Upgrade of the MSE diagnostic at ASDEX Upgrade

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Introduction

The direct measurement of the local field line pitch angle by means of the motional stark effect (MSE) diagnostic observed at several radially spaced locations in the plasma provides invaluable information for plasma equilibrium reconstruction codes like IDE [1], CLISTE or EFIT. The code results are required for the determination of radial positions of and local magnetic shear at rational surfaces (q=1/1, 3/2, 2/1, …) which are indispensable for modeling plasma behaviour and stability. Thus, the "q-profile" (flux surface averaged current density profile) is a highly desired quantity. The validity and hence the quality of the equilibrium code output – the numerical solution of the Grad-Shafranov equation – is strongly improved by using MSE measurements as constraints for the reconstruction of the internal plasma configuration. Thus, accurate and reliable MSE measurements maximize the the equilibrium-based q-profile measurement and hence need to be reliably provided.

Issues and novel ideas for improvement

Due to a recent confirmation of the presence of polarized background emission in medium to high density plasmas [2] the planned refurbishment of the ASDEX Upgrade MSE diagnostic was combined with a qualitative upgrade. Following suggestions by the Alcator C-Mod team for using a multi-spectral line-polarization approach [3] to enable a necessary „polarized background“ subtraction we employ their optical polychromator design (figure 1) with four exit ports and exploit it further by utilizing the high photon throughput of ASDEX Upgrade's MSE optical system.

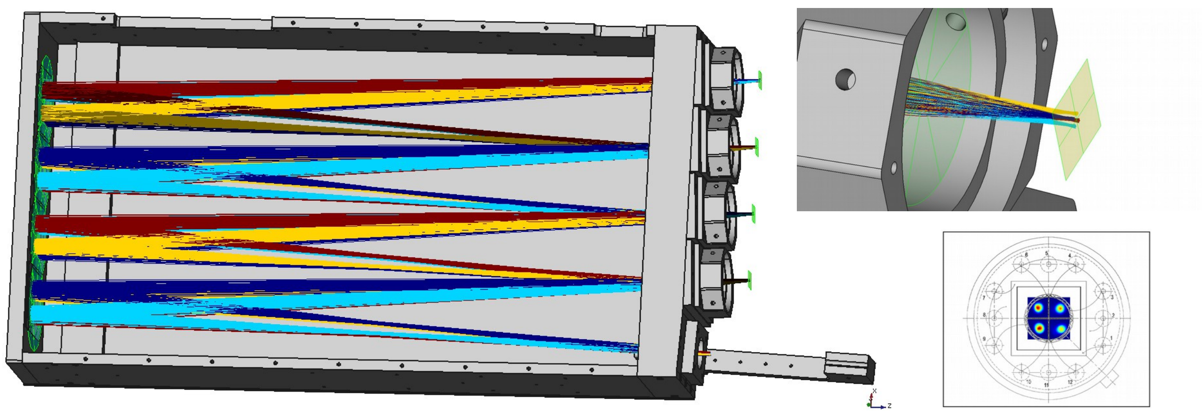

Figure 1: Overview of optical design for AUG polychromator (overview, detail, detector)

According to photon flux estimates, we can measure the local field line angle of 4 separate lines-of-sight on the same polychromator. An industry-procured four-quadrant avalanche photo diode (APD) detector was thus integrated with a pre-amplifier into a custom detector design to optimize for the actual photon flux received by the newly built system and at the same time observe the limits imposed by the measurement principle, which employs very narrow optical bandpass filters to single out certain parts of the MSE spectrum (figure 2).

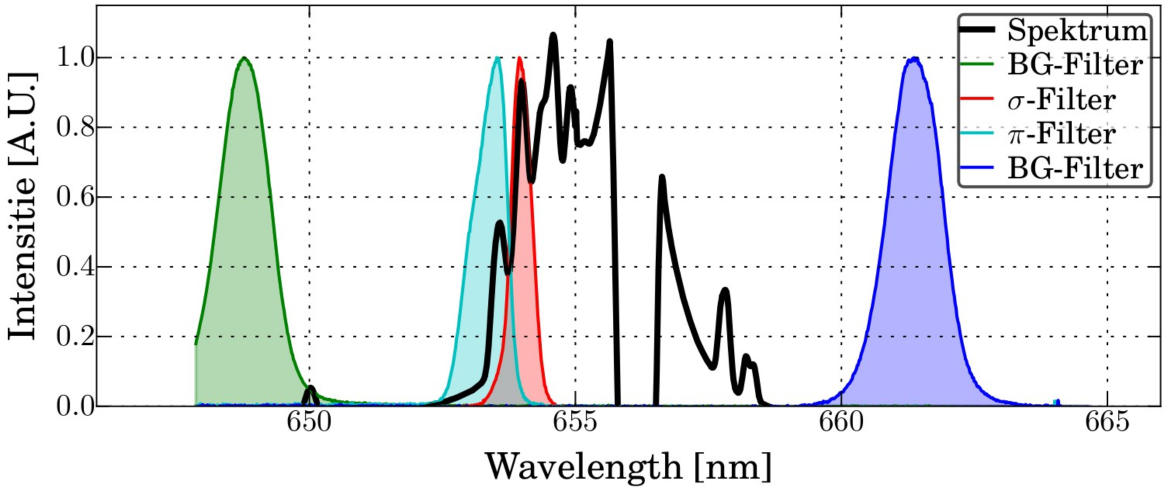

Figure 2: MSE spectrum with illustration of 4 different optical filters and their bandwidth used in the 4 exit ports of the polychromator

The performance of the detectors are sufficient for measuring p and s lines at similar signal-to-noise ratios than with the classic photomultiplier based system, albeit at only half the photon flux (single 1 mm fibre instead of double) which increases spatial resolution.

At the full system scale of 10 radial channels with up to 4 vertically stacked fibres and 4 signals (at π-, at σ- and at two background-wavelengths) per fibre, we could measure up to 160 signals. At this scale, the line polarization technique reaches a resolution of 10x4 pixels in the plasma which is currently only exceeded by so-called IMSE (imaging MSE) systems one of which is also in operation at ASDEX Upgrade and can be compared with the polychromator approach. The slow change of field line pitch from one LOS to the next allows to do cross-checks between adjacent lines-of-sight and validate the proposed method.

Calibration

In order to fully exploit the new detector system, we also made an attempt to absolutely calibrate the MSE diagnostic. First, we improved the usability and accuracy of the in-vessel line-of-sight geometry measurement which provides fundamental information used in relating system angles to field line angles. Any inaccuracy from this measurement would enter as a systematic error into the derived field line angles. Previously, we have measured a white light spot from backlit fibres at 2-3 points along the LOS in the vessel using a 3D metrology system (Nikon MCAx30+ at present) by hand. However, this is prone to making small – often systematic – errors due to the chromatic aberration and sometimes difficult eye-to-hand coordination. The new method uses a coordinate grid on a diffuse glass panel which is backlit with red light (from the correct spectral range) and mounted directly to the measurement arm of the Nikon system. When the measurement of 3D location and orientation is taken by the 3D measurement system, a photo of the mounted and backlit coordinate system is simultaneously recorded by a camera whose view is calibrated in the laboratory. This measurement is fast and accurate and provides many more measurement points per line-of-sight in less time resulting in a statistically approved LOS geometry. Second, we employ an in-house developed setup using Brewster-reflection to generate pure linearly polarized light. At the same time, we measure its orientation and position in the torus such that we can reconstruct the reflecting surface and hence the direction of the vector of polarization with high accuracy. Combined with the accurate LOS geometry this provides the zero reference of the polarimeter system for each line-of-sight. Third, we run system calibrations on each LOS with a rotating polarizer aligned normal to the LOS to calibrate non-linearities arising in the photoelastic modulators and recording electronics. Finally, with an in-vessel backlit fixed polarizer that provides LOS-specific, but constant linearly polarized light to the polarimeter, we can measure the instrument function with respect to strong magnetic fields (from Faraday rotation in a protection window and other optical elements like lenses) for each LOS. In addition, three in-vessel light sources with wire-grid polarizers provide known linear polarization to selected LOSs for long-term system monitoring and validation.

Since the design from C-mod already ensured image preservation at each exit port our main goal for optimization was the separation of light coming from 4 separate fibers into the 4 quadrants of the industry-provided APD chip. The necessary changes – exit port lens with larger focal length and consequently different distance for the detector sensitive area – were easily implemented and lead to (calculated) cross talk below 2% which was confirmed by a camera picture acquired after mounting a CCD chip exactly in the detector chip plane and acquiring an image while backlighting the fibres fed into the polychromator.

First measurements

Plasma discharge #33991 used a density ramp to generate a state where it is known that the classic (no background correction) MSE no longer provides accurate but rather systematically wrong measurements. As can clearly be seen from fig. 3, the measurement in central MSE channels (where beam attenuation leads to the strongest signal drop) is clearly wrong from about 3.0 seconds, while still appearing to be valid (due to much lower statistical noise than deviation from correct measurement angle). Simultaneously, the polychromator picks up background light intensity. However, the detected background photons are either mostly unpolarized or of insufficient quantity to determine the direction of polarization already at moderate background levels.

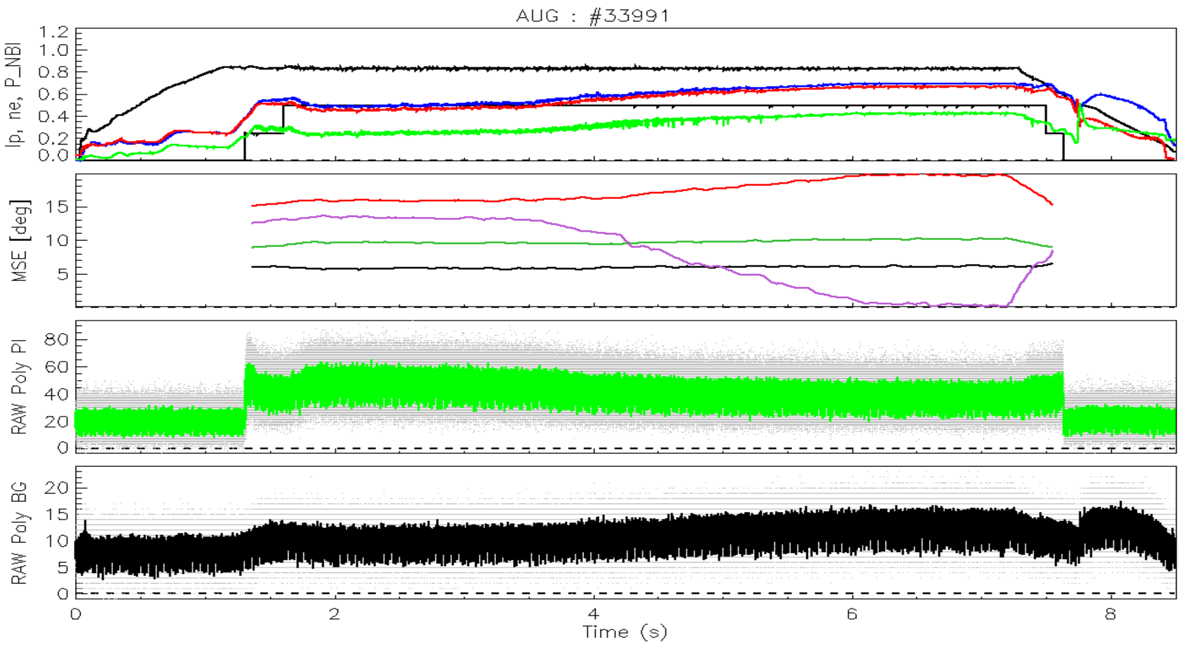

Figure 3: Demonstration discharge, a) plasma parameters Ip, ne and Power[NBI], b) Classic MSE angles, c) polychromator raw PI signal, d) polychromator raw background signal

Conclusions

A single (radial) channel prototype using a single fiber (4 signals at the data acquisition system) has been exposed to plasma light from near the plasma center. Both π and σ channels are measuring angles consistent with radially identical 'classic' PMT-based detectors. The background channels, however, receive only very low light levels. A more sensitive detector type (compared to the APD) may be necessary in order to measure at large enough SNR to be able to determine the polarization state of the background robustly enough for actually correcting the beam induced (but background affected) measurements on σ and π.

[1] R. Fischer et al., „Validation of the ohmic, neutral beam and bootstrap currents ...“, this conference.

[2] A. Bock et al., „Non-Inductive Improved H-Mode Operation at ASDEX Upgrade“, Nuc.Fus, accepted.

[3] R.T. Mumgaard et al., „The multi-spectral line-polarization MSE system on … “, DOI: 10.1063/1.4959793.