THE WENDELSTEIN 7-X ECRH PLANT - EXPERIENCE WITH RELIABLE LONG PULSE OPERATION OF A MULTI MW GYROTRON INSTALLATION

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W7-X is a steady-state capable optimized stellarator. The main heating system is electron cyclotron resonance heating (ECRH) with currently 11 gyrotrons operating at 140 GHz. In the design phase of W7-X a 10MW ECRH plant with 10 Gyrotrons with a nominal output power of 1MW cw was planned [1] and also realized. In 2024 an upgraded version based on the original gyrotron design with nominally 1.5MW was installed at W7-X. Taking transmission losses and the spread of the actually achieved power of individual gyrotrons in to account (~0.6...1MW) up to 8.5 MW heating power are available in the plasma vessel.

In the past years we continuously increased the reliability of the plant and thus the actually available heating power for W7-X. The control system was continuously upgraded in order to allow an automated recovery after failures like a mode loss or arcs on the transmission line. On the route reactor relevant stationary plasma operation it is crucial to provide the required heating power continuously. A key lesson learnt from the first experimental campaigns of W7-X is on the one hand that in most cases after a gyrotron tripped operation can be resumed on a time scale of seconds. On the other hand gyrotrons operate more reliable at reduced power levels of 80...90% of the maximum achievable power. At W7-X the power of all gyrotrons can be modulated continuously between ~25...100% by controlling the acceleration voltage. We recently introduced a feedback controller as part of the gyrotron control system which stabilizes the total heating power by controlling the acceleration voltage of individual gyrotrons. Each gyrotron receives a power set point from the the central W7-X control system. The total power controller is a PI controller which determines a power correction factor for all gyrotrons from

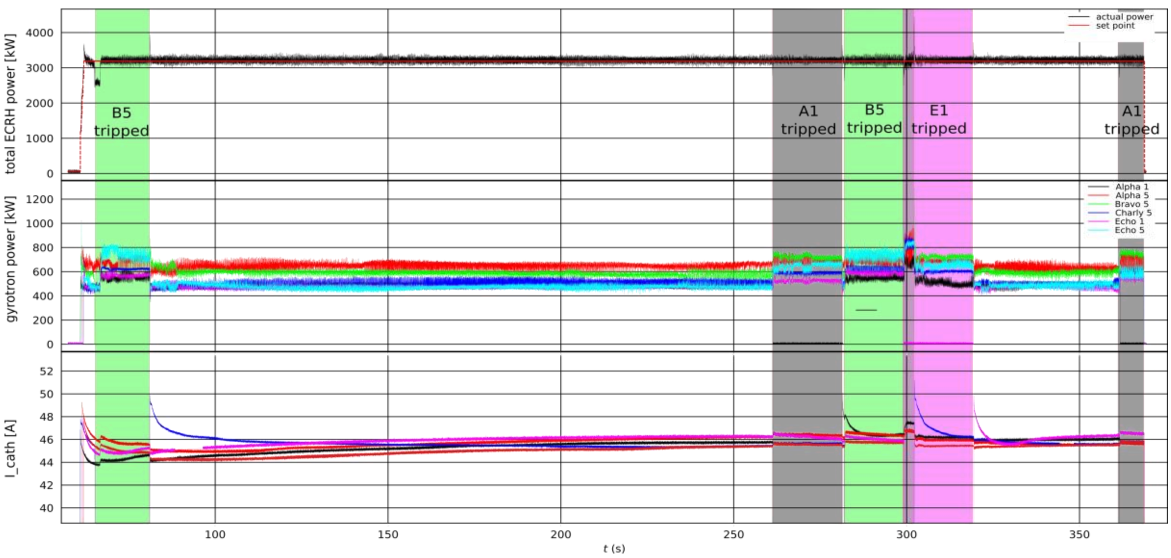

Fig. 1: Example for stationary ECRH operation using a feedback controller to keep the total heating power constant. During the shaded regions individual gyrotrons tripped and the lack of power was compensated by increasing the power of all other gyrotrons.

the difference between the total power set point and the actual power. When a gyrotron trips, the power of the remaining gyrotrons is increased until the tripped gyrotron resumes operation.

The successful application of this control technique is shown in fig. 1. Here we conducted an experiment program with 3MW ECRH heating from 6 gyrotrons. The program, which was intended to last 800s was terminated after 307s for reasons not related to ECRH. During the program the controller kept the total ECRH power constant although some gyrotrons tripped during the program as indicated by the shaded areas in fig. 1. The challenge when restarting gyrotrons on time scales of seconds is keeping the beam current constant. Stable gyrotron operation is only possible when the beam current can be stabilized in a narrow band around the optimum current. The cathode heater of our gyrotrons is a highly inert system. Cathode cooling due to electron emission during gyrotron operation is compensated by a feed forward boosting scheme for the filament heater current. We could show that after switching off a gyrotron operation either has to resume in less than ~3s or a break of at least 20s is required to reset a kind of memory effect of the cathode by applying an inverted boosting after switching off.

The strong inertia of the cathode heater is a big advantage of the presented feedback power controller compared to simply replacing a tripped gyrotron by a spare one. In order to stabilize the beam current during the first ~10s of operation, the active boosting of the cathode heater current has to start ~5s in advance. Therefore, it is most preferable to run all available gyrotrons at their most reliable working point of ~80-90% of maximum power. With enough gyrotrons participating in the feedback control scheme, which will be the case for a reactor scale device, the power of each gyrotron only has to be slightly increased in order to compensate the loss of an individual gyrotron.

ACKNOWLEDGEMENTS

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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