Optimization of ECRH operation at high densities in Wendelstein 7-X

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One of the major goals of Wendelstein 7-X is to achieve steady state operation (up to 30 min.) at plasma parameters relevant for a future fusion reactor. This includes operation at plasma pressures requiring a density above $10^{20}\mathrm{m}^{-3}$. The only steady state capable heating currently available is ECRH using high power gyrotrons. Wendelstein 7-X is equipped with 10 gyrotrons providing up to 7.5MW to the plasma vessel. The power is transmitted to the machine using a quasi optical transmission line where the polarization and launching angle can be remotely controlled by the central W7-X control system. Using X-mode polarization break down can easily be achieved and the launched power is nearly perfectly absorbed (>99%) over a wide range of plasma parameters. Here, the achievable density is limited by the X-mode cut-off density of $n = 1.2 \cdot 10^{20}\mathrm{m}^{-3}$ at the used frequency of 140GHz. In order to reach higher densities O-mode polarization is necessary where the single pass absorption depends more sensitively on the plasma parameters and is typically in the order of 50...80%. Plasma start-up in O-mode is not possible because a target plasma with $T_e > 1\mathrm{keV}$ is necessary to deposit enough energy to sustain a hot plasma. During the first experimental campaigns of W7-X a scenario to achieve ECR heated plasmas at densities above the X-mode cut-off was developed. The target plasma was created using two or three gyrotrons in X-mode. After creating a low density target plasma with $n_e \approx 2 \cdot 10^{19}\mathrm{m}^{-3}$ the remaining gyrotrons were switched on in O-mode and the density was ramped up to $n_e \approx 6 \cdot 10^{19}\mathrm{m}^{-3}$. While ramping up the denstiy the polarization of the start-up gyrotrons was changed to O-mode. Thus, a purely O-mode heated plasma was created. Using pellet injection the density could then be further increased. Line averaged densities of $n_e = 1.4 \cdot 10^{20}\mathrm{m}^{-3}$ as measured by a single channel interferometer were achieved. The exceeding of the X-mode cut-off was confirmed by ECE measurements where the signal was lost eventually. In order to maximize the heating efficiency a three pass heating scheme was established reflecting the beams through the plasma axis once at the high-field side of the vessel and once at the low field. Thus, a total absorption of >90% could be reached as determined by stray radiation measurements. Reducing the amount of non-absorbed microwave power in the vessel is not only necessary to maximize the plasma performance but also in terms of safe machine operation since in vessel components can suffer from heating up due to stray radiation. The stray radiation levels measured around the machine were comparable to or even lower than expected levels.