Ergodic Limiter for the Spherical Tokamak MEDUSA-CR

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Introduction

Plasma thermal power load and exhaustion is a problem for a nuclear fusion reactor based on magnetically confined plasmas. This is due to the lack of suitable materials and the relatively small contact area between the plasma edge and the wall, while the latter is mainly caused by the local divertor configuration. Therefore, alternatives to spread that power over the highest contact area between the plasma edge and the wall is a highly desirable feature and this might be the only solution for solving this problem for a feasible fusion reactor. An ergodic limiter was envisaged in the old tokamaks as a tool for studying plasma-wall interaction, with the possibility of reducing the power load in the solid poloidal or the toroidal limiters, via the creation of a more uniform distribution of this power. However, this scheme was nearly abandoned in tokamaks with the advent of H-mode operation, which can only be attained via a combination of the input power beyond a threshold in an X-point magnetic divertor plasma configuration. Although this X-point divertor was initially proposed as a scheme for reducing the impurities, it became lately a mainstream component for attaining the H-mode, as well as for the exhaust of power load in any modern tokamak. Power load is expected to be an even more severe problem in the compact fusion devices, such as the Spherical Tokamaks (STs) and the trade off of this and the attractiveness of higher beta cannot be ignored, assuming by comparison the same fusion output power of ST and conventional tokamak reactors.

We show here preliminary computing simulations on ergodic limiters in natural divertor configurations in the spherical tokamak MEDUSA (Madison Educational Small Aspect ratio tokamak), which was originally designed, built and operated at the University of Wisconsin at Madison [1]. This device is currently in the process of donation to the Technological Institute of Costa Rica ("ITCR") and renamed as MEDUSA-CR.

The ultimate aim of this study is to address via extrapolation whether the a ST device operating with an ergodic limiter is a more realistic path to and ST reactor with the expanse of the absence of the higher energy confinement lead by H-mode operation but without the problem of power load due to the X-point divertor, and also due to the ELM bursts. Alongside with training, this study is part of a more comprehensive scientific programme based on the flexible geometry and the feature of the MEDUSA-CR vessel, which is made of glass, allowing real time control and instant field penetration into the plasma [2].

MEDUSA-CR Device

The device's main characteristics are [1]: major radius Ro = 9-14cm, minor radius a = 4-10cm, Aspect ratio 1.5 (1.35 min.), toroidal field $B_T = 0.3$T (0.5T max.), plasma current $I_p =$ 20kA (40kA max.), 1ms (3ms max.) pulse. The plasma is limited top/bottom at one toroidal location by movable stainless rail limiters. Titanium gettering is planned for conditioning, and lithium could also be used [3]. One of the planned systems for MEDUSA-CR is an ergodic limiter for studying plasma-wall interactions.

MAPTOR-Code

For modelling such limiter, we present here simulations via Poincaré maps produced with the 3-D MAPTOR code [4], in which the axisymmetric field is broken via external perturbations produced by an inner coil with tilted circular loops, placed in the gap between the solenoid and vessel. This design is similar to that used in TEXTOR [5], but with the difference that in MEDUSA those coils are external to the vessel. The equilibrium poloidal field is provided by the vertical field coils and by the calculated field from the measured toroidal current density profile J, and the plasma boundary (Ro-a, Ro+a) was also fixed according the same MEDUSA equilibrium reconstruction [1]. The pressure profile is calculated via J. Problems due to the lack self-consistency in this must be resolved in the near future.

Results

In Fig. 1 Poincaré plots of a poloidal cross section taken at the plane of a toroidal field coil, are shown (plots in different toroidal angles show the same results, as expected). The inner coil which produces the external perturbation were composed by 20 loops, centred at the machine midplane, and tilted by 20° with respect this plane. On the left hand side of each picture there are brief descriptions of the run. Here, Ip = 16kA, B_T = 0.3T, Ro = 0.132m, a=0.095m, are fixed for all runs, and $q(r)$ is a line safety factor profile.

Fig.1a shows the plot with no external perturbation (*Ih*=0). In Fig.1b, *Ih*=100A (*Ih*/*Ip*=0.63%), which clearly shaped the plasma towards a more D-shape without change on the outboard region. This is simply because of the extra vertical field component of perturbation coil current. No ergodization layer (δ) is observed. The value of *Ih*=200A (*Ih*/*Ip*=1.3%) was set in the Fig.1c., and the shaping effect increases further, leading to a slightly bean-shaped cross section. The ergodization layer is still not clearly observed.

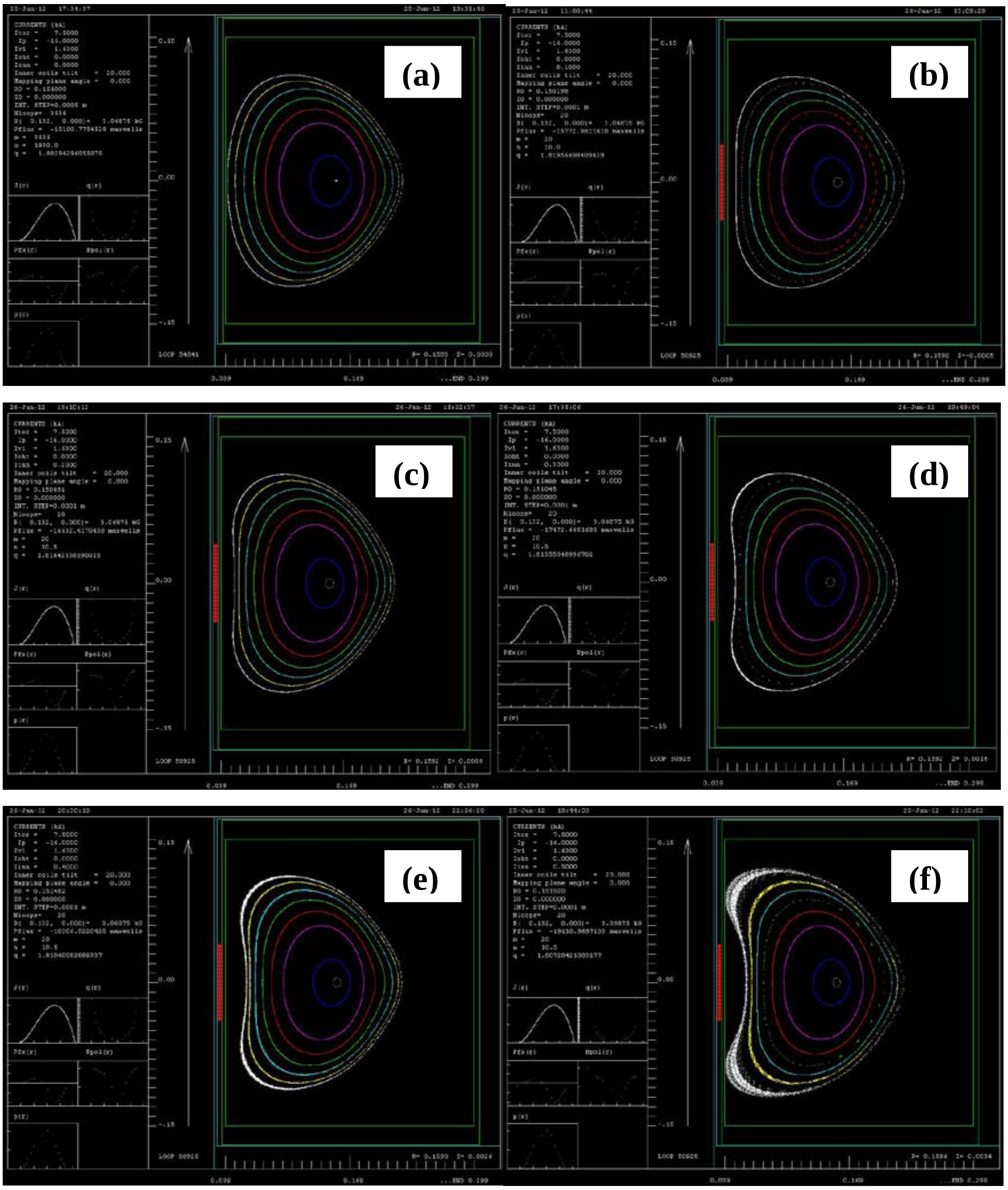

Fig.1 Poincaré plots of a poloidal cross section, taken at the plane of a toroidal field coil, for different perturbative currents (Ih): 0 (a), 100A (b), 200A(c) 300A(d), 400A(e), and 500A(f)

In the Fig. 1d, on the other hand, a clear δ is observed when *Ih*=300A (*Ih*/*Ip*=1.9%): we estimated δ*max* ~3mm (maximum thickness at top or bottom of inboard side, but near to the vertical elongation axis), which in turn leads to δ*max*/*a*~3%. By setting *Ih*=400A (*Ih*/*Ip*=2.5%), the bean-shape is further enhanced, and so the δ in the Fig.1e: δ*max*~5mm, δ*max*/*a*~3%. The δ is now no longer restricted to the inboard side but extends to the outboard side, although a simple evaluation is difficult because the poloidal flux tube shrinks rapidly towards this region. Finally, a much large δ is observed in the Fig.1f using *Ih*=500A (*Ih*/*Ip*=3.1%): δ*max* ~21mm, δ*max*/*a*~21% and at the very edge of the outboard side, δ*out* ~3mm, δ*out*/*a*~3%.

Conclusion

Stronger ergodization effects have been observed over the poloidal cross section by using relatively low perturbation currents to the plasma current (few percent). This effect seems more pronounced on the inboard than on the outboard side, due to the proximity with the perturbative coils, and it might be also related with the longer magnetic field transit time in that region. Estimations of the ergodization layer show that it does not scale linearly with the perturbative currents and also seem larger at top or bottom of the inboard side region near to the vertical elongation axis. Therefore, it is expected that the flattering of basic plasma profiles in these regions will be rapidly transferred to the inboard side due to the shorter magnetic connection length between the top inboard and outboard regions, inherent of the low aspect ratio tori geometry. This can lead a "natural" more uniform poloidal wall power load for spherical tokamaks, helping the studies for alternatives to overcome the general problem of the intolerable X-point divertor power load, and also having similarities with NSTX experiments where flattering the edge outboard plasma is created by lithization instead. An interesting bean-shaped plasma is easily and naturally created in this simulations, and can potentially enhance even further the already high beta observed in the spherical tokamak plasmas, while is tackling simultaneously the problem of the power load.

References

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