hinton and M.N. Rosenbluth, Physics Letters A 259 (1999)
[6] F.D. Halpern and al., 36th EPS Conference on Plasma Phys., ECA Vol.33E, P-2.199 (2009)
[7] A.H. Kritz and al., 51st Annual Meeting of the APS Division of Plasma Physics 54, Number 15 (2009)
[8] P. Helander, R.J. Akers and L.G. Eriksson, Physics of Plasmas 12, 112503 (2005)
[9] J.S. deGrassie and al., Physics of Plasmas 13, 112507 (2006)
[10] M. Yoshida and al., Physical review letters 100, 105002 (2008)
[11] P.C. de Vries and al., Nucl. Fusion 48, 035007 (2008)