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Verantwortlich / in charge	Dr. R. Jaspers r.jaspers@fz-juelich.de
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Detailergebnisse / Details

TEC Main Topic 5 — Advanced Tokamak Scenarios

The goal of the "advanced tokamak scenarios" (ATS) is to reach higher pressure at a given plasma current and approaching steady state operation with a large fraction of bootstrap current, i.e. a non-inductive, self generated current. These scenarios can be realized by modification of the current profile, which has been shown on many tokamaks to lead to internal transport barriers, thus improving the confinement quality. Moreover, these transport barriers lead to regions of high temperature and pressure gradients which in turn lead to a high bootstrap current. The main aim of the TEC topic group *advanced tokamak scenarios* for the moment is to create such an operational scenario with internal transport barriers and then focus on the role of rational values of the helical winding number q (directly related to the current density) and the electron transport in these regimes. Furthermore, by local heating or current drive with the electron cyclotron heating system, an active manipulation of the current density profile is foreseen.

After a longer shutdown, TEXTOR became operational in the reporting year. This shutdown period – to install the Dynamic Ergodic Divertor (DED) – was utilized as well to improve some hardware of relevance for the investigations of the advanced scenarios. The experimental campaign on TEXTOR was first used to bring these into operation. Aside from that, some physics results on the topics of transport barriers and electron transport could be made. Finally, similar experiments were performed in collaboration on different tokamaks, such that comparative studies could be undertaken.

Hardware

Undoubtedly the most eminent hardware improvement is the new 140 GHz, 800 kW gyrotron. This provides the possibility for local electron heating, thus creating large temperature gradients and even off-axis temperature maxima, which could change the current density profile as well. This latter effect can be directly influenced by the current drive capability of the gyrotron, i.e. launching the electron cyclotron waves oblique to the magnetic field. Furthermore, the gyrotron can also deliver modulated pulses to the plasma. From the analysis of the evolution of these heat pulses the electron transport can be examined. This gyrotron was successfully taken into operation. Showing a record pulse of 800 kW during more than 2.7 s, it outperformed the previous gyrotron by far, see Fig.1.

From the diagnostic side, developments in three different areas, being relevant for the ATS programme, were undertaken. The MSE, the Multi Pulse Thomson scattering and the 2D ECE-Imaging systems came into operation.

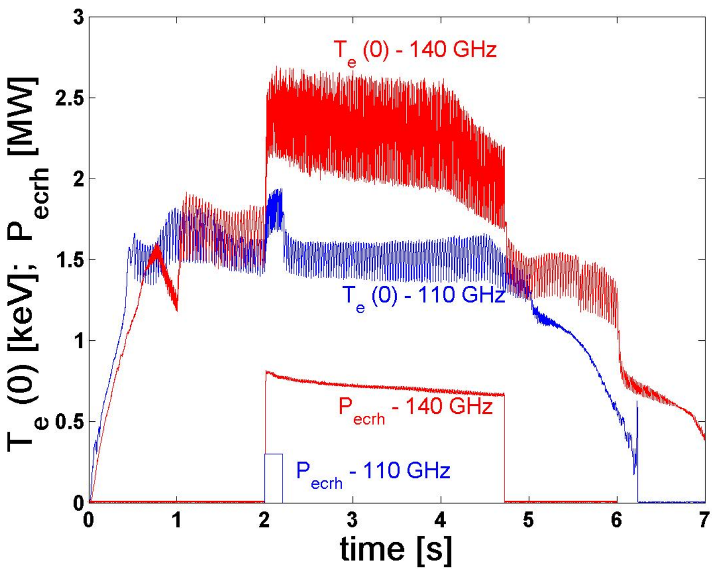

Fig. 1: *The effect of the new 140 GHz gyrotron on the central electron temperature, compared with the old 110 GHz gyrotron: longer pulse length, more power, leading to higher electron temperatures.*

MSE: the clear relation between the advanced scenarios and the current density profiles urged for a good diagnostic of the q-profile. Exploiting the motional stark effect of the injected neutral hydrogen atoms can reveal this q-profile, as has been demonstrated in the last decade on the big tokamaks. Before the DED-shutdown a prototype of an MSE system based on measuring the ratio of intensities of two orthogonal polarised lines of the Balmer-α spectrum was already tested. This has now been improved and became operational in the last experimental campaign (although not all 20 radial channels yet). The first results are depicted in Fig. 2.

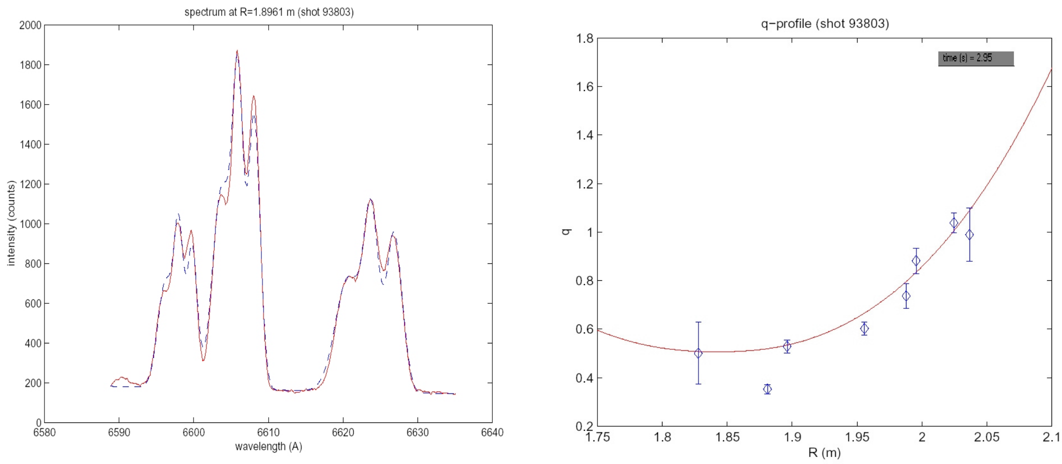

Fig. 2: *First results of the MSE diagnostic: On the left a typical spectrum is shown. From the ratio of the π and σ components and the Doppler shift, the q-value can be directly obtained. This q-profile is shown on the right for the 8 operational channels.*

Thomson scattering: The high resolution Thomson scattering system has been upgraded to provide time information as well. In the new design the laser cavity encompasses the plasma, so that the laser pulse passes many times through the plasma. In this way, a fast repetition of laser pulses is obtained; typically three bursts of 50 – 75 laser pulses with a repetition frequency of up to 10 kHz can be generated (see Fig. 3). Newly developed fast CMOS detectors are used to record measurements of the temperature and density profile for each individual pulse. The spatial resolution and accuracy are the same as that for the existing double-pulse Thomson scattering system.

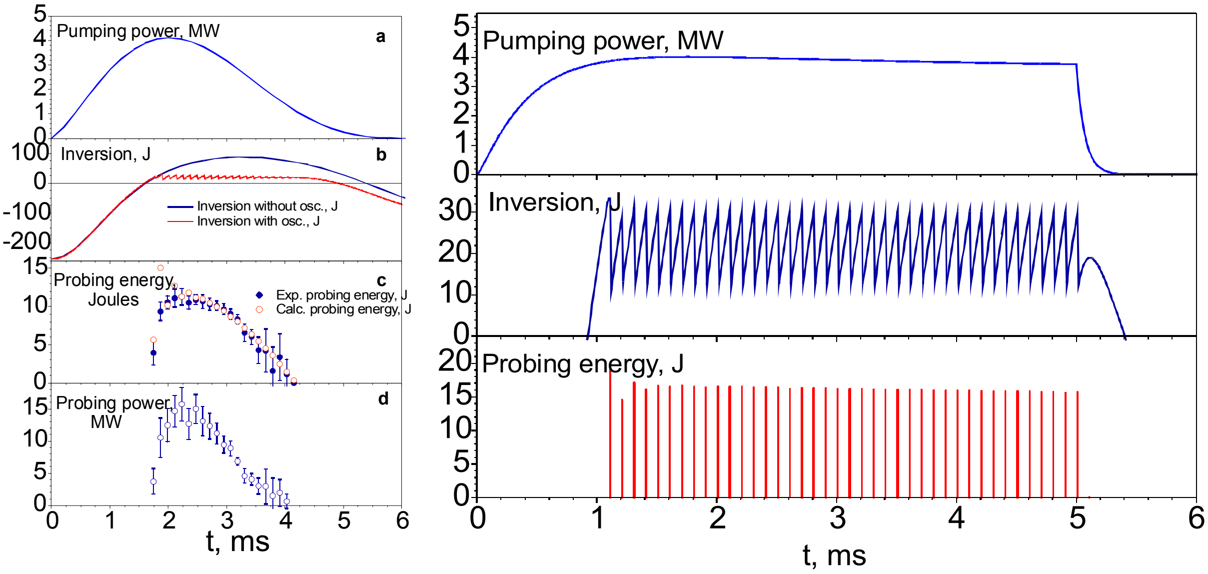

Fig. 3: *Output of the multi-pulse laser system for Thomson scattering. The left graphs show in blue the output that has been obtained thus far with an improvised capacitor bank. The red circles show the calculated values. Due to the short duration of the pumping power from the capacitor, the pulse energy quickly decreases. Still almost 20 laser pulses are obtained. The right figure shows the output energy of the laser with an improved capacitor bank as calculated with the same model being used in the left graphs.*

2D-ECE-imaging: This system images a two-dimensional part of the poloidal plane onto an MMIC array with in total 8 horizontal and 16 vertical measuring channels. The system has a spatial resolution of approximately one cm in the poloidal plane, which is better than that of most standard heterodyne ECE systems. This makes it possible to measure the detailed 2D profile of electron temperature fluctuations. The ECE-I system is combined with the Microwave Imaging Reflectometer (MIR) system and has been recently installed at TEXTOR.

Physics results

The physics experiments were concentrated on the issue of electron transport barriers. Before the shutdown, using the older gyrotron, L-mode discharges were made which exhibited a strong barrier associated with the q=1 surface. These experiments could reasonably well be described by the RTP q-comb model, in which the heat conduction is supposed to be a function of *q* only – with a constant high value interspersed with narrow regions of low conductivity located near the low rational values. Now, this q-comb model has been applied to a density scan and a current scan. Given the experimental density profile, the heat deposition profile, Z_{eff} and the heat diffusivity $\chi_e(q)$ according to the q-comb model (taken the same as on RTP, except for an L-mode scaling factor, thus no fitting parameters were used), the electron temperature profile was iterated until a stationary solution was obtained. In all cases the experimental data was insufficient to provide an accurate test of the model. Nevertheless, the model reproduced to a certain extent the main features of the experiment: the central temperature and the width of the profile. Some examples are shown in Fig. 4.

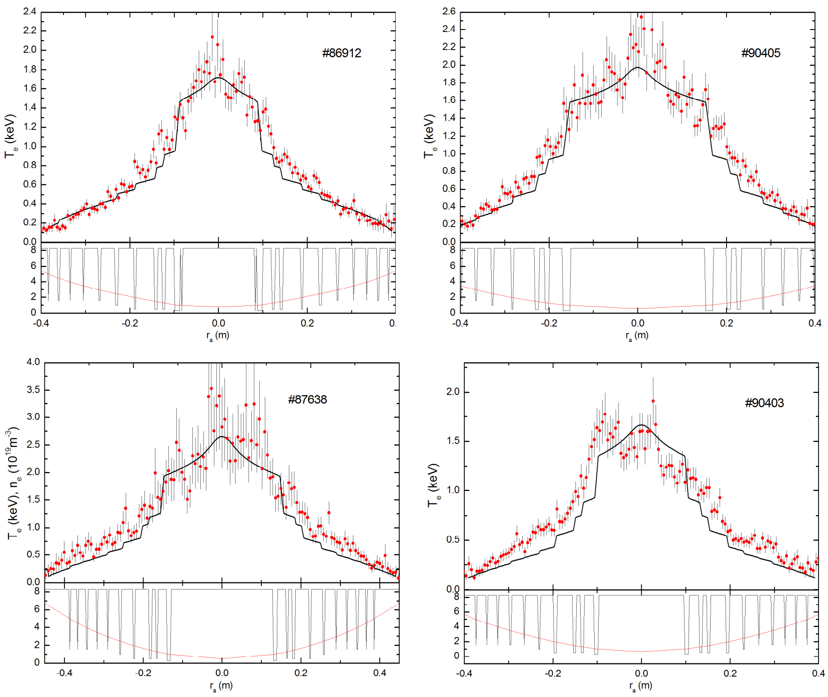

Fig. 4: *Application of the same q-comb model to centrally heated ECRH discharges at low [$n_e(0)$ = 1.0 x 10^{19} m^{-3}, 87638] and higher density [$n_e(0)$ = 2.5 x 10^{19} m^{-3}, 86912], both at I_p = 200 kA, and to two discharges differing in plasma current: 87650, I_p = 200 kA and 90405, I_p = 305 kA, both with $n_e(0)$ = 2.0 x 10^{19} m^{-3}. Although not all details are provided by the experimental data, some features such as the central temperature and the width of the profiles are reasonably well described.*

A further confirmation of the existence of at least the q=1 barrier was found in modulated ECRH experiments in which a modest change of the deposition radius around the inversion radius caused a sharp transition in the phase profile of the perturbation.

Apart from these discharges with central ECRH heating, an extensive set of experiments was made in which the deposition radius for the ECRH was dynamically scanned through the plasma. Contrary to RTP results, no transitions or crashes were observed when a rational q surface was crossed.

TEC proposed and was involved in the same kind of experiments performed on other tokamaks. On ASDEX and DIII-D, part of the phenomenology of RTP was found as well: off-axis heating of ECRH led to off-axis maxima in the electron temperature. However, the transition in confinement when the heating crossed a rational surface was not observed on ASDEX.

Also a collaboration with T10 was initiated. A very specific feature that has been observed in T10 plasmas, in which ECRH power is deposited just outside the q=1 radius, is that after switching off the ECRH gyrotrons the central temperature does not decrease immediately (see Fig. 5). Instead, it stays constant for several tens of ms before it starts to decay. The effect in T10 was most pronounced in case the ECRH power was just high enough to stabilize the sawtooth activity in the plasma core. From these results the statement that the necessary condition for the formation of a transport barrier was a low shear close to a rational value of the safety factor could be confirmed. Similar attempts were undertaken at TEXTOR, but due to the limited shot time, only a marginal effect could be observed up to now.

Finally, the TEC involvement in the JET advanced scenario's programme was concentrated on the realization of internal transport barriers at high density, equal ion and electron temperatures and a high fraction of bootstrap current. This could be achieved in a scenario in which there is first a preheat phase by lower hybrid heating to form a hollow q-profile, followed by a short ohmic phase, in which pellets were injected to rise the density, after which the main heating phase started and the internal barrier was formed in a high density plasma.

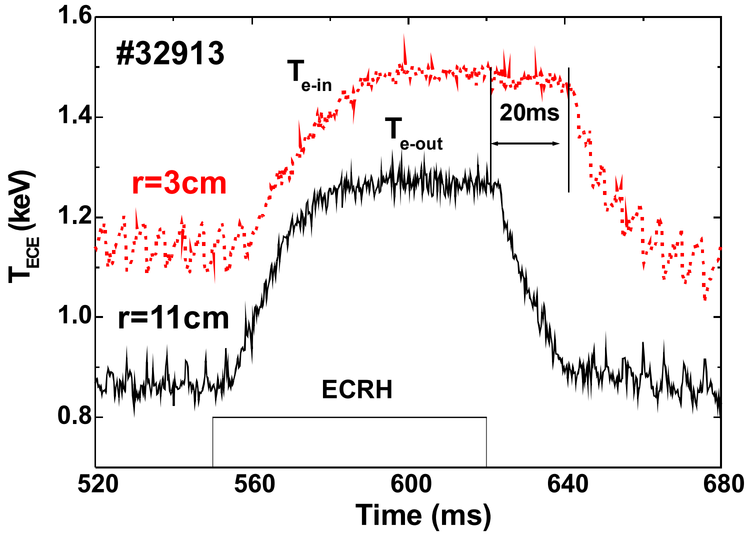

Fig. 5: *Result from T10: After switch off of ECRH the central temperature stays approximately constant for 20 ms, whereas outside the barrier the temperature immediately drops.*