MSE measurements during RI mode on TEXTOR-94.

T. Soetens[1,3], R. Jaspers[2] and E. Desoppere[1]

[1]Department of Applied Physics, University of Gent, Rozier 44, B-9000 Gent, Belgium.
[2]FOM-institute for Plasma Physics "Rijnhuizen", Nieuwegein, The Netherlands[*]
[3]Laboratoire de Physique/Laboratorium voor Plasmafysica, ERM/KMS,EURATOM Association, B-1000 Brussels, Belgium[*]

1. The MSE diagnostic.

To explain confinement in tokamak plasmas, knowledge of the magnetic configuration is indispensable. However, measuring magnetic and electric fields in the interior of the plasma is not trivial. Diagnostics using the motional Stark effect (MSE) have proven to provide reliable results[1,2]. It has also been shown that the MSE diagnostic can successfully measure the radial electric field as well[3,4].

Due to the high velocity of the neutral beam atoms (v) in the magnetic field (B), a Lorentz electric field (E_L) is experienced. The plasma creates a radial electric field (E_R) as well to achieve radial balance. The total electric field (E) is given by:

$$\vec{E} = \vec{E}_L + \vec{E}_R = \vec{v} \times \vec{B} + \vec{E}_R.$$

Neutral hydrogen spectra exhibit a Doppler shifted Stark splitting because of this electric field acting on the beam atoms.

The toroidal magnetic field is essentially proportional to the measured electric field, and thus to the spectral distance between the π components of the Stark multiplet. The ratio between the toroidal and the poloidal magnetic field is determined by the polarization angles of the Stark multiplet. Taking full and half energy into account, the radial electric field can be determined with a limited accuracy.

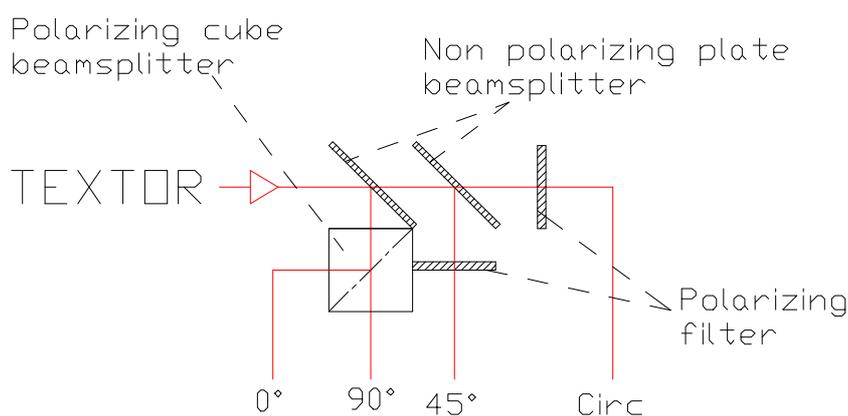Most large tokamak machines have an MSE diagnostic installed, making use of

Fig. 1: Schematic view of the motional Stark effect diagnostic. The light emitted by the neutral beam atoms is divided into four beams with a different known polarization.

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[*] Partner in the Trilateral Euregio Cluster (TEC)

dynamic polarimetry. This technique measures intensity modulations induced by photo-elastic modulators. A Stark component is selected with an interference filter.

A prototype of an MSE diagnostic has been built on TEXTOR-94, making use of static "spectral" polarimetry (see fig. 1, prev. page). The light emitted by the atoms of the neutral heating beam is divided into four beams with a different known polarization (0°, 45°, 90° and circular polarization). The intensity of the four signals gives us a means to reconstruct the polarization, described by the Stokes parameters[5,6].

The main advantage of the static "spectral" polarimeter on TEXTOR-94 is the availability of the complete spectrum. This allows us to calibrate the position of the observation volume during measurements (using the Doppler shift), to measure absolute values for the magnetic field (using the Stark splitting) and to perform a consistency check (using the 3 beam components). We also profit from the fact that MSE measurements can be done with different beam species and velocities, without altering components in the diagnostic. Finally the possibility exists to perform an in situ calibration of the optical system[5].

All these advantages make the MSE diagnostic on TEXTOR an autonomous magnetic diagnostic.

The H_α (D_α) line has been selected for the MSE measurements, because this line is in the visible range, where the spectrometer is active. Typical MSE signals and consecutive results are shown in figures 2 and 3.
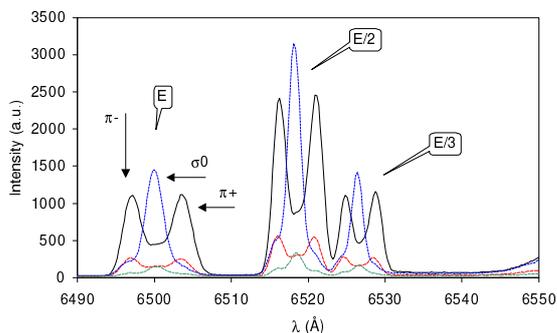

Fig. 2: Spectra, measured with the MSE diagnostic on TEXTOR-94 for one line of sight. The beam components are well separated, as are the Stark peaks. We need four measurements to trace the Stokes parameters.
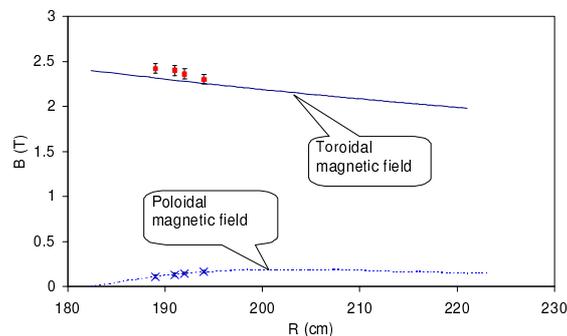
Fig. 3: Toroidal and poloidal magnetic field profiles. The toroidal magnetic field is inversely proportional to the major radius, the poloidal magnetic field is calculated from a quadratic current profile. The measurements from fig. 2 yield the markers.

2. Consistency measurements.

Because the currently installed MSE diagnostic of TEXTOR was meant only for testing the static spectral polarimetry principles, it was not fully optimized. Four channels placed close together inhibit measuring a full profile. A bad radial resolution (± 5 cm) because of the beam width renders a precise q profile measurement impossible. However, we can check whether MSE results are consistent. Therefore we applied controlled changes to a standard L mode plasma ($B_{\phi 0}$=2.25 T; I_P=350 kA; n_e=2.5 10^{13} cm^{-3}). Simulations have shown that the most effective change at the current position of the MSE diagnostic is a

change in horizontal position of the plasma. It was possible to displace the plasma 3 cm to the low field side and 2 cm to the high field side, without initiating a disruption. We can see in figure 4 that the MSE measurements follow the poloidal magnetic field profiles correctly.
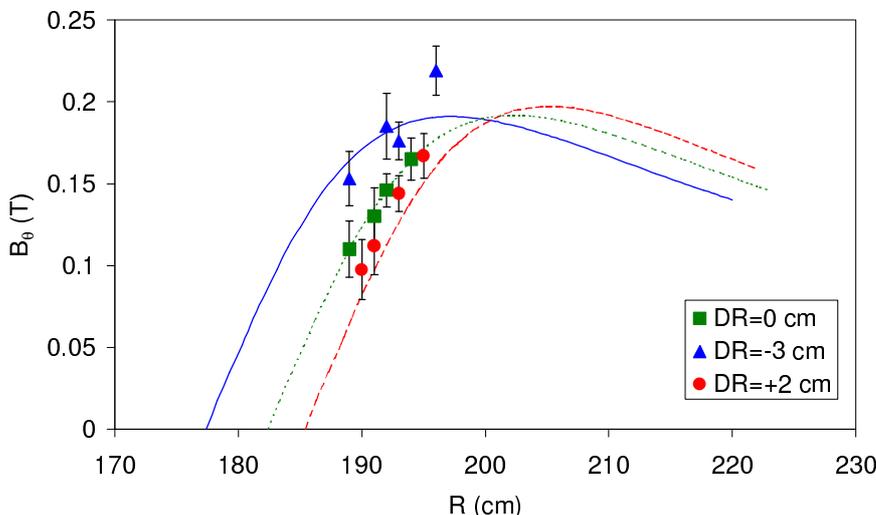

Fig. 4: MSE results for horizontally displaced plasma. We notice that the measurements follow the imposed poloidal magnetic field profiles very well.

3. RI mode.

It has been shown On TEXTOR-94 that a very good confinement regime (RI mode) can be achieved by injecting a small amount of impurities at the edge of the plasma. Radiative dissipation of energy cools the edge of the plasma; this results in a decrease of the current in this region. Because the total current is kept constant externally, the current is expected to be more concentrated in the centre of the plasma[7]. A model by Tokar explains RI mode making use of the hypothesis that the product of the safety factor and the electron density qn_e is constant over the major radius[8]. This hypothesis can be checked directly with an MSE diagnostic.

Polarimetric measurements have shown that in RI mode the centre of the plasma moves to the low field side because of the increased Shafranov shift and the central safety factor decreases. Using a quadratic current density profile with typical values (δ_0=6 cm, q_0=0.8 for normal
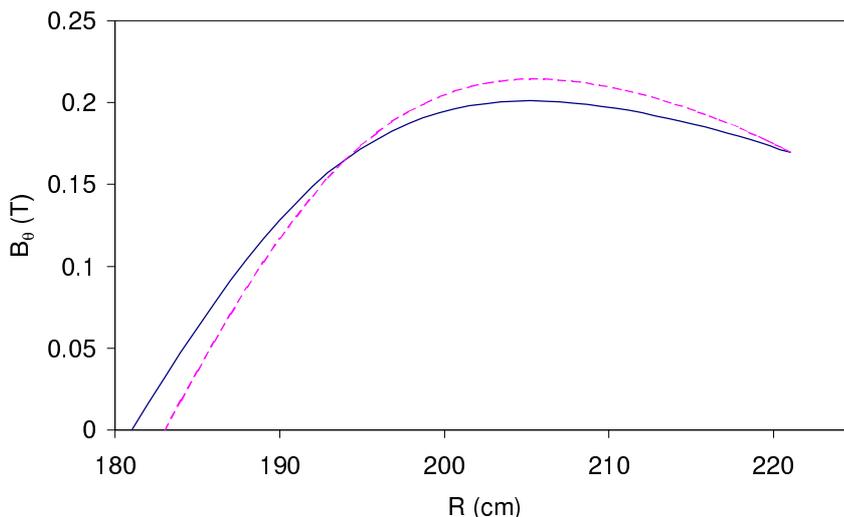

Fig. 5: Magnetic field profiles for normal and improved operation. The full line represents normal operation (d_0=6 cm; q_0=0.8) and the dashed line represents improved operation (d_0=9 cm; q_0=0.7).

operation; δ_0=9 cm, q_0=0.7 for improved operation) we generated the poloidal magnetic field profiles in figure 5 (prev. page).
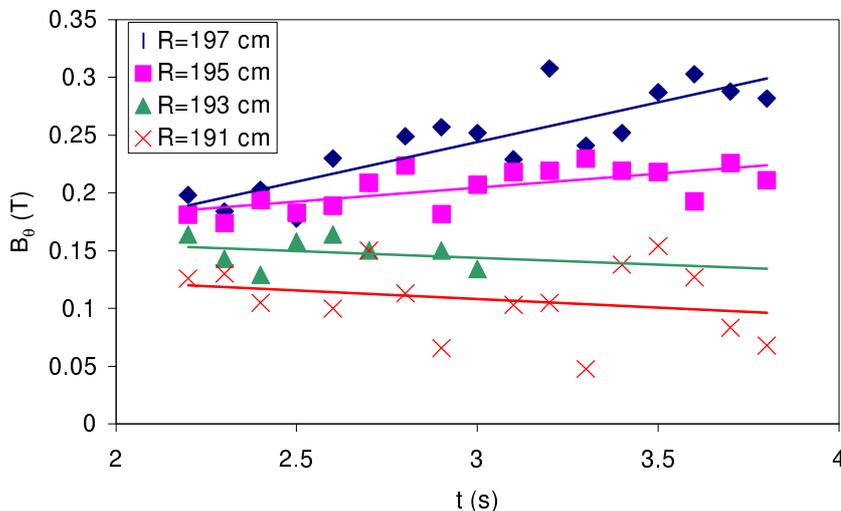

Fig. 6: *Timetraces for the poloidal magnetic field for the different channels of the MSE diagnostic. We can see that the signals for the channels on the low field side rise, while the signals for the channels on the high field side decrease.*

In the discharges we analysed, the central electron density varied linearly from 5 to $8\ 10^{13}$ cm^{-3} in the period when the neutral beam was active (2 to 4 s). Notice the point in figure 5 where the two profiles cross. More to the low field side the poloidal magnetic field will rise, to the high field side the poloidal magnetic field will decrease. This is in agreement with the MSE measurements (see fig. 6).

4. Conclusions.

We have constructed a Motional Stark Effect diagnostic on TEXTOR-94 using static "spectral" polarimetry. The availability of the complete spectrum allows us to calibrate the position of the observation volume during shots, to measure absolute values of the magnetic field and to perform a consistency check.

Changes applied to the plasma are followed by the MSE measurements. Horizontal displacement of the plasma proved the consistency of the diagnostic.

Modifications of the poloidal magnetic field profile were induced by increasing the density during an RI mode discharge up to $8\ 10^{13}$ cm^{-3}. This caused the centre of the plasma to move to the low field side and the profile to steeper. These characteristics were also visible in MSE measurements.

Based on the measurements done so far with the MSE diagnostic on TEXTOR-94, a new diagnostic is now being designed, which scans the full profile and of which the accuracy and the radial resolution will improve.

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