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Increasing the Density in W7-X: Benefits and Limitations

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As the first comprehensively optimized stellarator, Wendelstein 7-X (W7-X) is an essential experiment to study high density operation in this kind of device. This contribution presents first experiments on the density dependence of the energy confinement in W7-X and limitations of the achievable density. Theoretical predictions and empirical scaling laws for the energy confinement time in stellarators (e.g. the ISS04) predict a positive correlation between the plasma density and the energy confinement time. However, this might not be valid for plasma operation close to operational limits. Hence, the energy confinement time scaling and the presence of operational limits have to be studied as an intertwined system. The experimental exploitation of W7-X has only started, however, the gradual completion of the machine capabilities is an ideal opportunity to map out the configuration space and to identify key issues on the route to high-performance long-pulse operation.
In the first two experimental campaigns, featuring a limiter and a test divertor configuration, the energy confinement time has been analyzed. A positive density dependence has been found and the scaling coefficient is close to the expectation from ISS04. During these experiments, however, radiative collapses have been observed. Such a radiative density limit is predicted by simplified analytical models. Such a model has been applied to W7-X in order to estimate a critical density and in purely gas-fueled hydrogen plasmas, no stable plasma operation has been achieved above this density. It has been observed that the critical density also depends on the magnetic configuration, which directly relates this issue to scenario development. Furthermore, first experiments with pellet-fueling showed densities well above the critical density, which indicates the importance of profile and fueling effects. These experiments confirm that an increasing density is indeed beneficial for the energy confinement, at least in the currently accessible density range. It remains to be shown that this trend extrapolates to the high-performance plasmas W7-X was designed for. The experiments have also shown, however, that high-density operation involves a careful scenario development, as fueling issues and radiative instabilities limit the currently accessible operational space of W7-X in its current state of completion.

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Author: Dr FUCHERT, Golo (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany)

Co-authors: Dr DINKLAGE, Andreas (Max-Planck-Institut für Plasmaphysik); Dr LANGENBERG, Andreas (Max-Planck-Institut für Plasmaphysik,17491 Greifswald, Germany); Dr BEIDLER, Craig (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr ZHANG, Daihong (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr PASCH, Ekkehard (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr WARMER, Felix (Max Planck Institute for Plasma Physics); Mr DAMM, Hannes (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr LAQUA, Heinrich (Max-Planck-Institute for Plasma Physics, Greifswald, Germany); Dr KNAUER, Jens (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr BALDZUHN, Jürgen (Max--Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr BRUNNER, Kai-Jakob (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr RAHBARNIA, Kian (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr HIRSCH, Matthias (Max-Planck-Institut für Plasmaphysik); Dr PABLANT, Novimir (Princeton Plasma Physics Laboratory); Dr BURHENN, Rainer (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Prof. WOLF, Robert (Max-Planck-Institute for Plasma Physics); Dr LAZERSON, Samuel (Princeton Plasma Physics

Laboratory); Dr EVAN, Scott (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr BOZHENKOV, Sergey (Max-Planck Insitute of Plasma Physics); Prof. PEDERSEN, Thomas Sunn (Max Planck Institute for Plasma Physics); Dr STANGE, Torsten (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany); Dr KAZAKOV, Yevgen (Laboratory for Plasma Physics, LPP-ERM/KMS); Dr FENG, Yühe (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany)

Presenter: Dr FUCHERT, Golo (Max-Planck-Institut für Plasmaphysik, Greifswald, Germany)

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