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Optimization of the relative calibration for a visible bremsstrahlung Z_{eff} diagnostic on TEXTOR via requirements of profile consistency

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The bremsstrahlung Z_{eff} diagnostic

On TEXTOR a new diagnostic was commissioned for the determination of the ion effective charge Z_{eff} from bremsstrahlung emissivity measurements in the visible [1]. The line-integrated bremsstrahlung emissivity is measured along 24 lines of sight within a single poloidal cross-section. The total field of view is indicated by the red lines in Figure 1. The light from the plasma is passed through an interference filter, selecting a narrow wavelength band in the visible that is free of line emission on TEXTOR. The light from the 24 channels is then focused on a CCD array. From the measured bremsstrahlung line-integrals, a radial bremsstrahlung profile is reconstructed using (regularized) Abel inversion. Together with profiles of electron density and electron temperature, Z_{eff} profiles can be calculated.

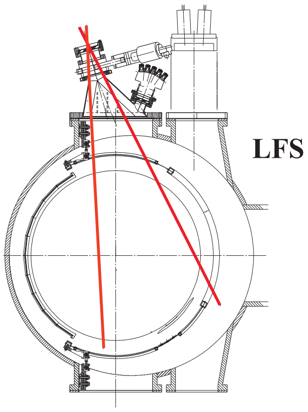

Figure 1: The viewing geometry of the bremsstrahlung system.

Calibration of the camera system

The absolute calibration of the camera system was performed by taking an integrating sphere inside the TEXTOR vessel. This calibration is a delicate operation, requiring the careful design of a dedicated calibration set-up. Access to the tokamak vessel is needed, or the fibre support at the TEXTOR side has to be dismounted to position the integrating sphere in front of the fibres.

In order to avoid the disadvantages of a calibration using an integrating sphere, an alternative calibration method was devised. This alternative technique also allows the optimization of an existing calibration. First, the relative (channel-to-channel) calibration of the system was assessed, based on the requirement of consistency of line-integrated bremsstrahlung profiles during horizontal shifts of the plasma column. Here, in principle the plasma is used as a calibration light source. For two channels, say A and B, the principle of the method is the following. Suppose A and B measure along the same physical line of sight through the plasma. We call the two corresponding measurements with the camera m_A and m_B, respectively, both expressed in analog-to-digital units. Either measurement should, apart from any measurement error, lead to the same line-integrated emissivity L_{ff}:

$$L_{\mathrm{ff}} = \frac{m_A}{a} = \frac{m_B}{b}. \tag{1}$$

Here, a and b are the calibration factors associated with channels A and B, respectively. If a is fixed to an arbitrary value, then the relative calibration of this two-channel system can be calculated. This procedure can be repeated for the other channels, and eventually the complete relative calibration of the 24-channel system can be assessed.

In practice, the question rises how to feed the same physical line-integral L_{ff} to different channels. Here, we assume that the line-integrated emissivity profile is sufficiently smooth. In this case, the relative calibration factors can be estimated as follows. The line-integrated bremsstrahlung emissivities along the 24 channels are measured in two discharges with very similar plasma parameters (which we assume to be identical), but with a relative shift H in horizontal plasma position. In practice a few cm is sufficient, while H is taken positive when the shift is towards the high field side of the machine. This results in two sets of measurements (m_i, respectively n_i) along two chord fans with different intercepts on the equatorial plane, relative to the plasma[1], (b_i, resp. $b_i + H$, $i = 1\ldots24$), but with the same calibration factors c_i. Every measurement m_i, resp. n_i, corresponds with a calibrated line-integral $M_i = \frac{m_i}{c_i}$, resp. $N_i = \frac{n_i}{c_i}$. The M_i are now interpolated as a function of intercept using a curve $f(b)$. Alternatively, we may use a low order polynomial fit, which is less biased towards individual points $M_i(b_i)$. The latter is particularly useful in the case were the number of channels within the field of view is relatively low. In both cases, to a good approximation, the following equalities should hold:

$$N_i = f(b_i + H), \quad i = 1, \ldots, 24. \tag{2}$$

These equations simply express the fact that in both cases the same line-integrated profile was measured. To avoid extrapolation of the emissivity profile, and depending on H, the equations for some outer channels are not taken into account. In the case of linear interpolation of the line-integrated emissivity profile, the calculation of the relative calibration coefficients amounts to the solution of a system of linear equations. The shift H should then not be too large, otherwise the system may become unsolvable.

Figure 2(a) gives a visual representation of equations (2). The geometry is shown of a line of sight, viewed by channel k, under a plasma shift H towards the high field side. In the figure, the plasma is depicted stationary, and instead an equivalent shift of the line of sight is shown. The blue line represents the chord C_k (intercept b_k) viewed by channel k before the shift has

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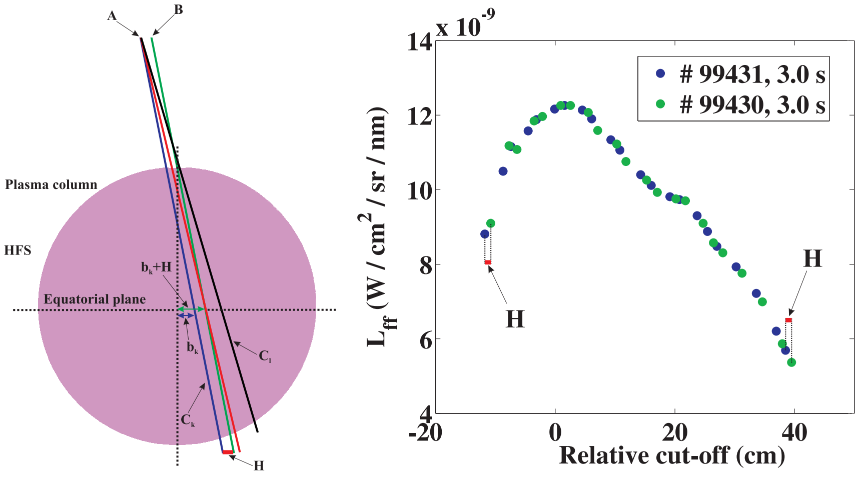
[1] Naturally, the intercept relative to the machine does not change under a plasma shift.

occurred. The black line is a second, adjacent chord C_l viewed by another channel l. These channels view a physical line-integrated emissivity M_k, resp. M_l. The green line depicts the line of sight viewed by channel k, after the shift has occurred (intercept $b_k + H$, relative to the plasma). Channel k now views an emissivity N_k. Next to a shift in intercept, there is also a shift of observation point (A to B), relative to the plasma. The red line represents the line of sight for a fictitious channel, with associated emissivity $f(b_k + H)$, resulting from the fitting or interpolation process of the initial set of line-integrated emissivities M_i. The intercept for the red chord is the same $(b_k + H)$ as for the green chord. Now, according to (2), N_k and $f(b_k + H)$ should be equal. However, it can be seen in Figure 2(a) that this is in reality not entirely true. On the other hand, it is also clear that in the present geometry, the difference δ in emissivity viewed by the red and the green chord, is relatively small. Simulations with a typical radial bremsstrahlung profile show that δ is typically a few percent or less of the emissivity along the shifted (green) chord. Therefore, it is allowed to neglect the shift of observation point relative to the plasma.

Up to this point, only the relative calibration of the channels was assessed. Indeed, if a set of calibration factors c_i is found that satisfies (2), then it is easy to see that also the set $a \cdot c_i$ will satisfy these equations, for an arbitrary factor a. Although the relative calibration on its own already allows the reconstruction of relative Z_{eff} profiles on an arbitrary scale, an absolute calibration is required for the assessment of absolute impurity concentration levels. The full absolute calibration can be fixed by the calibration of a single channel with an integrating sphere. This requires only a reduced experimental set-up, as compared to the calibration of all channels with the sphere.

Figure 2(b) concerns a preliminary result of this approach. The line-integrated bremsstrahlung profiles are shown for two similar discharges with a relative horizontal plasma shift of 1 cm towards the high field side (from # 99431 to # 99430). The bremsstrahlung emissivity is plotted against the intercept b, relative to the plasma. The profiles were calibrated by the calibration factors that were calculated via linear interpolation of the starting profile. There is a good correspondence between the two profiles, implying that the equations (2) are well satisfied. The outermost channels at both sides were discarded, since the corresponding calculated calibration factors were not satisfactory. The absolute calibration was determined from the calibration of a centrally pointed channel using the integrating sphere. The thus determined calibration yields physically acceptable radial Z_{eff} profiles. Preliminary simulations using a known radial bremsstrahlung emissivity profile, show a good accuracy of the retrieved calibration. Future simulations and experiments are planned to estimate the error bars of a set of calculated calibration



(a) (b)

Figure 2: (a) The geometry of a chord during a horizontal plasma shift. (b) The calibrated line-integrated bremsstrahlung profiles resulting from the requirement of profile consistency under a horizontal plasma shift H. H is indicated in the figure for two channels.

factors.

Conclusion

An alternative technique for the relative calibration of the bremsstrahlung Z_{eff} system was proposed. A satisfactory calibration can be obtained from the requirement of consistency of line-integrated bremsstrahlung emissivity profiles during a horizontal plasma shift. The absolute calibration of the system then comes down to the absolute calibration of one of the channels.

The here outlined relative calibration method is of general applicability, and provides a simple and self-consistent way for the relative calibration of any multi-channel spectroscopic diagnostic. It can in principle be carried out at any time, without requiring access to the tokamak vessel itself or the establishment of a calibration set-up. Since the plasma acts as a calibration light source, no specialized light sources are needed for the relative calibration. This is a considerable advantage, especially in the case of spectroscopy outside the visible range. In addition, this method provides a valuable way for the check or optimization of an existing relative calibration.

References

[1] G. Verdoolaege, G. Telesca, E. Delabie, G. Van Oost, and the TEXTOR team, Rev. Sci. Instrum. (2006), accepted for publication.