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BOOTSTRAP CURRENT STUDIES IN THE TJ-II HELIAC

J. A. Jiménez, R. Sánchez†, A. L. Fraguas,
L. A. Berry†† and S. P. Hirshman††
Asociación EURATOM-CIEMAT, Madrid, SPAIN
† *Universidad CARLOS III, Madrid, SPAIN*
†† *Oak Ridge National Laboratory, Oak Ridge, TN, U.S.A.*

Introduction

The TJ-II device is a four period shearless heliac-type stellarator, whose stability is mainly provided by the existence of a deep magnetic well across the whole plasma radius that diminishes the need for magnetic shear stabilization. But under certain operational conditions with $\bar{\beta} \sim 0.2\%$, total toroidal currents up to $1.5kA$ have been observed in TJ-II. These currents have been seen to be sufficiently large to introduce low-order rational surfaces into the plasma (for example, the 3/2 rational surface has been seen to enter the plasma for configurations with rotational transform close to 1.5). In this case, the rational surface may give rise to the appearance of magnetic perturbations that can be detected with the Mirnov coils [1]. Therefore, the almost shearless configuration characteristic of heliacs can be compromised and a very precise control of the sources of toroidal current might be essential to eliminate undesired results. In this sense, the importance of such a control has already been stressed for ECRH current drive (ECCD) studies [2]. This is an issue to take into account since the bootstrap current may yield values for the toroidal current of the order of kA, even when the machine is normally operated with near zero ECCD. Therefore, we have tried to look at the possible effects on the rotational transform profile of the expected bootstrap current by running a bootstrap current code recently developed [3] on the different numerical equilibria obtained for the most characteristic configurations of TJ-II.

Method

To study the possible impact of the bootstrap current throughout the wide configuration space of the machine, we have used a bootstrap current code that makes use of some analytical expressions derived for asymmetric devices in the collisionless regime [4]. The code has been recently updated and applied to the design of quasi-omnigeneous compact stellerators (QOS)[5] and it has been carefully benchmarked against δ-f and Monte-Carlo codes. Previous studies for TJ-II used the DKES code [6], but this code is impractical in terms of computational time if we want to keep the large number of Fourier modes required for the MHD equilibrium description to obtain reliable results.

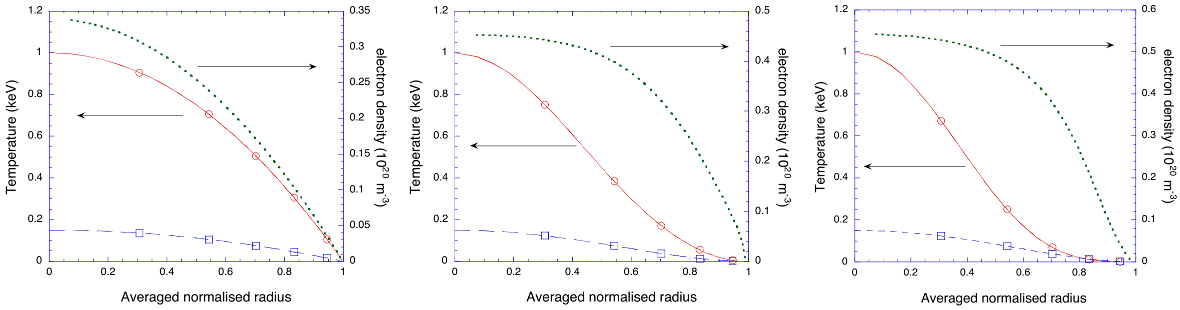

Figure 1: Profiles of the electron temperature (line with open circles), ion temperature (line with squares) and electron density (dotted line) for the three cases considered in this study. The profiles are referred as 1, 2 and 3 from left to right, and correspond to increasingly peaked pressure profiles. Profile 3 (right) is the one that most resemble the experimental conditions in TJ-II.

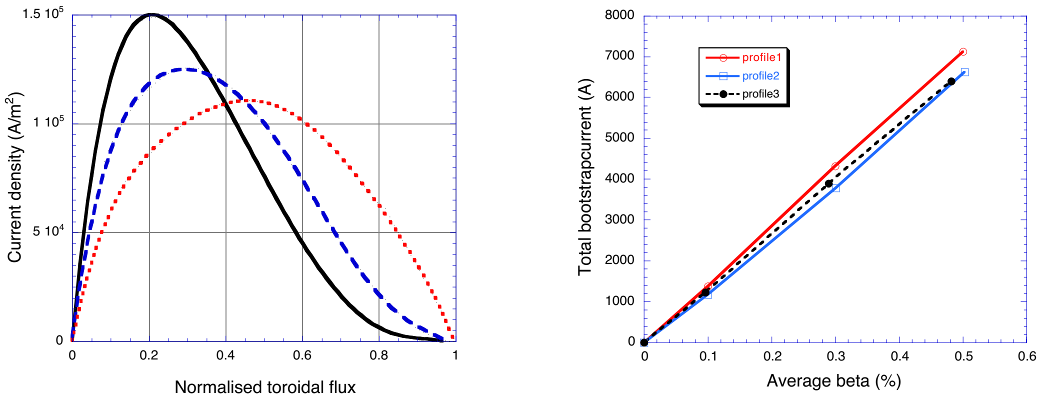

Figure 2: Current density profiles (left) for the three cases considered at $\bar{\beta} \sim 0.5\%$. The figure on the left show the total value of the bootstrap current for the whole range of $\bar{\beta}$ and for all the profiles. The currents flow in the negative direction but here its absolute values are depicted for clarity.

In the present first experimental phase of TJ-II only ECRH heating has been used. Therefore the T_e/T_i ratio observed is between $5-7$. The central T_e can reach values up to $1.2keV$ and the main variation of the plasma pressure is due to changes in density. To model this situation we have set $T_e = 1keV$ for all calculations with $\bar{\beta}$ ranging up to 0.5%. This value is about twice the presently obtained value experimentally in TJ-II with a total power available of $600kW$. The density has been then varied accordingly to match the pressure profile. With these values for the density and temperatures the plasma can be shown to be in the collisionless regime all across the plasma. We have made calculations for other values for the ratio T_e/T_i but the difference is only about 10% between the case with $T_e = T_i$ and the one with $T_e/T_i = 6.7$ used in this study (notice that a lower current is generated in the former case). Regarding Z_{eff}, a value of 2 has been chosen since the bootstrap current shows a weak dependency ($< 4\%$) with respect to this parameter. For reference, the experimental variation fo Z_{eff} has been measured to be between 2 and 5.

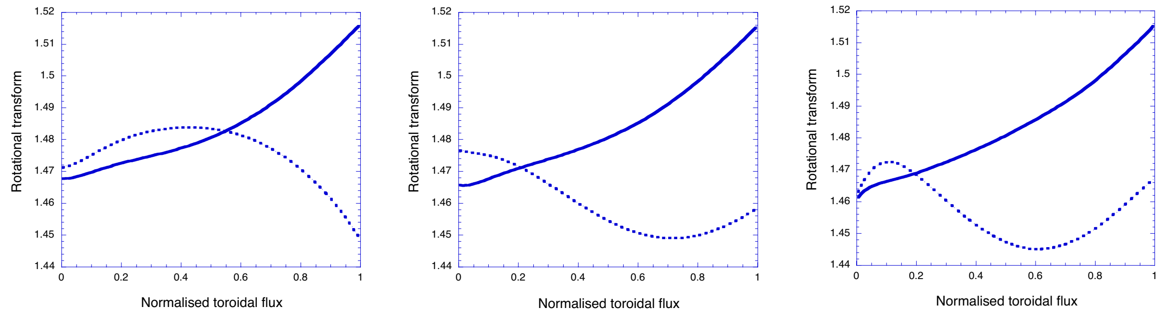

Figure 3: Variation of the rotational transform profiles for the three different pressure profiles considered in this study. The figures correspond, from left to right, to profiles 1, 2 and 3. The equilibria are calculated at $\bar{\beta} \sim 0.5\%$

The bootstrap current computed for the standard configuration flows in the negative direction (opposite to the toroidal magnetic field, i.e. contrary to that in a tokamak). This means that the helically trapped particles are those which give rise to the bootstrap current instead of those trapped in the toroidal wells. As a result of this, the current lowers the absolute value of the rotational transform (the rotational transform in TJ-II is negative). This result cannot be generalised though, as in other configurations with smaller average radius, a very small bootstrap current flowing in positive direction was obtained [7]. The calculation method employed in this work is in good agreement with previous calculations using the DKES code ($5kA$ vs. $5.5kA$ at $\bar{\beta} = 0.2\%$ for a parabolic pressure profile).

In figure 3 the effect of the calculated bootstrap current on the rotational transform profile of the standard configuration is shown for three different pressure profiles. It can be seen that the rational surface 3/2 is left out of the plasma which could in principle prevent the appearance of a magnetic island and improve the stability. However, for other configurations the situation can be the opposite, since a low order rational surface can be made to enter the plasma. This effect has been observed experimentally [1] for the configuration 100_40_63 with a vacuum rotational transform slightly over 1.5 and where a 3/2 mode is detected. This situation has been seen to be in agreement with the expected modification of the rotational transform profile caused by the computed boostrap current for that case.

Conclusions

For the operation of almost shearless devices like TJ-II it is neccessary to have an accurate knowledge of the magnitude and direction of the bootstrap current as it may produce a change in the rotational transform profile. This modification may introduce shear in the configuration or, more importantly, allow for the introduction of low-order rational surfaces into the plasma.

Even when the total toroidal current generated depends mainly on the value of $\bar{\beta}$, different pressure profiles can give rise to different bootstrap current profiles that change the rotational transform in different fashion. In this way, different configurations can be found where rational surfaces are respectively expulsed or introduced into the plasma. Calculations carried out for some particular cases agree with the measurement of magnetic activity detected in the Mirnov coils for these configurations in which the bootstrap current seems to introduce the 3/2 rational surface inside the plasma. Finally, for the current values obtained in this study we have seen no destabilizing effects with respect to ideal ballooning modes. But the inclusion of low order rational surfaces may have an effect on Mercier stability which is yet to be studied. Given the flexibility that TJ-II has to change the vacuum rotational transform this negative effect can be easily avoided by properly shifting the configuration to a slightly higher/lower value of the rotational transform.

Acknowledgements

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