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A novel technique for an alignment-insensitive density calibration of Thomson scattering diagnostics developed at Wendelstein 7-X

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In most fields of plasma physics, laser-based Thomson scattering diagnostics are employed to measure the electron density (and temperature). With absolute calibration, the measurement does not require input from other diagnostics. Common ways to achieve this calibration are (rotational) Raman or Rayleigh scattering on various gases. An issue connecting calibration and measurement is the alignment stability of the laser beam and observation optics. Vibrations lead to positional variations of subsequent pulses, while mechanical deformations cause alignment drifts over time. This is a challenge for large fusion experiments, where access for alignment and calibration is restricted. Simple and robust calibration methods are required. At the stellarator Wendelstein 7-X (W7-X), a novel method was developed to account for systematic errors imposed by these positional variations.

It was observed at W7-X that even a shift of the beam axis of less than 1 mm noticeably affects the measured electron density. Every scattering volume (spatial point in the measured profile) responds in a unique way and, hence, even the shape of the profile is determined incorrectly. By monitoring the beam position precisely, its deterministic relationship with the measured density was reconstructed. In the last experimental campaign, this was done retrospectively during plasma operation by shifting the laser beam path and a correction was indeed possible. However, not all relevant degrees of freedom had been considered for this proof-of-principle: With two coordinates at the entrance and exit window, respectively, the problem becomes effectively four-dimensional. For future campaigns, the beam path will be varied during the Raman calibration performed at W7-X (the same method would work identically for Rayleigh calibrations) to cover the full range of expected misalignments. In contrast to the conventional Raman calibration, the result will be a four-dimensional function of the beam position at the entrance and exit window. During the actual experiments, the beam positions will be monitored likewise and each density profile will be evaluated with the most suitable calibration factor. While probably not needed for W7-X, vibrations of the observation optics could be included in the same way. This method decreases both the pulse-to-pulse variations and allows for a longer time duration before a recalibration becomes necessary.