§19. Proof of Real-Time Feedback Optimization Scheme of Polarization of EC-Waves

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Polarization is parameterized by the polarization rotation angle ($-90° \leq \alpha \leq 90°$) and the degree of ellipticity ($-45° \leq \beta \leq 45°$). ECRH transmission lines on LHD are equipped with a set of polarizer miterbends to change the polarization of the EC waves. In general, two corrugated mirrors with groove depth in the order of 1/4 or 1/8 of the free space wavelength λ can be used to vary the polarization rotation angle α and the ellipticity β. The obtained polarization depends on the polarizer angles ($\phi_{\lambda/4}$, $\phi_{\lambda/8}$), defined as the orientation of the grooves with respect to the plane of incidence for the polarizing mirror with groove depth of order $\lambda/4$ and $\lambda/8$, respectively.

A type of feedback controller, more appropriate for real-time implementation than usual hill-climbing numerical algorithm is the so-called extremum seeking controller[1,2]. This is a type of nonlinear adaptive controller. Its attractiveness stems from the relative simplicity of the feedback scheme and the well-established analysis and design methods. The controller was implemented and tested for an optimization of polarizer rotation angle setting during long-pulse ECRH-sustained plasma experiments on LHD. In these experiments, plasmas were sustained using three 77GHz gyrotrons for several minutes. The plasma density was of the order $0.5\times10^{19}\mathrm{m}^{-3}$. For these experiments, we controlled the polarizers for a gyrotron connected to 2-O port providing low-field side injection. In the scenario used (B=2.75T, R_{ax}=3.75m) the EC first harmonic resonance was located on axis, directly in front of the steering antenna. An ECE sygnal (T_{ece}) measuring the ECE temperature on the inboard side at ρ=0.66 (no real-time measurement of a central chord was available for this magnetic configuration due to technical reasons) was used as a measure of the first-pass absorption. This was adequate since the gyrotron power and density did not change significantly.

In order to test the controller, we moved the polarizer angles during the pulse to a position away from the pre-determined setting. The feedback controller was then activated and carried out the extremum seeking, i.e. it searched for a polarizer setting which maximized the measured ECE temperature. As seen in Fig. 1, it was found that the algorithm returns the polarizers to their original rotation angles, corresponding to the pre-calculated angles based on the B-field direction at the SOL. Fig. 1 shows the trajectories followed by the polarizers during the feedback control experiment. The traces are overlaid on the landscape portraying the O-mode purity as calculated from the SOL-based calculations. The fact that the feedback control system moves the polarizers to a zone of high O-mode purity indicates that the extremum seeking algorithm works well so that these calculations are indeed correct, and that the pre-calculated polarizer settings would have been adequate for the injection scenario considered.

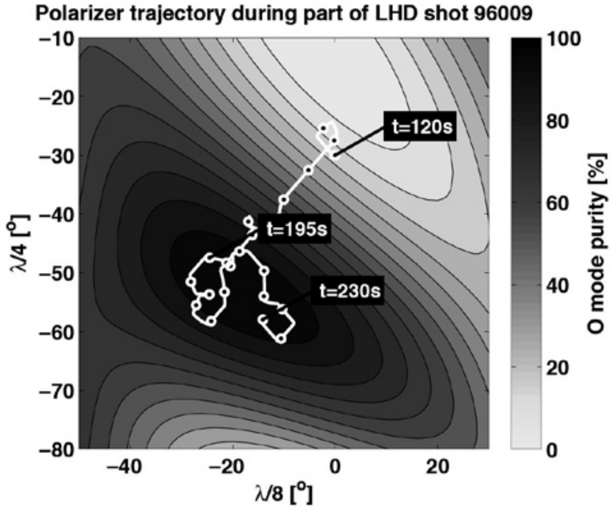

Fig. 1 A trajectory of a set of polarizer rotation angles $\phi_{\lambda/4}$, $\phi_{\lambda/8}$ during the feedback control experiment.

The polarizer angle traces plotted in Fig. 2, corresponding to Fig. 1, show that the movement is a superposition of the triangular position oscillation (from a square velocity perturbation) and a slower compensation signal from the feedback loop, which are typical for the extremum seeking controller.

The experimental results shown above demonstrate that the extremum seeking algorithm is able to find, from a non-optimal setting of the polarizer angles, a better setting corresponding to the theoretically expected optimum. An important point is that the method presented here is sufficiently general to be easily implemented on other tokamaks or stellarators with ECRH and controllable polarizers.

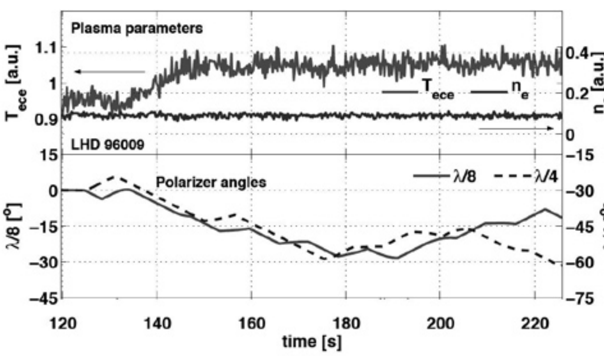

Fig. 2 Waveforms of the electron temperature and density, $\phi_{\lambda/4}$ and $\phi_{\lambda/8}$ corresponding to the same discharge for Fig. 1.

1) Krstic, M. et al.: Automatica, **36**, 595 (2000).
2) Felici, F. et al.: Rev. Sci. Inst., **80**, 013504 (2009).