Vertical stability margin studies on TCV: experiments and modelling

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1. Introduction

The stabilization of the vertical position in future fusion devices (e.g. DEMO [1]) is particularly challenging, due to a number of reasons. First of all, the high fusion performances required of the plasma call for a relatively high elongation [2], which in turn increases the vertical instability growth rate. Secondly, toroidally conducting structures providing most of the passive stabilization (typically the vessel) are very far from the plasma, since massive blankets are required to shield and collect neutrons produced by fusion reactions.

The electric power needed for stabilization is one of the key drivers in the design of a new device. This quantity depends critically on the so-called stability margin [3], which is a fundamental indication on the passive stability properties of a given configuration.

During the recent experimental campaign carried out on TCV under the auspices of the EUROFusion Medium Size Tokamak Task Force, dedicated experiments have been carried out, aimed at extensively studying the minimum achievable stability margin beyond which stability is lost. The results achieved, reported in the present paper, allow us in particular to experimentally validate the modelling approach used for the design of future devices.

2. Experimental and modelling strategy

The experimental strategy is based on arranging a plasma configuration exhibiting a slowly decreasing stability margin, e.g. thanks to a slow ramp in elongation during a shot. The plasma is subject to repetitive perturbations (ELMs) during the configuration ramp. The instant at which the feedback controller is not able to stabilize the plasma any longer corresponds to the limit value of the stability margin, which depends on the feedback controller and the perturbation under analysis.

The configuration under analysis is a Single Null ELMy H-mode heated by 1 MW NBI (plasma current 210 kA, toroidal field 1.43 T, peak electron density 6×10^{19} m^{-3}). The configuration ramp is achieved via a pre-programmed time trace in the PF coils currents, starting immediately after the switch-on of NBI system.

Since the stability margin cannot be directly measured, a specific modelling activity is carried out a posteriori after the experiment, with the CREATE_L model [4], an axisymmetric linearized plasma response model, which can provide indications on passive and active stabilization also beyond the calculation of the stability margin. For each selected time instant, typically just before the ELM crashes, the measured values of PF coil currents, total plasma current, poloidal beta and internal inductance are used to retrieve the nominal equilibrium configuration with CREATE_L. Starting from this equilibrium, the plasma current density profile parameters and the PF coil currents are slightly modified around the nominal values, to get a best fit of the magnetic field at the sensor position (38 in-vessel sensors), providing the final equilibrium configuration and the corresponding linearized model. Typical fitting errors achieved on magnetic fields are around 3%.

3. Results

Three shots are considered, which correspond to configuration ramps of different speed: 58572 (fast), 57202 (intermediate), 58574 (slow). Fig. 1 reports some sample configurations for shot#58572, which illustrate how the elongation increases in time.

Figure 2 illustrates the time dependence of the poloidal beta for the three shots under analysis. The drops in poloidal beta correspond to ELMs; the shots terminate with a loss of control at the instant when the traces stop. In shot#58574 a remarkable reduction in poloidal beta is observed between 1.10 s and 1.15 s, corresponding to a change in the ELM regime and a reduction in confinement apparently triggered by an MHD mode. While in shot#58574 the feedback control is able to survive this event, in shot#57202 control is lost exactly at its occurrence.

The time dependence of the stability margin, as computed by CREATE_L according to the definition proposed in [3], is reported in Fig. 3 for the three shots under analysis. Evidently, the vertical control is lost when the stability margin approaches a value between 0.2 and 0.3, which can be assumed as an empirical limit for the configuration under analysis.

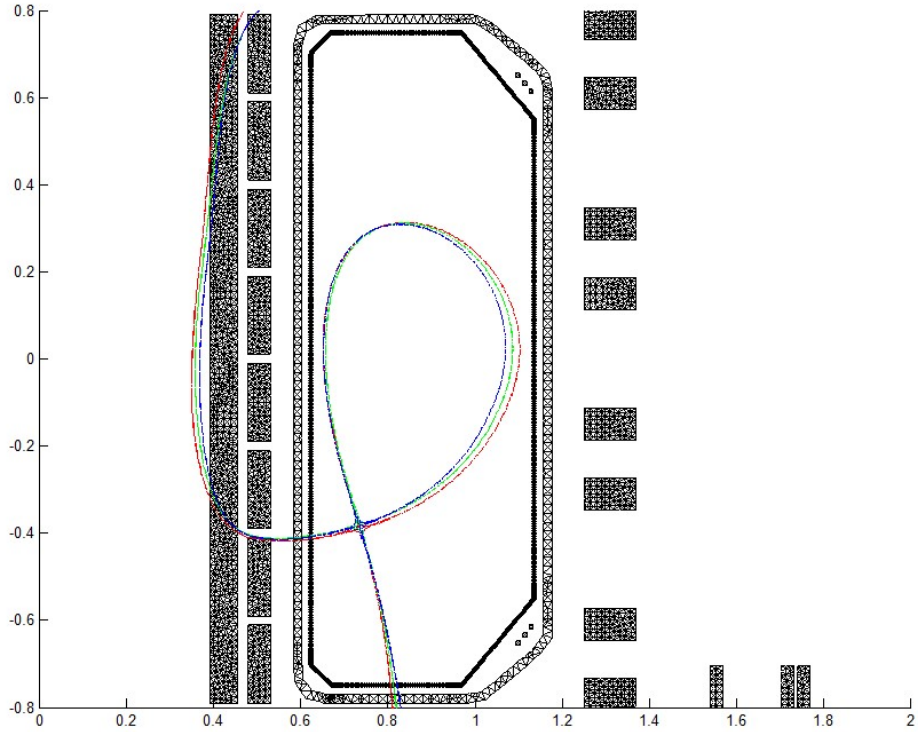


Fig. 1. Sample plasma equilibrium shapes for shot#58572:
t = 0.937 s (red), t = 0.978 s (green), t = 1.024 s (blue).

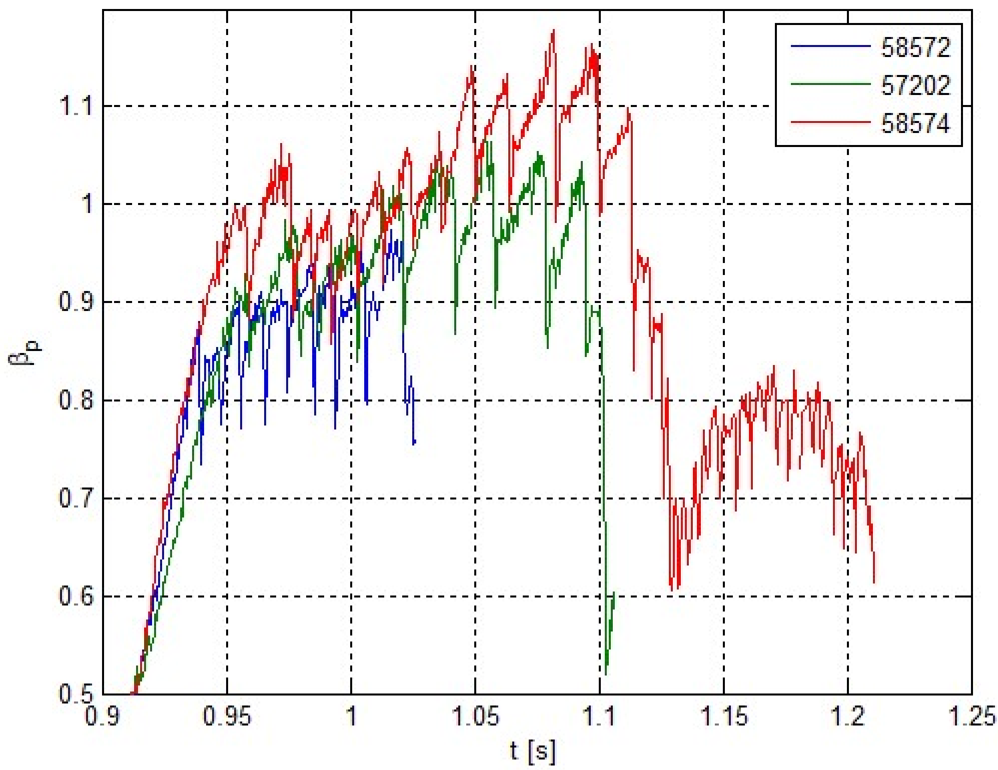
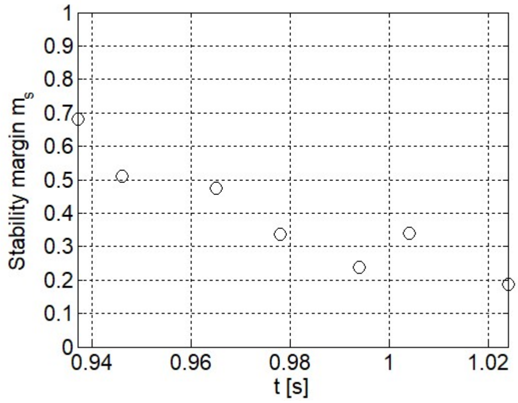
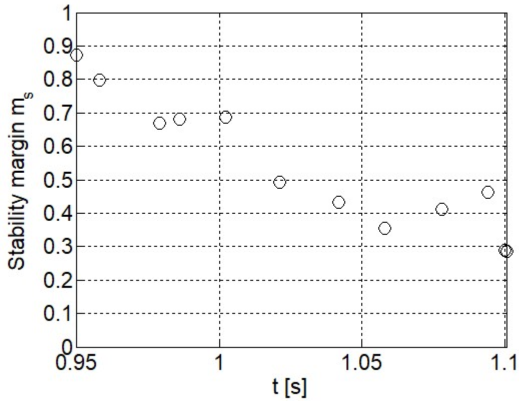


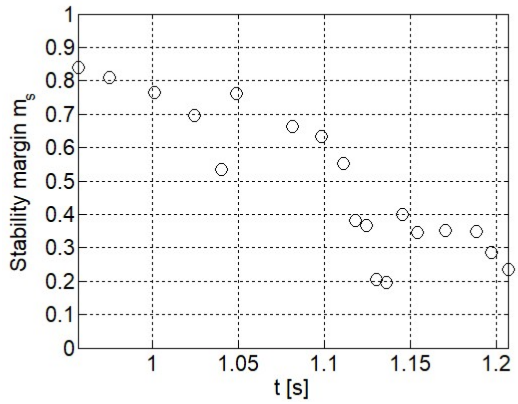
Fig. 2. Time dependence of poloidal beta for the three shots under analysis.



(a)



(b)



(c)

Fig. 3. Time dependence of the stability margin for shots# 58572 (a), 57202 (b), 58574 (c).

4. Conclusions

Dedicated experiments have been carried out on TCV to evaluate the limit value of the stability margin achievable before loss of vertical stability control. The results presented above show that, for a single-null diverted H-mode configuration, such limit value can be quantified between 0.2 and 0.3, following the definition proposed in [3]. Further experimental efforts are currently being planned to extend the analysis to plasma configurations geometrically and magnetically different, e.g. double null or negative triangularity.

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