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Sheared flow amplification by vacuum magnetic islands in stellarator plasmas

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Transport barriers in toroidal magnetically confined plasmas tend to be linked to regions of unique magnetic topology, such as the location of a minimum in the safety factor, rational q surfaces, or the boundary between closed and open flux surfaces. Recent experimental results have shown the possible influence of low-mode-number islands in the formation of edge transport barriers [1].

Experiments in the TJ-II stellarator show the formation of E×B sheared flows in the proximity of rational surfaces [2]. These results can be interpreted in terms of the symmetry-breaking mechanisms in the radial-poloidal structure of fluctuations (i.e., Reynolds stress) at rational surfaces. We have used a resistive interchange model to study the effect of magnetic islands on poloidal flow generation and turbulence. For vacuum magnetic islands below a threshold value, there is a near cancellation of the electrostatic and magnetic components of the Reynolds stress. Above the threshold, the magnetic component dominates and a strong sheared flow is established. In spite of that, the fluctuation level increases, and the particle and the heat flux remain almost the same.

The flow structure seems to result from a self-organization process involving nonlinear flow amplification through Reynolds stress and fluctuation reduction by sheared flows. In stellarators, a large contribution to the Reynolds stress comes from the coupling of the magnetic field component of a vacuum field island with a plasma instability. In this process, the self-organization principle seems to be marginal stability for the fluctuations driving the flow.

Similar results were obtained in the study of resistive pressure-gradient-driven turbulence with an external sheared flow [3]. In that case, the numerical results showed that shear flow effects were not significant when the single helicity dominated near the low-m rational surfaces. Therefore, multiple helicity calculations are needed to assess the effect of vacuum islands on turbulence. These calculations are now under way.

The calculations show that the presence of small vacuum magnetic field islands can stop the poloidal propagation of some of the fluctuation components. Under these circumstances, the flux surface average and time average are not equivalent. The result may be an erroneous estimation of the averaged value of the fluctuations and, as a consequence, an erroneous estimation of the fluxes.

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