# DIAG-9 Spectral MSE (MSE-LS) experiments as design driver for ITER MSE

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| **TG priority:** Critical | **Start date:** 2015 | **Status:**  On-going | **Personnel exchange:**  No |
| **IO priority:**   | **End date:** Not fixed | **Motivation:** Plasma Control |

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| **Device /****Association** | **Contact****Person** | **2016 TGRequest** | **Activity (from JEX/JA spreadsheet)** |
| **2015** | **2016** | **2017** | **2018** | **2019** |
| ITER  | M. De Bock | Desirable |   |   |   |   |   |
| JET  | N. Hawkes | Desirable | Considering |   |   |   |   |
| DIII-D  | K. BurrellL. Lao | Desirable | Analysis |   |   |   |   |
| C-Mod  | S. ScottW. Rowan | Desirable | Committed |   |   |   |   |
| AUG | TBD | Desirable | Considering |   |   |   |   |
| KSTAR | J.-S. Ko | Desirable | Upgrade |   |   |   |   |
| NSTX | B. StrattonF. Levinton | Desirable | Not doing |   |   |   |   |

**Motivation**

Conventional MSE based on line polarisation measurement (MSE-LP) is likely to be extremely challenging on ITER because of FM degradation, multiple mirror reflections and polarized background emission. Calibration of the polarization will, therefore, be very hard and is likely to drift.

On the other hand, simulation predicts that a spectral measurement (line-splitting) can be as effective a constraint on the equilibrium as the conventional polarisation measurement on ITER. Such a spectral measurement would be less sensitive to FM degradation and background emission and its calibration would be far more stable. The spectral MSE technique based on line splitting (MSE-LS), therefore, is considered as serious candidate for the ITER MSE diagnostic.

However, due to the spectral overlap of the Stark lines on current devices, in contrast to ITER, MSE-LS is poorly studied. Experiments to benchmark MSE-LS on current devices are vital to assess the feasibility of MSE-LS as the main MSE technique for ITER.

A choice between the polarization and the spectral techniques needs to be made soon so that the design effort for the ITER MSE diagnostic can focus on one or the other approach.

This JEX proposal is directed towards machines that have the capability to make simultaneous polarisation and spectral MSE measurements.

**Primary Tasks**

1. **Simultaneous acquiring of experimental spectral and polarization data.** Dedicated experiments, approaching ITER conditions as closely as reasonably achievable (high magnetic field, high neutral beam velocity, minimizing spectral overlap, high spectral SNR). Variations in q-profile (e.g. through current ramps) of the same order as those predicted (by simulation) to have an effect on the line splitting. Piggy-back experiments could be used to prepare for the dedicated experiments
2. **Comparing simulation results with the spectral data.** Experimental data (density, Zeff, temperature, equilibrium based on polarization measurement) and geometric parameters (beam velocity distribution, collection optics geometry …) of the dedicated experiments should be used as input of the spectral MSE simulations. Noise levels, absolute values and relative changes in the line splitting should be compared between simulation and experiment. As sensitivity study should be performed to assess the effect of small changes to the simulation inputs (e.g. geometry) on e.g. systematic deviations between simulation and experiment.
3. **Comparing equilibrium reconstruction based on MSE-LS with reconstruction based on MSE-LP.** For the same plasma reconstruct the equilibrium based on the MSE-LP constraint, the MSE-LS constraint and both and compare the results.

**Results for 2015**

**DIII-D (task 1, 2 & 3):**

* EFIT Module for calculating MSE line splitting based on input (EFIT) equilibrium, beam and optical geometry was developed and benchmarked
* Calculated be MSE line splitting for 10 discharges, using MSE-LP constrained EFIT equilibria as input, was compared to measured MSE line splitting
* EFIT was update with a MSE-LS constraint. This was benchmarked thoroughly using calculated MSE line splitting data. Secondly measure MSE-LS data was used to constrain the equilibrium reconstruction.
* Work is still ongoing on the 10 selected discharges

**KSTAR (tasks 1 & 2):**

* MSE-LP system commissioned and calibrated.
* MSE-LS spectrometers collected data throughout campaign
* 1 pilot channel performing simultaneous MSE-LP and MSE-LS measurements along the same line of sight commissioned
* Campaign only just ended, data analysis about to start

**JET (tasks 1 & 2)**

* Experimental scenarios proposed and accepted as ‘high priority backup experiments” for MSE-LS tests. These experiments focus on task 1 and 2, not task 3 (i.e. equilibrium reconstruction using MSE-LS)
* Experimental campaign still ongoing and experiments itself not yet carried out

**C-MOD (tasks 1 & 2)**

* MSE-LS experimental proposal accepted for 2016 campaign

**Plans for 2016**

**DIII-D**

* Continuation and closing of the current experimental program on MSE-LS

**KSTAR**

* Dedicated MSE-LS experiments using the commissioned MSE-LP and MSE-LS systems and the pilot simultaneous MSE-LP-LS channel
* Introduction of more simultaneous MSE-LP-LS channels

**JET**

* Analysis of MSE-LS experiments: plasma current scan and power scan.
* If results are encouraging, further experiments and potential equilibrium reconstruction using MSE-LS (task 3)

**C-MOD**

* MSE-LS experiments at high B-field (8T ⬄ |vxB| of same order as for ITER DNB. Also geometry comparable to ITER DNB)
* Several discharges with different B-field with beam-into-gas for benchmarking (i.e. B-field is known exactly)
* Several discharges with different B-field & different plasma currents (plasma current scan)

**NSTX-U**

* Commissioning of the LIF-MSE diagnostic which should provide spectra with a shift/width ratio similar to what is expected in ITER
* Analysis of experimental data of the commissioning phase
* Preparation of dedicated MSE-LS experiments.

**More detailed description of the JEX proposal**

**Background:** Motional Stark effect (MSE) is proposed for ITER to measure the q-profile. The established technique (MS-LP) uses measurements of the polarisation angle of Hα light from heating beams.

However, the multiple mirror reflections needed in the port plug will induce polarisation changes and ellipticity requiring in-situ polarisation calibration sources. These sources have to mounted before the first mirror. Due to the anticipated evolution of the first mirror properties as it becomes contaminated/eroded, some sort of on-line monitor is required. The design of such a calibration source is a significant challenge for the diagnostic.

Moreover, a large fraction of the (continuum) background emission in ITER will come from wall reflections. These reflections can polarize the background. Tests on Alcator C-Mod have shown that the reflected background can have any polarization fraction between 0 and 100% and any polarization angle between 0 and 180 degrees (<https://user.iter.org/?uid=GUD54H>). Correcting for background polarization requires an additional, real-time calibration whereby the background emission needs to be measured simultaneously. Again an extra challenge for the diagnostic.

An alternative to the polarisation measurement it to use a spectral measurement of the wavelength splitting of the Stark multiplet: MSE-LS. Numerical simulations [Foley, Zakharov, 12th ITPA; Nucl. Fusion 48 (2008) 085004] show that spectral measurements can provide a constraint on the equilibrium that is at least as effective as polarisation measurements. Moreover, a spectral measurement would be less sensitive to FM degradation and background emission and its calibration would be far more stable.

For the MSE-LS technique to work, the line splitting needs to be measured accurately. On ITER the strong magnetic field, the negative ion beam(s) and the high energy of the beams causes the 9 Stark lines to be clearly separated, yielding the required accuracy in determining the line splitting.

A choice between the two techniques needs to be made soon so that the design effort can focus on either the MSE-LP or the MSE-LS approach. It is not desirable to design for both techniques as a compromises will have to be made in such case (due to other constraints such as neutron shielding and integration) resulting in both techniques likely to be performing poorly.

However, whereas in ITER the Stark lines are clearly separated, in current devices there is usually strong spectral overlap of the Stark lines. MSE-LS has, therefore, not been studied extensively, although e.g. DIII-D has collected a large database of spectral MSE measurements over the years for analysis in combination with the MSE-LP technique. To assess the feasibility of MSE-LS as the main MSE technique for ITER experiments to benchmark MSE-LS on current devices are vital, whereby the ITER conditions should be approached as closely as reasonably possible.

**Methodology:** This JEX proposal is directed towards machines that have the capability to make simultaneous polarisation and spectral MSE measurements. The proposal is to take data with the spectral measurements, reconstruct the q-profile using equilibrium codes and to compare the results with those obtained for the same plasma when using a polarisation-based MSE constraint.

**Primary Tasks:** The primary tasks are:

1. **Simultaneous acquiring of experimental spectral and polarization data.** Dedicated experiments, approaching ITER conditions as closely as reasonably achievable (high magnetic field, high neutral beam velocity, minimizing spectral overlap, high spectral SNR) would be preferred.

Machines with a (reasonably) strong magnetic field and a capability of both spectral and polarization MSE measurements are targeted for these experiments (DIII-D, JET, AUG, KSTAR in the near future …). Machines with a presence of ITER-like impurities (Be, W) such as JET, AUG and WEST (in the future) would be able to assess possible impurity lines interfering with the MSE spectrum. Other machines may also be able to help.

The experiments should attempt to vary the q-profile (e.g. through current ramps). These variations should be such that they should (just) have a measurable effect on the line splitting according to simulation.

To prepare the dedicated experiments both existing spectral MSE measurements (e.g. the large database at DIII-D) and piggy-back experiments could be used.

For the spectral MSE data an absolute intensity calibration would be required in order to be able to validate the predicted noise level.

Apart from the spectral MSE data the experiments should also return the toroidal magnetic field, the total plasma current, an equilibrium reconstructed with the MSE-LP constraint and the Zeff, electron density and electron temperature profiles in order to provide validated input to the MSE-LS simulation code.

1. **Comparing simulation results with the spectral data.** The experimental data (density, Zeff, temperature, equilibrium based on polarization measurement) and geometric parameters (beam velocity distribution, collection optics geometry …) of the dedicated experiments should be used as input of the spectral MSE simulations.

The output should not only contain the MSE spectra, but also the predicted noise levels. Noise levels, absolute values and relative changes in the line splitting should be compared between simulation and experiment.

As sensitivity study should be performed to assess the effect of small changes to the simulation inputs (e.g. geometry) on e.g. systematic deviations between simulation and experiment. This assessment could also lead to a proposal for calibrating the MSE-LS technique (e.g. based on the Doppler shift measurement).

1. **Comparing equilibrium reconstruction based on MSE-LS with reconstruction based on MSE-LP.** For the same plasma reconstruct the equilibrium based on the MSE-LP constraint, the MSE-LS constraint and both and compare the results.

For this the equilibrium code might need to be adjusted to accept the MSE-LS constraint, or the ESC-ERV code used for the ITER predictions should be adjusted to the device where the measurements are performed.