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Progress on the MSE Diagnostic for ITER

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Introduction.

The Motional Stark Effect diagnostic is now considered as an essential diagnostic for an accurate determination of current profiles in tokamak discharges. For this reason, this diagnostic is implemented on most of the existing machines. It mainly allows a measurement of the direction of the total magnetic field, a very powerful constraint for the determination of the safety factor profile. On ITER, the knowledge and the control of current profiles will be of crucial importance to realise the long-lasting, high-performance discharges. This is why it was proposed [1] to install a MSE diagnostic on one of the heating beams.

The realisation of such a diagnostic on ITER implies to face new challenges, because of the bigger size of the machine and of its hard environment. Now, most of the foreseen difficulties have been examined, solutions envisaged, and we propose to review them in this paper.

I. Principle of the diagnostic and feasibility at higher Lorentz Electric Field.

The MSE diagnostic observes the line radiation, usually the D_α, emitted by a fast beam of neutrals propagating (with velocity v) through the plasma discharge. In the presence of a magnetic field B, the radiation is split into several components equally separated in frequency (first order Stark effect). These components have a polarisation either parallel (π components) or perpendicular (σ components) to the Lorentz electric field (F= v x B), when observed transversally. The spectrum is also Doppler-shifted due to the beam velocity, which allows a separation of the lines emitted by the neutral beam, from the intense edge D_α lines.

The first question addressed concerns the feasibility of the method for the higher value of the Lorentz electric field. For ITER heating beams, as the magnetic field and the velocity of the beams increase (*1 MeV*), the Lorentz electric field is almost one order of magnitude higher than in the existing machines, and thus the Stark quadratic term needs to be added in the calculation of the excited states of the hydrogen atom.

It was verified [2] that for the values of the electric field expected for ITER, the addition of the quadratic term does not modify significantly the position of the emitted lines, but induces just a slight shift towards the negative energies (or wavelengths), and a split of the central σ_0 line (due to a removal of degeneracy by the quadratic term). There is no mixing between the σ and π lines.

A recent calculation of the lines intensity with the quadratic term using results from [3] shows that the low frequency component (right of σ_0) is slightly reduced, as the high frequency component (left of σ_0) is slightly increased.

The variation due to the quadratic term is more important for the lines with smaller intensity. For instance the correction is 10% for σ_5 or σ_6 lines, 4% and 5% for π_3 and π_4, but only 2% for σ_1 and π_2, the correction being positive for the high frequencies and negative for the low frequencies. This is illustrated on figure 1 where the calculation was done for illustrative reasons for an electric field three times higher than the maximum values expected for ITER.

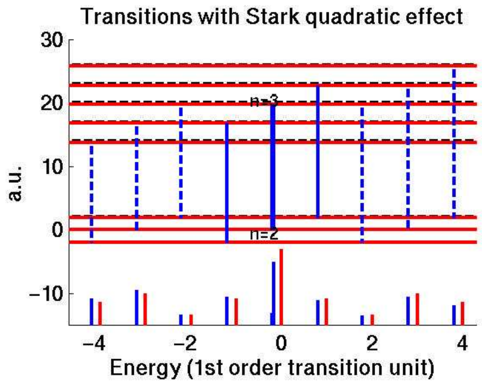


Figure 1 *Hydrogen atom energy levels n= 3 and n=2 with linear (dashed lines) and quadratic (solid lines) Stark effect (horizontal lines), and the corresponding transitions (vertical lines sigma in solid and pi in dashed lines), for E_L= 21.10^7 V/m. The bottom of the figure shows the energy position of the lines and their relative intensities, with the red lines corresponding to the first order Stark effect and the blue lines to the 2° order effect.*

The possible ionisation of D^0 atoms by the high Lorentz electric field was also considered [2]. No quenching nor direct attenuation of the D_α line is expected, but a slight attenuation of the neutral beam could be due to the ionisation of the atoms having their electrons going to energy levels higher than n=5.

Since no mixing between the σ and π components is expected, as well as only a slight variation in line intensities compared to the usual first order Stark effect, it is clear that the polarimetry method can still be applied on the heating beams.

II. Spatial and time Resolution of the diagnostic.

Detailed calculations [4,5] on the diagnostic spatial resolution showed that in addition to the allocated e-port3 from where edge measurements could be done, a second equatorial port was required to extend the diagnostic coverage to the plasma core. A recent review of the port allocations by the ITER International Team has now attributed e-port1 for the core MSE diagnostic [10]. With this new configuration, which is a compromise with other diagnostics requirements, the q profile can be determined with a spatial resolution better than 15 cm for almost all plasma radii (figure 2). Since each diagnostic is viewing a different beam, the presence of two heating beams is necessary to measure a full MSE profile.

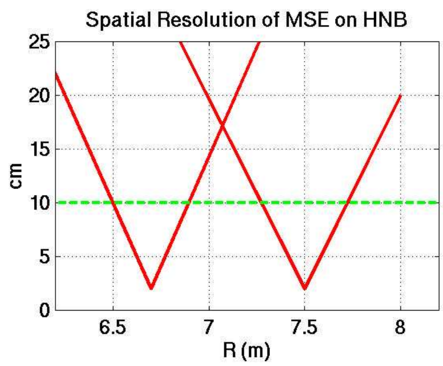
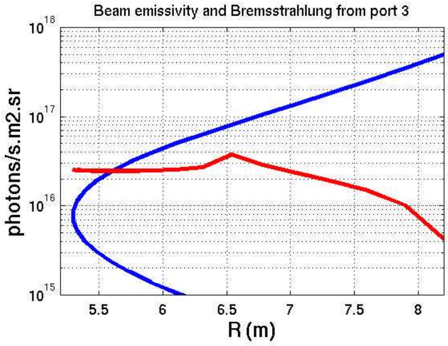


Figure 2 *Diagnostic spatial resolution as a function of plasma radius, combining edge and core MSE systems. The green line represents ITER measurement requirements.*

Calculation of the heating beam emissivity [4] (in blue on figure 3), compared to the plasma Bremsstrahlung (in red) considered as the major source of noise for MSE, indicates when compared to the existing diagnostics, that a measurement time resolution of 20 ms is possible.



The high Lorentz electric field, consequence of the high beam velocity, will induce a clear separation between the σ and π lines of the Dα spectrum [4,5], so that a high polarisation fraction of the signal is expected. JET observations of C, Be, and He lines indicate that no parasitic plasma line will interfere with the spectrum [5]. A correct elevation of the diagnostics in the ports will avoid a direct view of the other beams, which could interfere in the measured spectrum otherwise [7].

Figure 3 *Beam emissivity (blue) and plasma Bremsstrahlung (red) as a function of plasma radius.*

The first calculations [11] of the plasma radial electric field compared to the Lorentz electric field values show that its influence on the MSE angles is negligible in most plasmas scenarios. If this is confirmed, the important consequence is that the MSE measurements will not have to be corrected by measurements from other diagnostics [4]. On the other hand, this comparison combined with the difficulties of installing other views of the same plasma volume on the machine, reveals that a direct measurement of the radial electric field with the MSE diagnostic seems very difficult.

III. The light collection system.

A design of the light collection system has been done using ray tracing to define the positions of the optical components. Four mirrors at least are necessary, with a W-shape of the light path, to minimise the neutrons flux escaping from the machine through the optical channel [7]. Because of the thermal load and neutrons flux in the machine, the first two mirrors will probably be metallic, while the other ones are likely to be dielectric mirrors.

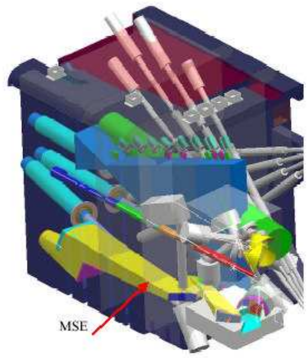


Figure 4 *MSE design in e-port 1*

Up to now, the MSE systems were designed with one mirror only. As the multi-reflections are known to alter the direction of the initial polarisation to be measured, it was important to prove that the MSE measurements could still be done. For this, laboratory experiments using the same geometry as in the ITER present design, and using the usual detection technique with modulators, were done in parallel with calculations using Mueller matrix formalism.
They show [8] that the modification of the initial angle after reflections on four Rhodium mirrors is lower than 2°, and that the additional circular polarised fraction stays below 20%. This small variation should be easily compensated by a correct calibration of the system. In addition, this effect can be minimised by an optimisation of the labyrinth design so as to keep the light incidence angles on the mirrors as low as possible (even if one mirror must be added), by using mirror symmetries, and by the choice of an adequate metal for the mirrors.

It is also expected that the first mirror will suffer from erosion and particles depositions. The induced variations of the mirror optical properties will be another cause of polarisation modification. To evaluate the influence of the first mirror coating on the MSE angles, a model was developed in which the polarisation modification was computed as a function of C or Be layers thickness [7]. In parallel laboratory measurements on plasma exposed mirrors were done and the results were compared to calculations using one or two interfaces models for the mirrors [6]. Both simulations show that the initial angle can be modified by several degrees depending on the characteristics of the coating. For the moment the rate of impurity deposition was not estimated, but to cope with these effects, it is important to imagine in-situ calibrations of the diagnostic during the design, which could be for instance performed easily between shots. In the same way mirror laser-cleaning techniques must be developed. Real time check-up techniques, as the simultaneous measurement of σ and π components, should also be envisaged. This promising method already tested on JET [5] could bring additional information on the mirror system degradation, or be used to detect when MSE measurements become not reliable (during strong Elms…) [6].

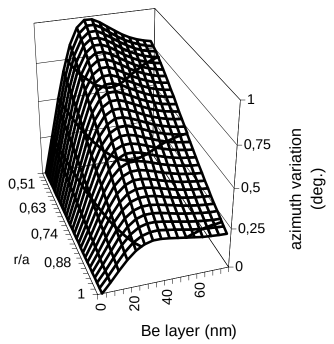


Figure 5. MSE angle modification as a function of Be layer thickness and plasma normalised radius.

A third cause of modification of the MSE angle could be due to the neutral beam itself. Because of the height of the neutral beam source the accelerator is composed of four vertical segments focussing at the same point. The MSE measurement is then an average between the different beamlets contributions, with up to 3.5° difference in the measured polarisation angle from different parts of the ion source [5]. For reliable MSE measurements it would be important that the ion source remain highly uniform (this is, in any case, a design goal of the heating beams). The beamline calorimetry potentially provides a method of monitoring source uniformity.

In parallel to MSE on the heating beams, MSE using the σ/π ratiometry method is proposed on the diagnostic neutral beam as a complement to charge exchange measurements [9]. Calculations indicate that the chosen ports for this diagnostic allow a high sensitivity to σ/π ratio and thus to the q-profile modification. This method has similarly to face ratio modifications due to multi-mirror and coating [7], and its calibration is also of crucial importance. A proof of principle of this method is envisaged on TEXTOR.

The use of both methods should result in a performing MSE diagnostic, with a cross checking of the measurements when possible.

Conclusions

Several important issues concerning the diagnostic feasibility have been examined. No serious difficulty remains. The more crucial point, as in the present MSE systems, will be the calibration of the diagnostic, and a particular care must be given to it during the design.

References:

[1] F. Levinton et al. Task agreement D323. Final report (Oct. 1997).
[2] Ph. Lotte et al. EPS 2002, Montreux, Switzerland.
[3] A. Kamenski, V. Ovsiannikov J.Phys.B, Atom Mol. Phys. Vol 33, p491, p5543, 2000
[4] Ph. Lotte. Final Report of EFDA Contract 02-1003, June 2004
[5] Nick Hawkes. Final Report of EFDA Contract 02-1005, March 2004
[6] M. Kuldkepp et al. HTPD conference 2004. San Diego.
[7] A. Malaquias et al. HTPD conference 2004. San Diego .
[8] E. Rachlew, M. Kuldkepp. Final Report of EFDA Contract 02-1006, Jun e 2004
[9] M. von Hellermann. Final Report of EFDA Contract 01-649, December 2003
[10] C. Walker et al. 6th ITPA on diagnostics. Naka. (Japan).
[11] R Budny. PPPL. (USA). Private communication.