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THE INFLUENCES OF MAGNETIC SHEAR ON THE IMPROVEMENT OF THE QUALITY OF CONFINEMENT IN THE PLASMA OF TOKAMAK

M. El Mouden[1], D. Saifaoui[1], A. Dezairi[2], H. Imzi[1]

[1]*Laboratory of Theoretical Physics, Faculty of Sciences- Ain Chock, Casablanca, Morocco,*
[2]*Laboratory of the Physics of Condensed Matter, Faculty of Sciences- Ben M'sik, Casablanca, Morocco,*

INTRODUCTION: The reversed magnetic shear is the most important factor in the studies of the plasmas of tokamak. For this raison, we are interested, in this work, - firstly- in the survey of the dynamics of the lines of magnetic fields, and of plasma's particles in the ulterior stage.

The other very important point that we will develop in this work consists of studying the contribution of the reversed shear to the improvement of the plasma's confinement in the tokamak and other rules of improvement of the confinement. Indeed, the research concentrates currently more on the control of these improved confinement régimes where we observe the plasma diffusion's reduction, and what is impressive is the formation of the transport barrier. We studied the motion of the guiding center of particles, under the action of electrostatic field perturbation, and in a configuration known as of reversed magnetic shear. This configuration is adopted more and more in the new machines of fusion, since we observe important reductions there in the diffusion coefficients. The equations of the motion of the guiding center will be replaced by equations of the mapping known as Nontwist Standard Mapping, and in the phases space of the particles, we simulated the trajectory in two completely different cases of the safety factor profile: the normal profile and the reversed one.

I – MAPPING EQUATIONS: [1, 3, 5]

I-1 Equation of motion: In our survey, we use a simplified model of an equilibrium magnetic field, according to toroidal geometry, which is described by the following relation: $\vec{B}=B_\theta(r)\vec{e}_\theta+B_\varphi\vec{e}_\varphi$ **(1)** consists of the poloïdal magnetic field component and the toroidal magnetic field component which are bound through the relation : $B_\theta(r)=\dfrac{r}{q(r)R_0}B\varphi$, of which r is the minor radius of plasma, θ and φ are respectively the poloïdal and toroidal angle, and finally, *q(r)* is the safety factor. In the Gauss units system, the equation of the motion of the guiding center is given by: $\frac{d\vec{x}}{dt} = v_{//}\frac{\vec{B}}{\|\vec{B}\|} + c\frac{\vec{E}\Lambda\vec{B}}{B^2}$ **(2)**; where, $\boldsymbol{v}_{//}$ is the parallel velocity, $\vec{\boldsymbol{E}}$ and $\vec{\boldsymbol{B}}$ are the electric and magnetic fields, and the last term of this equation represents the drift velocity. The electric field satisfies the relation: $\vec{\boldsymbol{E}} = -\vec{\nabla}\boldsymbol{\phi}$ **(3)**.

The correspondent electrostatic potential ϕ can be written as the sum of two terms, the first is the radial part supposed at equilibrium, and the second one represents the fluctuating part, noted $\tilde{\phi}$. We use the model of the spectrum of drift wave, and we have:

$$\tilde{\phi}(\vec{x},t) = \sum_{m,l,n}\phi_{m,l,n}\cos(m\theta - l\varphi - n\omega_0 t) \quad \textbf{(4)}$$

where ω_0 is the lowest angular frequency in the spectrum of drift wave, and θ and φ are random variables. The disrupted electrostatic field $\tilde{E}$ is joined to the potential of perturbation with [3]: $\tilde{E} = -\vec{\nabla}\tilde{\phi}$.

In the continuation of our survey, we suppose that $\boldsymbol{B} \approx \boldsymbol{B_\varphi} \rangle\rangle \boldsymbol{B_\theta}$ and $\boldsymbol{B_r} = \boldsymbol{0}$ respect the system of toroidal coordinates $(\boldsymbol{r},\boldsymbol{\theta},\boldsymbol{\varphi})$ and we introduce $\overline{\boldsymbol{E}}_{\boldsymbol{r}}$ as the equilibrium radial electric field. The previous equation of motion will be projected in this system of coordinates, and we get the following system:

$$\frac{dr}{dt} = -\frac{c}{B}\frac{1}{r}\frac{\partial\tilde{\phi}}{\partial\theta}$$

$$r\frac{d\theta}{dt} = v_{//}\frac{B_\theta}{B} + \frac{c}{B}\frac{\partial\tilde{\phi}}{\partial r} - \frac{c\tilde{E}_r}{B} \quad \textbf{(5)}$$

$$R\frac{d\varphi}{dt} = v_{//}$$

Substituting **(4)** into **(5)**, we obtain: $\frac{dr}{dt} = \frac{2\pi c}{Br}\sum_{M,L} M\phi_{M,L}\sin(M\theta - L\varphi)\delta(\omega_0 t - 2\pi n)$ **(6)**

Hence this model spectrum gives impulsive jumps in *r* at time $t_n = 2\pi n/\omega_0$.

<u>I-2 Transformation into a global mapping equation</u>: In order to introduce the effects of reversed magnetic shear and the radial electric field, we define the system of equation of global mapping that is the following:[2, 3]

$$J_{N+1} = J_N + \frac{4\pi c}{a^2 B_0}\frac{M\phi}{\omega_0}\sin(M\theta_N - L\varphi_N) \quad \& \quad K_{N+1} = K_N + RK1(J_{N+1}) + RK2(J_{N+1})$$

where: $RK1(J)=\frac{v_{//}(J)}{\omega_0 q R}(M-Lq(J))$ & $RK2(J)=-\frac{cM}{\omega_0 a B_0}\frac{\bar{E}_r(J)}{\sqrt{J}}$ & $v_{//}(J)=\sqrt{\frac{2}{m}(\zeta_t-e\Phi_0(J))(1-\lambda B_0)}$

Choice of the profiles of the factor of security: The choice of the potential Φ_0 depends on the nature of the *q*- profile, therefore, in the normal case we use $\Phi_0(r) = -\Phi_0(1-(r/a)^2)$ and for the reversed profile we take $\Phi_0(r) = \Phi_0(1-(1-2r/a)^2)$ ***[5]*** .

<u>II- NUMERICAL INTEGRATION AND INTERPRETATIONS</u>: In the next section, we neglect the electric field radial component and investigate the map phase structure by calculating 1000 massive D^+ trajectories with various initial conditions in configuration spaces for the reversed and normal shear cases of the safety factor.

In the calculation below, we have used the Texas Experimental Tokamak (TEXT) system parameters, with major radius $R_0=26cm$, minor radius $a=10cm$, and center- line field $B=3tesla$. We took; $\omega_0 = 1.93*10^5$; and we chose the mode of perturbation $(M = 12 ; L = 6)$ and $\lambda=\mu/\zeta$, with $\zeta = 167eV$: the energy of the particles.

Simulations & interpretations: In presence of the electrostatic perturbations and the normal profile of the safety coefficient *q*, the stochasticity of the trajectories increases and it is the principle reason for the particles' diffusion through the magnetic surfaces (**Figure 1.** (b)). While in the case of reversed shear, the principle result shows that the transport barrier is near of surface that corresponds to the minimal value of *q* exists. This barrier plays an important role on the reduction of the transport and the diffusion of the particles, which drives to the improvement of the plasma confinement (**Figure 1.** (a)).

In the case of the 3D simulation, we observe the same phenomena as those in the case of 2D simulation except that we do not see the formation of islands, and what we observe is a transition of the particles from the regions ($r/a < 0.5$) toward regions ($r/a > 0.5$). While increasing the amplitude of the perturbation, and in the reversed case (**Figure 2.** (a)) we observe that this transition drives to a transition of this barrier toward the outside regions of the tokamak ($r/a \rightarrow 1$) to prevent the diffusion of these particles. Whereas in the normal case (**Figure 2.** (b)), we observe that the majority of the particles escaped which means that we observe the total destruction of the magnetic surfaces of the confinement.

<u>CONCLUSION & PERSPECTIVES</u>: Anomalous transport observed in tokamaks is known as the result of the electrostatic and magnetic turbulence. Thus, in the presence of electric perturbation and for the normal profile of the safety factor *q*, the stochasticity of the trajectories increases and this is the principal cause of diffusion of particles through magnetic surfaces. However for the reversed shear case, the most important result is the impressive formation of a strong transport barrier, which is localized near of minimum value of *q* (**Figure 1.** (a)). This barrier plays a very important role in the improvement of the plasma confinement while preventing its radial diffusion.

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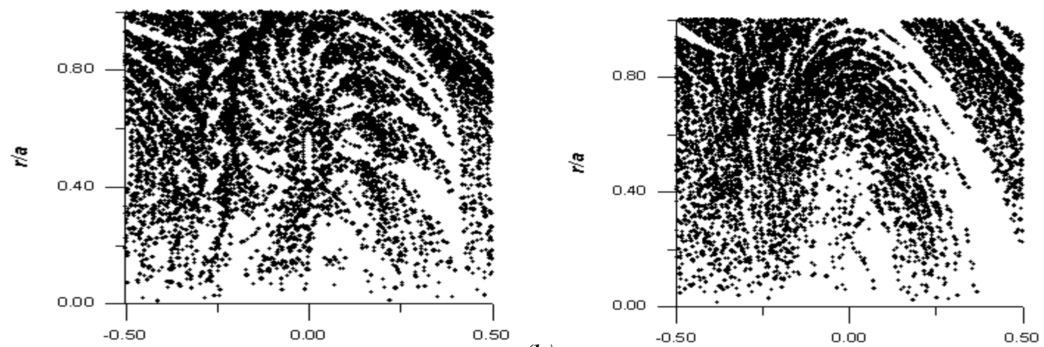
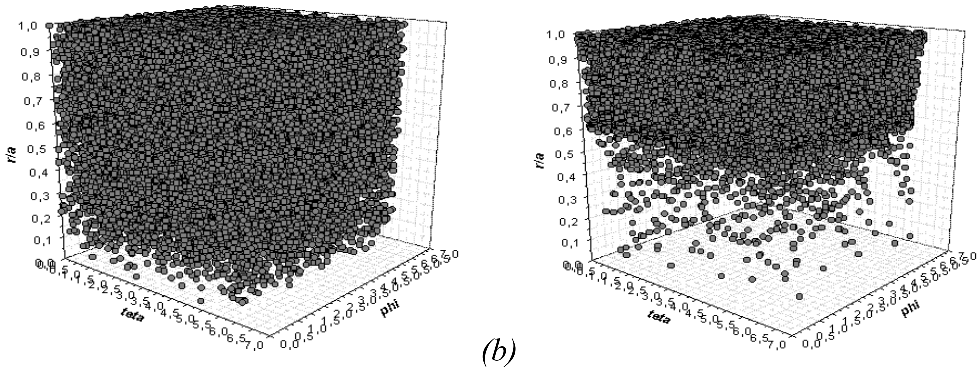


(a) *(b)*

Figure 1. Poincaré Section for 1000 particles in the *(χ, r/a)* plane for the value 2.0 *eV* of the perturbation: *(a)* reversed shear; *(b)* normal shear.



(a) *(b)*

Figure 2. Simulation of the trajectories of 1000 particles at 3- dimensional *(θ, φ, r/a)* for the value 1.1 *eV* of the perturbation: *(a)* reversed shear ; *(b)* normal shear.