Wendelstein 7-X

NEWSLETTER

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First divertor operation: higher plasma densities, longer discharges

Shortly before Christmas, the 2017 experimental campaign on Wendelstein 7-X was finished as planned. Starting in early September, fifteen weeks of operation were conducted and major machine components worked without failures allowing the scientists an efficient use of the machine time. The W7-X team currently comprises about 150 scientific staff members based in Greifswald and more than 60 scientists from EUROfusion laboratories, the US, Japan, and Australia.

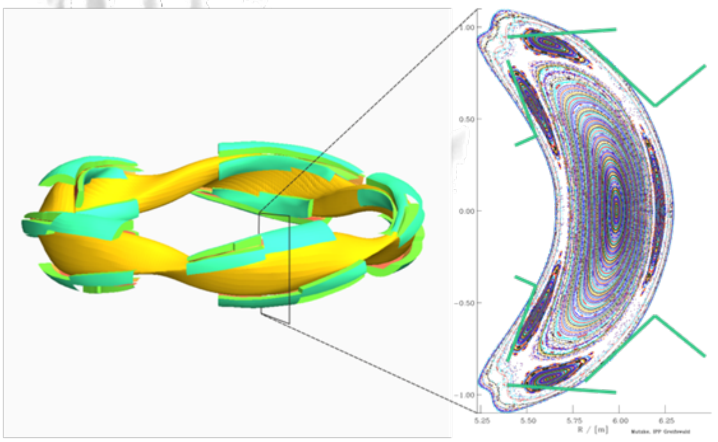

Fig. 1 Wendelstein 7-X plasma (yellow) with divertor (green); plasma cross-section with magnetic islands cut by divertor targets

The expectations for the experiments were high: after the first campaign, ending in March 2016, W7-X was equipped with a new component for plasma exhaust – the so-called island divertor. The divertor takes up heat loads conducted along magnetic field lines onto its special targets which interact magnetic islands external to the confinement volume in which nested magnetic surfaces exist (see fig. 1).

Having been installed for the recently conducted campaign and experiments to be carried out in 2018, the test divertor is part of a long-term strategy to extend plasma operation. Prior to this experimental campaign, ten divertor units had been installed. Still lacking of water-cooling, the test divertor units are more tolerant to unexpected loads and thus an ideal tool for first divertor tests. Consequently, the goal of this divertor phase was to gain experience with the magnetic field in the presence of the divertor and to develop safe and reliable operation. This will form the basis for experiments, which will ultimately extend the pulse lengths from seconds to several minutes.

Fig. 2 shows how the plasma acts on the divertor. The figure shows thermography data indicating the location of the heat loads. During the campaign the maximum surface temperature on the divertor reached up to 900 °C after a few seconds of the discharge. A first analysis indicates the observed temperature to match with theoretical predictions. Having gained confidence that the heat loads can be controlled, longer discharges of up to 30 s became routine by the end of the campaign. With the longer discharges, the divertor allowed deposit of up to 75 MJ of heating energy in W7-X – more than 18 times larger than the energy limit of the first campaign.

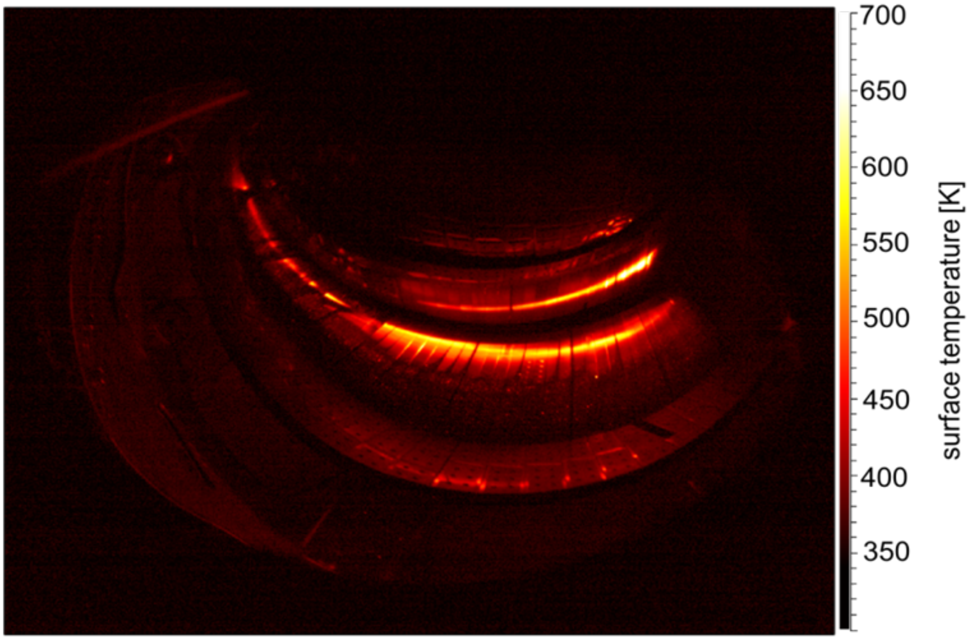

Fig. 2 Infrared image of one out of ten divertor units during a plasma discharge in W7-X. Two bright stripes indicate the most highly loaded areas called strike lines. The strike-lines are typically a few centimetres wide and reach a temperature of up to more than 400 °C in this example.

In order to successively extend the heating power and pulse lengths, however, small deviations from the ideal magnetic fields leading to asymmetric power loads needed to be overcome. These are due to small inaccuracies in the construction of the superconducting coils of Wendelstein 7-X, but small magnetic field errors can be corrected with a set of supplementary trim coils. Using these coils we successfully equalized the heat load to each divertor unit as confirmed by the infrared cameras.

With these symmetrised power loads it was possible to extend the heating energy. With correspondingly extended heating power, the plasma density could be increased. Core plasma densities up to 1.4 x 10^{20} m^{-3} were achieved - more than four times more than in in the previous campaign. Two developments made this achievement possible:

1. A new system for efficient fueling of Wendelstein 7-X plasmas - the pellet injection system - was successfully brought into operation. The injector shoots tiny frozen hydrogen pellets into the plasma as illustrated in Figure 2. As the pellets propagate through the plasma, they are ablated and finally ionized, thereby fueling the plasma.

Fig. 3 View into the plasma vessel of W7-X during pellet injection. Tiles of the structured wall protection are seen in the lower central region illuminated by the visible plasma light (blurry regions). The pellet is indicated by the arrow.

2. A new heating scheme is required at high densities. A special polarization of the microwave beams allows them to penetrate into the plasma centre beyond regions of high plasma density, where the beam would be reflected. The microwave beam polarization is changed during the initial two seconds of plasma operation, when densities are lower. This heating scheme creates plasmas with excellent energy confinement and high ion temperatures.

Finally, the capability of plasma operation at high plasma density appears to be a key ingredient to operate the divertor under favourable conditions – so-called detachment. This is the state of the divertor plasma at which the divertor target plates are well isolated preventing higher heat fluxes reaching the target plates. Divertor detachment may be a requirement for future fusion power plants, as it significantly minimizes the power loads to the divertor surface. In this campaign, we could reach stable, complete detachment for several seconds. This achievement results in a reduction of the power loads by a factor of 10 on all 10 divertors.

Additional physics aspects benefitted from the extension of achievable plasma densities at different heating power as well. Crucial aspects of stellarator optimization could be addressed such as the control of internal plasma currents and the stellarator specific heat transport. First exciting insights into plasma turbulence and the flows of impurities were possible with new and upgraded diagnostics systems. All experiments performed included variations of the magnetic field configuration which is an important parameter influencing the plasma transport and stability properties.

In summary, the 2017 experimental campaign has been successfully completed. The time until summer 2018 will be used for completing and commissioning new installations including new plasma diagnostics, a specially designed divertor element (the so-called scraper element) and new heating systems.The present plan foresees that plasma operation will be commenced in July 2018.

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