Influence of magnetic configuration in the development of long-range correlations in the TJ-II stellarator

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Outline

• Experimental set-up:
  • Diagnostics
  • Characteristic of the magnetic configuration modulation

• Iota scan in the proximity of the 8/5 rational surface:
  • Radial profiles
  • Long-range correlations measurements
  • Comparison with results obtained in a fixed configuration

• Iota scan in the proximity of the 3/2 rational surface

• Shearing rate of the long-range correlated structures

• Conclusions
Experimental set-up

TJ-II has 7 coil systems:

- TF - Toroidal
- VF - Vertical
- RF - Radial
- HX - 2 Helical
- CC - Central
- OH - Ohmic. The OH system is used to compensate voltages during configuration sweeps.

$r/a \approx 0.85$
Experimental set-up

Modulation of the TJ-II magnetic configuration allows studying the effect of the presence of different rational surfaces on the radial structure of floating potential as well as on long-range toroidal correlations.

• Dynamic magnetic configuration scan in narrow iota ranges (5 - 10%).
• Presence of different rational surfaces (8/5, 3/2, 5/3,…).
• Good control of plasma density.
• Volume changes less than 5% during scan.
• Magnetic axis displacement lower than 0.7 cm between the extreme configurations of each scan.
• The voltage drive due to the configuration sweep is compensated by the OH system coil, to minimize the induced currents in the plasma.
Densities around $0.6 \times 10^{19} \, \text{m}^{-3}$, close to the plasma density at which edge sheared flows are spontaneously developed in the TJ-II stellarator in the considered range of configurations.
Edge radial profiles: modulated configuration

Floating Potential

1 kHz low-pass filtered signals

0.82<r/a<1
Edge radial profiles: modulated configuration

Floating Potential

1 kHz low-pass filtered signals

$0.82 < r/a < 1$

$\nu(a)/2\pi = 1.63$

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Edge radial profiles: fixed configuration

Floating Potential

1 kHz low-pass filtered signals

0.82<\(r/a\)<1

100_42_63 \(\rho(a)/2\pi = 1.63\)
Minor changes in the iota value produce strong modifications in the radial profiles of the floating potential ($V_{fl}$) and its gradients.

# 24747

Modulated configuration

Fixed configuration

# 24751
Edge radial profiles: modulated configuration

Floating Potential Gradient

Floating Potential
Long-range correlations: modulated configuration

Long-range toroidal correlations are strongly modulated during the magnetic configuration scan.

The level of long-range correlation shows a clear radial structure with a characteristic radial decay length in the order of 1-2 cm.
The degree of long-range correlation between ion saturation current signals is weaker than the one observed for floating potential signals.

The time delay for the maximum $V_{fl}\text{ long-range correlation}$ is in the range of few micro-seconds.

The long-range correlation between floating potential signals is due to fluctuations with frequencies below 20 kHz.
Iota scan in the proximity of the 3/2 rational surface

Densities around the plasma density at which edge sheared flows are spontaneously developed in the TJ-II stellarator in the considered range of configurations.

Dynamic magnetic configuration scan

\[ \iota(a)/2\pi \approx 1.48 – 1.55 \]
Edge radial profiles: modulated configuration

1 kHz low-pass filtered signals

\( r/a \) (inner tip) \( \approx 0.9 \)
Long-range toroidal correlations are strongly modulated during the magnetic configuration scan. Long-range toroidal correlations in the presence of 3/2 rational are lower than in the presence of the 8/5 rational surface.
Shearing rate of the long-range correlated structures

Shearing rate can be estimated by

$$V_{fl}^{LR} \Delta r^2 B$$

$V_{fl}^{LR}$ low frequency (below 20 kHz) component of the floating potential

$$\approx 20 - 30 \text{ V}$$

$\Delta r$ typical radial scale where long-range correlations are damped

$$\approx 1 - 2 \text{ cm}$$

The resulting shearing rate is in the order of $10^5 \text{ s}^{-1}$, comparable to the decorrelation rate of fluctuations (calculated as the inverse of autocorrelation time)

Time-varying flows are important to stabilize turbulence.
Conclusions

✓ Radial structures in the plasma potential and changes in the degree of long-range toroidal correlations have been observed during fine dynamical magnetic configuration scans in the proximity of low order rational surfaces in TJ-II.

✓ These findings provide a direct evidence of the development of long-range toroidal correlations consistent with the theory of zonal flows and linked to the magnetic topology in low magnetic shear configurations.

✓ Results are in line with the expectation that magnetic topology (rational surfaces) is a crucial ingredient in the development of mean and fluctuating sheared flows in fusion plasmas.

✓ These results could explain the existence of restricted iota-profiles for H-mode development in different devices.
Edge radial profiles at different probes positions

# 25259 \( r/a(\text{inner tip}) \approx 0.86 \)

# 25256 \( r/a(\text{inner tip}) \approx 0.88 \)

# 24884 \( r/a(\text{inner tip}) \approx 0.9 \)

# 25253 \( r/a(\text{inner tip}) \approx 0.93 \)
Densities around the plasma density at which edge sheared flows are spontaneously developed in the TJ-II stellarator in the considered range of configurations.
Edge radial profiles: modulated configuration

Floating Potential

1 kHz low-pass filtered signals

0.85<r/a<0.98
Long-range correlations: modulated configuration

Long-range toroidal correlations are strongly modulated during the magnetic configuration scan.

Long-range toroidal correlations in the presence of 5/3 rational are lower than in the presence of the 8/5 rational surface.