Calibration of Thomson scattering density measurements at ASDEX Upgrade

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Accurately measuring plasma parameters is a crucial task in modern fusion research reactors. The electron density is one main parameter to be determined. At ASDEX Upgrade, the Thomson scattering diagnostics (TS) is one of the systems used for this purpose [1,2].

Figure 1 shows the current experimental setup for the core and edge Thomson scattering in red and the interferometry diagnostic (DCN) in blue. The TS diagnostic provides electron density measurements at each of the red points individually, while the DCN diagnostic measures the line integrated densities along the blue lines. In order to determine the density, the TS diagnostic needs an absolute calibration. This is done by Raman scattering in nitrogen. It was observed that after the initial calibration errors due to misalignment emerge in the measurements. However, since the calibration by Raman scattering is time intensive and the vacuum vessel needs to be filled with nitrogen, it is not feasible to do this on a regular basis. Until now, these errors have been corrected by determining and
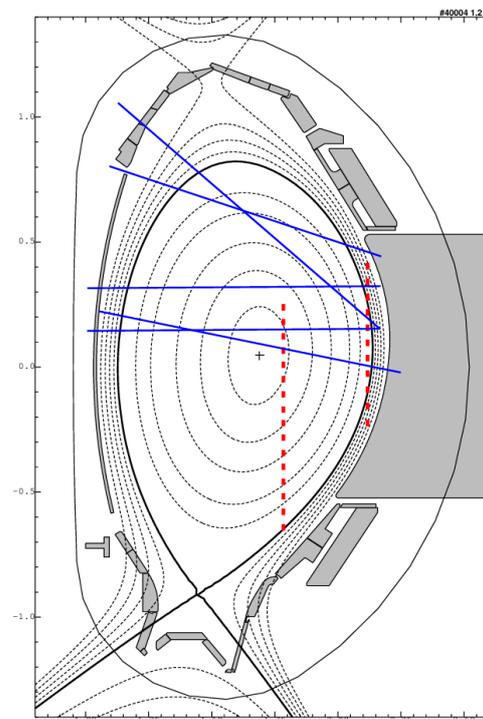

Figure 1: Diagnostic setup at ASDEX Upgrade with the measurement points for density measurements with Thomson scattering in red and the lines of sight for the five interferometry channels in blue.

applying correction factors to each individual measurement channel by hand. In order to further improve the data of the core Thomson scattering system, this work presents two new and reproducible ways of determining correction factors for the Thomson scattering diagnostic at ASDEX Upgrade.

New calibration methods

Neural network approach

As a first approach, a neural network based correction has been implemented. This approach has been developed at W7-X and has been adapted to ASDEX Upgrade in the scope of this work [3]. Since every misalignment position has a specific effect on each channel, the misalignment position can be determined by the error pattern in the profile. To determine similar error patterns an autoencoder neural network was used. A schematic picture of an autoencoder network can be seen in figure 2. For better comparability between different plasma scenarios, only the ratios between 2 adjacent channels starting from channel 0 up to channel 13 are used as inputs for the neural network since the channels close to the plasma edge show large variation due to steep gradients and uncertainties in equilibrium reconstruction. During the training phase, around $55\,000$ profiles are given to the network. The encoder reduces the dimension of the input to the size of the middle layer. The decoder then tries to recreate the original profile from the abstract representation given by the middle layer. By reducing the dimension of the input data, the neural network learns to represent the unique features of each profile in an abstract space. Profiles with similar characteristics are therefore close to each other in this representation. In order to further reduce the level of noise and only correct for errors due to misalignment the 30 closest profiles by Euclidean distance in the reduced representation are grouped into a cell and are averaged
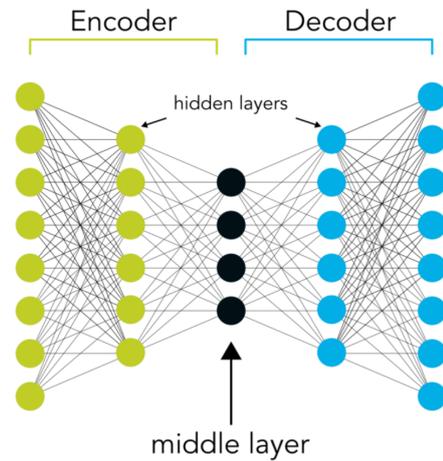

Figure 2: Schematic picture of an autoencoder network. The dimension of the input data is reduced to the size of the middle layer.
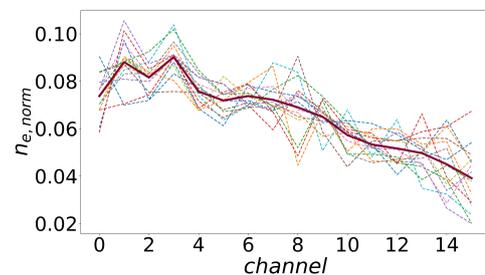

Figure 3: Example of a calibration cell with the corresponding generalized profile given by the continuous red line.

to get a generalized profile. Each cell represents a misalignment position in the diagnostic. An example of a cell and the corresponding generalized profile can be seen in figure 3. The last key step is to determine the correction factors for each cell. Generally, the correction factors are found by the ratio of the generalized profiles of a given cell and the "correct" cell, which corresponds to the alignment during the Raman scattering. In order to find the "correct" cell 200 test profiles are corrected assuming each cell as the "correct" cell once. The corrected profiles are then fitted with a smooth polynomial. The cell corresponding to the set of corrected profiles

with the lowest mean squared error is then chosen as the "correct" cell. In order to correct for the errors in a given density profile, the abstract representation is calculated using the trained neural network, and the correction factors of the closest cell are applied to each channel.

Reference discharge method

Figure 4 shows the shot numbers of profiles in three example cells. It can be seen that profiles from similar times also show similar error patterns. Since the misalignment does not change rapidly in time as a second correction approach, a traditional reference discharge method was implemented. Here the corrections are determined during a standard H-mode discharge, which is routinely performed at ASDEX Upgrade. This is done by fitting a smooth polynomial function to the average electron density profile measured in a 150 ms time interval in the L-mode phase at the beginning of the discharge. Figure 5 shows an example of the measured profiles (dots), their average (blue) and the corresponding fit function (orange). Since the uncertainties in the profile close to the plasma edge are very large due to steep gradients and uncertainties in the equilibrium reconstruction, the two outermost channels are not used to determine the polynomial fit. The correction factors for each channel are simply calculated by dividing the fit function at the point of the measurement by the average density value of the channel. The set of correction factors is then used for all subsequent discharges until the next standard H-mode.
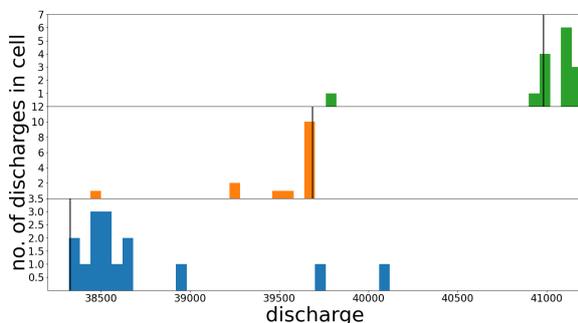

Figure 4: Histogram of the distribution of the discharge number within a cell for three different cells. The black vertical line indicates the discharge number of the center of the cell.
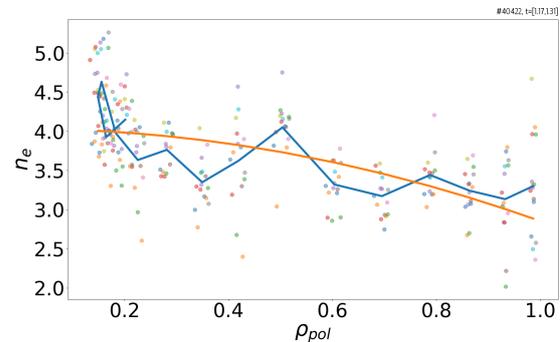

Figure 5: Calculated fit function (orange) assuming a polynomial of degree two. The blue line indicates the calculated mean electron density in the considered time frame.

Comparison of correction methods

To evaluate the quality of the corrected density profiles integrated data analysis (IDA) was used [4]. IDA uses a combination of diagnostics including interferometry and Thomson scattering to calculate the most likely density and temperature profile. Furthermore the residua for the different diagnostics are calculated, which describe how well a measurement from one diagnostic fits to the calculated IDA profile. To compare the different correction methods IDA calculations have been conducted using the corrected Thomson scattering profiles from the various methods while keeping the other inputs unchanged. Afterwards the residuum for both

interferometry and TS are compared, since smaller residua for both independent diagnostics at the same time indicate a better agreement between the two. As mentioned before, both new correction methods use a polynomial fit function to determine the correction factors in some way. However since the correct shape of the profile is unknown, various fit functions can be used. In this work a polynomial of degree 2 and degree 4 have been tested. Figure 6 shows an example of the residua for the TS and interferometry using different correction methods. It can be seen that especially in the core region, the residua for the TS are reduced the most when using the reference discharge method and a fit function of degree 2. Table 1 lists the average sum of the squared residua for the Thomson scattering and DCN diagnostic for 27 randomly chosen analyzed discharges. It can be seen that the agreement between TS and interferometry is increased for both new methods when assuming a polynomial of degree 2 as a fit function with the best results coming from the reference discharge approach.

	old	reference 2	reference 4	NN 2	NN 4
TS	185.91	131.57	139.57	175.27	224.72
DCN	19.06	16.81	21.64	16.62	18.14

Table 1: Average sum of squared residua for the Thomson scattering (TS) and the interferometry (DCN) diagnostic calculated using IDA for 27 randomly chosen discharges.
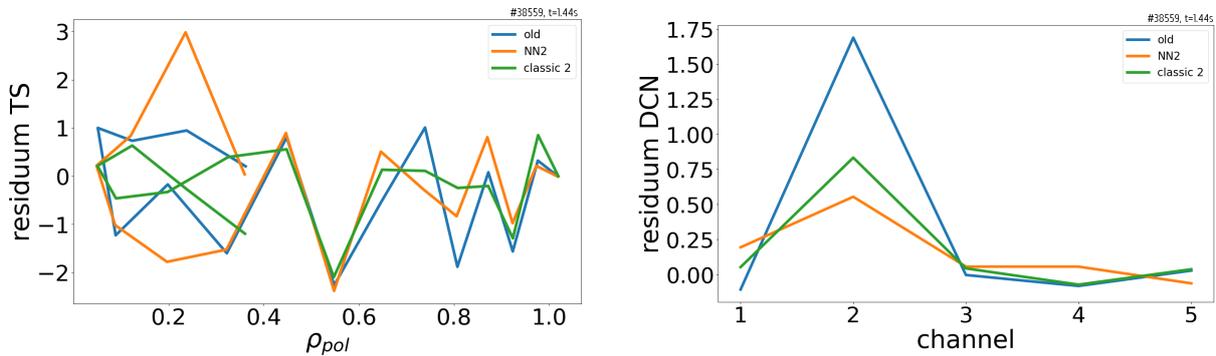

Figure 6: Residua for TS diagnostic (left) and DCN (right) calculated by IDA corrected TS data using the old (blue), neural network (orange) and reference discharge method (green) assuming a polynomial of degree 2 as a fit function.

References

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