Impact of plasma pressure on the edge magnetic field of Wendelstein 7-X

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The Wendelstein 7-X stellarator aims to achieve plasma performance regimes in steady-state operation competitive with Tokamaks [1], [2]. For heat- and particle-exhaust, Wendelstein 7-X relies on an island divertor, where the divertor target plates are separated from the main plasma by a chain of magnetic islands. In standard configuration the islands form an $n/m = 5/5$ island chain. The geometry of the divertor islands determines the location of the strike-line on the divertor plates. During operation, plasma pressure and -current driven changes in the edge field geometry can re-direct plasma onto other machine components, potentially exceeding those components' heat limits. It is therefore important that the effect of those changes is understood.

Pressure profile dependence of HINT equilibria

HINT is a FORTRAN-based code for the solution of the MHD force balance equation. For calculation of the equilibria, the resistive MHD equations are solved using a finite difference method in space and a high-order explicit Runge-Kutta scheme in time. To keep the pressure profile consistent with the magnetic topology, the pressure is repeatedly averaged using a field-line tracing method.

To give an estimate of the dependence on pressure distribution, three pressure profiles as shown in figure 1 - as well as the vacuum configuration - are compared. Figure 2 shows the differences between the vacuum configuration and $\beta_{\text{central}} = 2\%$ equilibria in the $n/m = 5/5$ standard configuration. With increasing pressure a re-distribution of strike points from the horizontal onto the vertical target plate can be observed. Additionally, the onset of stochastization around the magnetic islands is visible. However, in contrast to the central pressure, the edge magnetic topology seems to be less sensitive to the pressure profile. Only a slight increase

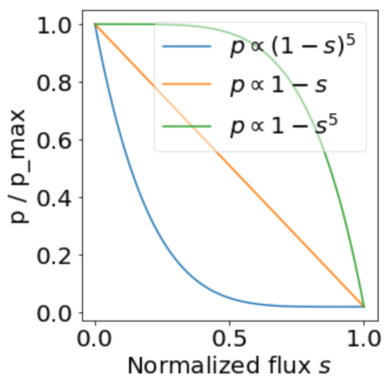

Figure 1: Pressure profiles used for the sensitivity studies

in stochastization can be observed for the peaked profile, accompanied with a very slight redistribution of heat flux from the right (image view) side of the vertical target plate to the left side of the horizontal target.

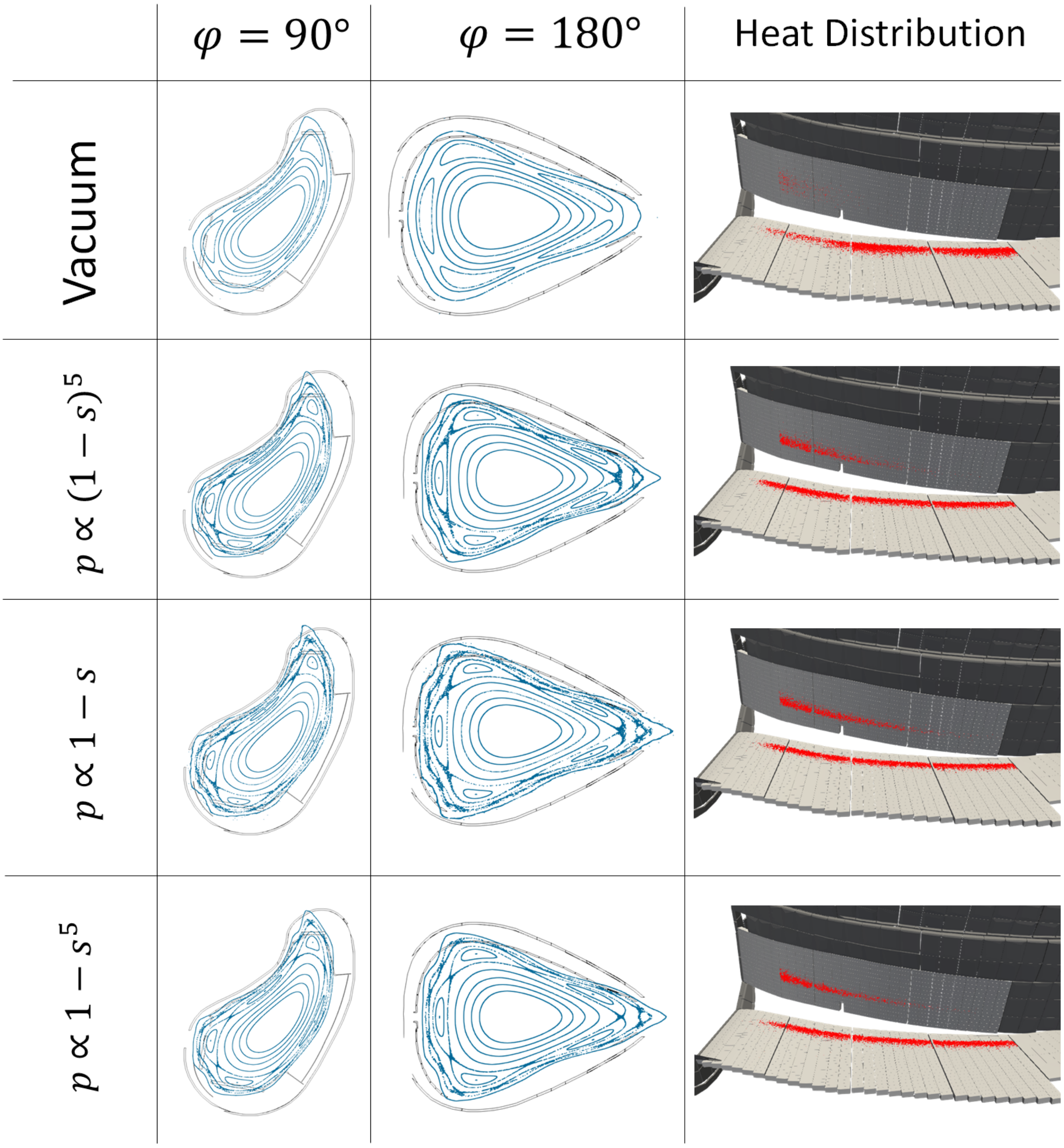

Figure 2: Poincaré maps at two different angles and heat flux distributions obtained using fieldline-diffusion simulations for the 5/5 vacuum case and three pressure profiles with $\beta_{axis} = 2\%$.

Experimental benchmarking of HINT equilibria

The upgraded magnetic probe

For experimental measurements of the plasma response, a reciprocating magnetic 3D probe (see figure 3) was employed as part of the Combined Probe [4] for the Multi-Purpose-Manipulator [5]. The manipulator is located 17 cm below the mid-plane at the toroidal angle of $\phi = -159.3°$. For the most recent experimental campaign, the magnetic probe electronics were extended with an analog signal integrator to combat time-dependent drifts encountered in later stages of the signal processing chain.

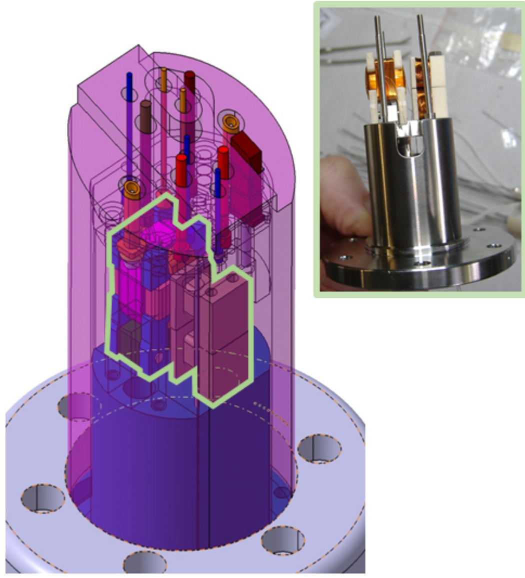

Figure 3: The combined probe *FZJ-COMB2* and (highlighted) the magnetic probe system

Edge magnetic field measurements vs prediction

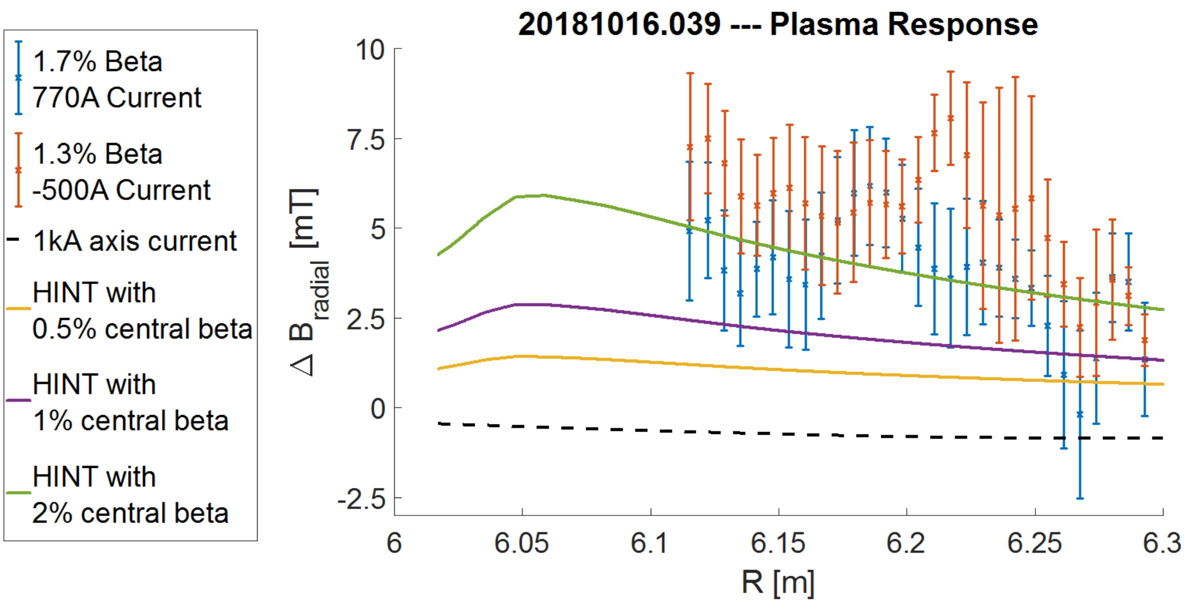

Figure 4: Comparison of predicted and measured plasma response

For a first experimental benchmark, the plasma response predicted using a $p \propto 1 - s$ pressure profile (with s being the normalized magnetic flux) - corresponding approximately to a parabolic pressure in minor radius - is compared to the plasma response measured using the upgraded magnetic probe (see fig 4). To acquire the plasma response, a plunge measuring the vacuum field was performed right before plasma startup, followed by two plunges during a single plasma at different beta values. Constant drifts in-between plunges were compensated using a linear subtraction.

The plasma response measurement agrees reasonable with the predicted magnetic field changes (solid lines). The remaining deviations can be explained when

The plasma response measurement agrees reasonably with the predicted magnetic field changes, especially when taking into account the additional contribution from the toroidal plasma current.

Summary and outlook

At a central β of about 2% the dependence on central pressure far outweights the dependence on the pressure profile (in standard configuration). This is highly beneficial for the creation of an equilibrium database and extended benchmarking of the numerical model. One of the near-term goals will be to potentially confirm the same behavior in other configurations. The same stability also extends to the heat-load distributions on the divertor plates, which makes a comparison to infrared camera measurements another natural next step.

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