Experimental investigation of effects of the magnetic field geometry on turbulent transport

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A significant part of the radial transport in magnetically confined plasmas is due to turbulent processes. As driving forces the pressure gradients are known to play a key role. In addition, the properties of the magnetic configuration enter sensitively into the theoretical growth rate of the instabilities. Thus, magnetic curvature, local magnetic shear and trapped particle populations are known to be determining factors. Especially for stellarators which offer a great flexibility for the optimization of plasma properties through the magnetic configuration, a better knowledge of the influence of geometry parameters on turbulent transport is of high value. This would open the route to a second optimization step of the turbulent transport after the neoclassical one. Although many theoretical works have addressed this issue related to the magnetic configuration, detailed experimental verification is required.

The experimental investigation of turbulent transport related to geometry is done in low-temperature plasmas of the stellarator experiment TJ-K [1], which are dimensionally similar to fusion edge plasmas and dominated by drift wave turbulence [2]. The plasma is heated with microwaves (2 kW) at 2.45 GHz [3] corresponding to a magnetic field of $B = 88$ mT. Thus, plasma densities of $n = 1.1 \cdot 10^{17}$ m^{-3} and electron temperatures of $T_e = 8.5$ eV ($T_i \approx 1$ eV) are achieved at a neutral gas pressure of $p = 2.6$ mPa in helium. By means of two 64-

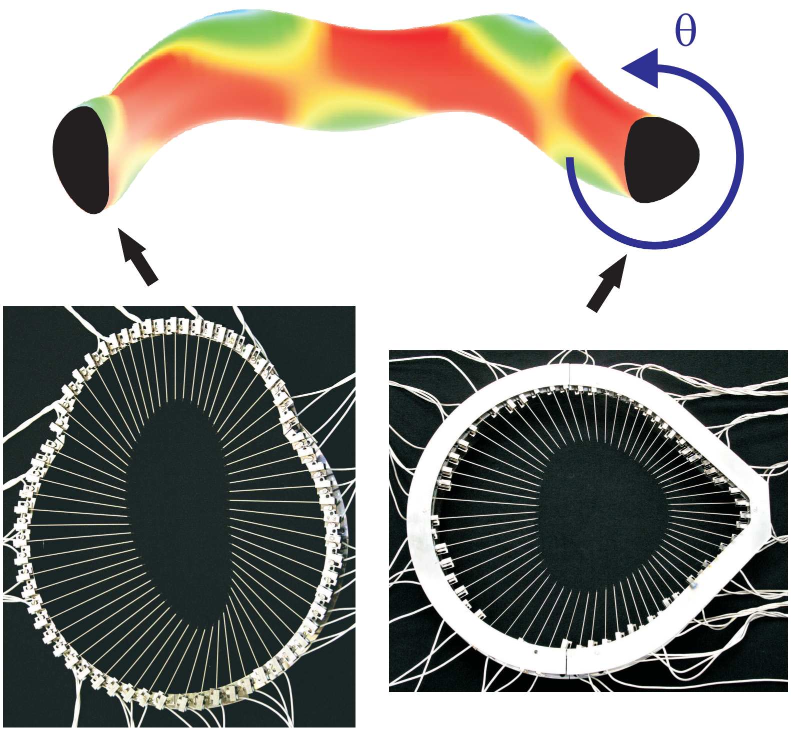

Figure 1: Two 64-multi-Langmuir-probe arrays are installed at different toroidal positions. Left: TPA. Right: OPA. Top: color map of the B-field strength on a TJ-K flux surface.

multi-Langmuir-probe arrays whose probe tips are aligned to the local shape of the flux surface at two different toroidal positions ($\varphi = 30^{\circ}$: Top Port Array (TPA) installed at a top port, see Fig. 1, left, and $\varphi = 270^{\circ}$: OPA (OPA) installed at an outer port, see Fig. 1, right), the ion-saturation current ($\tilde{I}_{i,sat}$) and floating potential fluctuations ($\tilde{\phi}_{fl}$) are simultaneously measured at 128 positions on a single flux surface with a sampling rate of 1 MHz. Alternating pin assignment of the 128 probes with $\tilde{\phi}_{fl}$ (proportional to plasma potential fluctuations $\tilde{\phi}_{p}$) and $\tilde{I}_{i,sat}$ (proportional to density fluctuations $\tilde{n}$) allows to measure the turbulent transport

$$\Gamma = \langle \tilde{v}_r \tilde{n} \rangle = \left\langle \frac{\tilde{E}_\theta}{B} \tilde{n} \right\rangle \sim \left\langle -\frac{\left(\tilde{\phi}_{fl,2} - \tilde{\phi}_{fl,1}\right)}{Bdx} \tilde{I}_{i,sat} \right\rangle$$

with the fluctuations of the radial velocity $\tilde{v}_r$, the poloidal electric field $\tilde{E}_\theta$, the floating potential at two adjacent positions $\tilde{\phi}_{fl,i}$ separated by the probe distance dx, and the magnetic field B. $\langle\ \rangle$ denotes averaging in time.

The measured poloidal dependence (with respect to the poloidal angle $\theta \in [-\pi, \pi]$ counted counter-clockwise starting at the inboard midplane) of fluctuation amplitudes σ and transport Γ is shown in Fig. 2 (left column: TPA, right column: OPA). At both toroidal positions, where the arrays are installed, strong poloidal variations of fluctuation amplitudes (Fig. 2 (b)) and transport (Fig. 2 (a)) are found.

The turbulent transport has a pronounced maximum at the top side of the flux surface ($\theta = 0.6\pi$) for the TPA. For the OPA, the transport maximum is found at the outboard side ($\theta = 0.1\pi$). Therefore, at different toroidal positions different locations of the maximum are observed. At particular positions ($\theta = -0.1\pi$ at the TPA and $\theta = -0.7\pi$ at the OPA), the turbulent transport has small negative values corresponding to inward transport resulting from a negative cross phase between density and potential fluctuations. The poloidal shapes of the fluctuation amplitude profiles differ from the transport profiles at the bottom of the flux surface ($\theta \in [-1.0, 0.0]$) for both arrays. This shows the important role of the cross phase, too.

In order to compare the experimental findings with the geometry of the magnetic field, the poloidal dependence of geometry parameters are calculated by means of a field line tracing code. Fig. 2 (c) shows the normal curvature κ_n at the toroidal positions of the two probe arrays. The normal curvature varies poloidally differently for the two toroidal positions of observation. At the outer port array, it has almost a sinusoidal profile with large negative values at the outboard side as in tokamaks. At the top port, however, the shape of the normal curvature is more asymmetric reflecting the 3D-field structure of the torsatron. There, the normal curvature has its minimum at the top side of the flux surface.

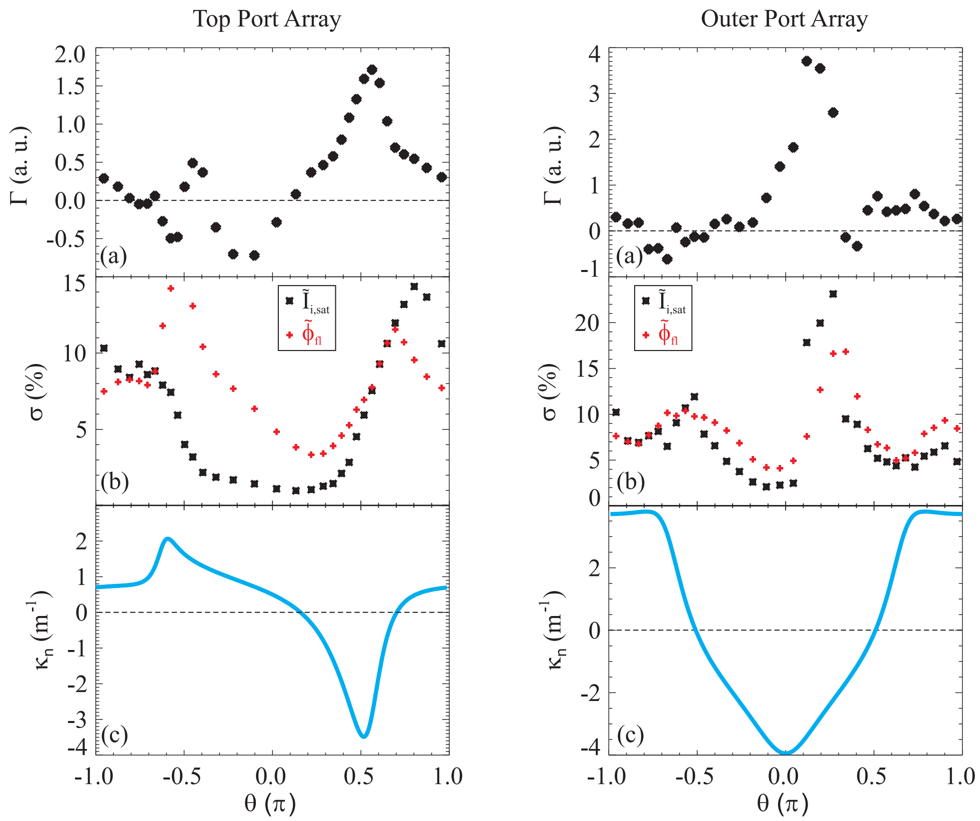

Figure 2: Poloidal dependence of measured turbulent transport (a), fluctuation amplitudes (b), and calculated normal curvature (c). Left column: TPA, right column: OPA.

The comparison of the geometry parameters with the measurement data shows, that the highest transport levels for both toroidal measurement positions are found in a region of negative normal curvature ("bad curvature"). The transport maxima are not exactly located at the position of minimum normal curvature but slightly shifted to larger values of θ. This is possibly caused by the influence of the geodesic curvature κ_g whose shape is similar to the shape of the fluctuations and which is positive in the region of maximum transport. Hence, the transport maximum is found where the normal curvature is negative and simultaneously the geodesic curvature is positive.

In order to validate the correlation of maximum transport and curvature terms, the same measurements as described above but with reversed magnetic field direction are carried out in TJ-K. This procedure only affects the poloidal shape of the geodesic curvature κ_g. The normal curvature κ_n, as well as the shape of the flux surface and the plasma density and temperature, however, stay the same as in forward field operation. Again, a strong poloidal asymmetry of fluctuation amplitudes and turbulent transport is observed for both arrays.

The transport peaks in regions where the normal curvature is large and negative also in the reversed field case. Since κ_g changes the sign at reversed field, there is again a shift of the transport maximum into a region of positive geodesic curvature. Thus, the transport maxima are again located where normal curvature is negative and simultaneously the geodesic curvature is positive.

We conclude that the measured fluctuation amplitudes and the turbulent transport are a result of local effects of field line curvature and only weakly affected by local magnetic shear. We found a strong poloidal asymmetry of fluctuations and transport, and the maximum of transport is located in a region where normal curvature is negative and simultaneously the geodesic curvature is positive.

References

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