# Stellarator β Limits

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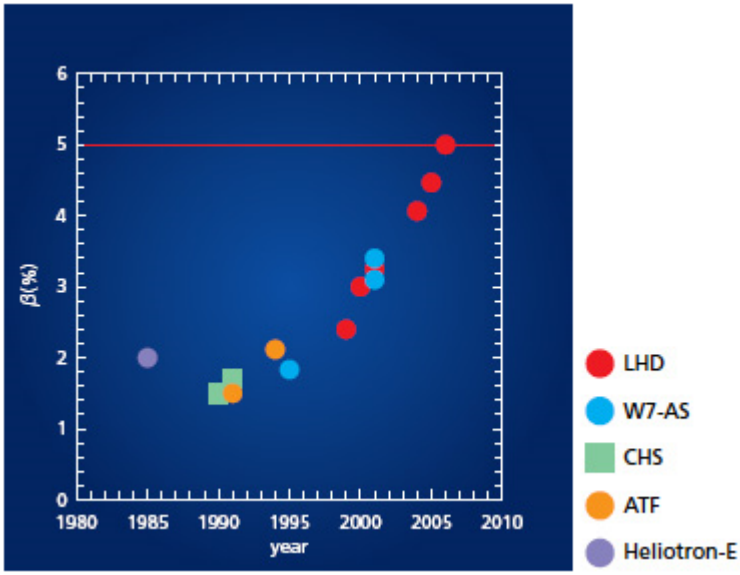


*Fig. 1. Values of ⟨β⟩ achieved in stellarators as a function of the year.*

The highest values of β in stellarators have been achieved in the W7AS (German) and LHD (Japanese) devices, $\langle\beta\rangle \approx 3.4\%$ and $\langle\beta\rangle \approx 5\%$ respectively.[1,2] In both cases the achievable β was limited by the available heating power, with no hard β limit seen. As described below, the values of ⟨β⟩ achieved are well above predicted MHD instability thresholds for global modes in W7AS and for Mercier modes in LHD. Neither device has experienced disruptive instabilities triggered by increasing β. The achieved value of ⟨β⟩ in LHD has continuously increased over the years as the available heating power has increased. (Fig. 1.)

For W7AS[3], the CAS3D and TERPSICHORE codes predict the presence of global ideal MHD instabilities in the range $1.5\% < \langle\beta\rangle < 2.5\%$. MHD activity seen in the experiment is consistent with the theoretical predictions, but the modes saturate and they do not significantly degrade confinement in most cases or impede access to higher ⟨β⟩ values. The MHD activity disappears for $\langle\beta\rangle > 2.5\%$.

Three-dimensional equilibrium codes that do not assume the existence of nested flux surfaces find a substantial region of stochastic magnetic field lines in the outer region of the plasma at the highest values of β in both W7AS and LHD.[1,3-5] The W7AS calculations have been shown to be consistent with the experimental observations, with the appearance and growth of the stochastic region providing a plausible explanation for a deterioration in confinement with increasing β. No other plausible explanation for the deterioration in confinement in W7AS has been proposed, as there is no observed MHD activity in the high β shots, and no MHD instabilities are predicted by theory.

It is important to note that calculations for the W7X stellarator[6] indicate that its flux surfaces will be considerably more robust than those of W7AS. This is to be expected, because of the strong suppression of the Pfirsch-Schlueter currents, and of the associated Shafranov shift, in W7X. Further, the NCSX design study has shown that calculations

with 3D equilibrium codes can be used in guiding the design of stellarators with robust flux surfaces.[7]

In the design of the LHD stellarator, a reference equilibrium was chosen which represented a compromise between the desire for improved neoclassical confinement and a desire for Mercier stability at low β. No deleterious effects due to Mercier instability at low β have been observed, and it has been found to be advantageous to routinely operate the experiment with the magnetic axis shifted inward relative to the reference equilibrium, improving neoclassical (and anomalous) confinement while degrading the predicted Mercier stability properties.[8]

As in W7AS, a degradation in confinement with increasing β has been observed at high β in LHD.[1,8] The corresponding calculated equilibria are found to have a substantial region of stochasticity in the outer region of the plasma. MHD activity is also observed in these shots. Unlike W7AS (and W7X), LHD has a magnetic hill in the outer region of the plasma, so that resistive interchange modes are unstable, and this is believed to be the cause of the observed MHD activity. It is not known at present whether the field line stochasticity or the MHD activity play a more important role in the degradation of confinement.

In conclusion, no hard β limits have been seen in stellarators, even when MHD instability thresholds are exceeded. No disruptive instabilities are triggered by increasing β. The value of $\langle\beta\rangle$ attained in the largest stellarator operating at present, LHD, has continuously increased over the years as the available heating power has increased. There is evidence for a β induced stochastization in the outer region of the plasma at the highest values of β attained in W7AS and LHD. There are now methods available for designing stellarator configurations with more robust flux surfaces, and both the W7X and NCSX configurations were designed to have robust flux surfaces at higher values of $\langle\beta\rangle$.

## References


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