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Numerical and experimental investigations of a microwave interferometer for the negative ion source SPIDER

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The electron density close to the extraction grids and the co-extracted electrons represent a crucial issue when operating negative ion sources for fusion. An excessive electron density in the plasma expansion region can indeed inhibit the negative ion production and introduce potentially harmful electrons in the accelerator. When entering the accelerator, electrons risk overheating the accelerator grids, representing a major problem especially for MITICA, designed to accelerate negative ions up to 1 MeV.
Among the set of plasma and beam diagnostics proposed for SPIDER upgrade, a heterodyne microwave (mw) interferometer at 100 GHz is currently being explored as a possibility to measure electron density in the plasma extraction region. The major issue in applying this technique in SPIDER is the poor accessibility of the probing microwave beam through the source metal walls and the long distance of 4 m at which mw modules are located outside the vacuum vessel. Numerical investigations in a full-scale geometry showed that the power transmitted through the plasma source apertures was above the signal-to-noise ratio threshold for the microwave module sensitivity, so, an experimental proof-of-principle of the setup to assess the possibility of signal phase detection was performed. The microwave system was tested on an experimental full-scale test-bench mimicking SPIDER viewports accessibility constraints, including the presence of a SPIDER-like plasma. The outcome of first tests revealed that, despite the geometrical constraints, in certain conditions, the phase detection, and, therefore, the electron density measurement is possible. The main issue arises from decoupling the one-pass signal component from spurious multipaths generated by mw beam reflections, requiring dedicated signal cross correlation analysis. These preliminary tests demonstrated that despite the 4 m distance between the mw modules and the presence of metal walls, phase signal detection in different conditions of plasma densities is possible when full 8 cm diameter viewports are available.
In this contribution, we discuss the numerical simulations, the outcome of the preliminary experimental tests and suggest design upgrades of the interferometric setup to enhance signal transmission. This includes a new design of the emitting horn to improve its directivity and the addition of focusing elements to enhance mw beam transport along the propagation path. Moreover, it is envisaged to perform next tests in frequency sweep mode; by measuring the phase shift over a frequency range, it is expected to reduce the error on phase shift at a given frequency.

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