MOTIONAL STARK EFFECT DIAGNOSTIC FOR MULTI-CHORD MEASUREMENTS OF PLASMA BETA IN GDT


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Measurement of plasma magnetic field in magnetic confinement devices by observation of Stark splitting of the diagnostic beam emission line (MSE diagnostic) is the reliable and commonly used approach. The spectral MSE diagnostic developed for the gas dynamic trap (GDT), allows for measurements of $|B|$ in plasma, which are of significant importance for the study of hot-ion GDT plasma with $B_{||} < 0.4$. Further experimental program for study of anisotropic plasma with high pressure implies higher requirements for the temporal and spatial resolution and precision of measurements using MSE diagnostic. Accordingly, the diagnostic system with enhanced capabilities is projected, comprising neutral beam injector RFX-DNBI and the optical system for single-shot magnetic field spatial profile measurements. H-alpha emission of diagnostic beam atoms recorded from each of eight light collection chord, is digitized by the CCD-based detector and then processed using the quantum mechanical model, which allows $\beta$ calculation for a wide range of experiment parameters.

II. MSE DIAGNOSTIC AT GDT AND MOTIVATION FOR UPGRADE

Recent measurements of the radial profile of plasma $\beta$ in the turning point region have been made with a Motional Stark Effect (MSE) spectroscopic diagnostic temporarily loaned to the Budker Institute by the University of Wisconsin-Madison [3]. This diagnostic utilizes the effect of appearing of the Lorentz electric field $E = vB$ in the frame of reference of a fast atom transverse to a magnetic field. For a hydrogen atom injected by a diagnostic neutral beam the resulting Stark splitting of hydrogen emission lines is linear in magnetic field. The magnitude of the Stark splitting can be precisely measured with sensitive spectroscopic instrumentation. Since the beam energy, and thus atom velocity, is accurately known, this technique provides a robust method of local magnetic field measurements.

The existing diagnostic is comprised of the neutral beam DINA-5M [5] and the single viewing chord optical system with CCD spectrometer [6]. Accordingly, to measure the spatial profile of magnetic field, a series of shots is required. This is a strong reason to modernize the diagnostic so as to allow for a single-shot profile measurements. Another reason is low signal-to-noise ratio of about 1.5, which characterizes the existing diagnostic. To overcome this problem, an additional averaging over a series of shots in each spatial point is made. In GDT experiments discussed in Ref. 4, the magnetic field was
typically 0.4-0.5 T, so with a beam velocity of 2.7×10^7 m/s, other effects contributing to emission line splitting (Zeeman splitting, fine structure of atom energy levels, and other relativistic corrections) are small compared to Stark splitting. However, for planned low-field measurements (<0.2 T) the noted effects are significant thus requesting to develop an advanced model [7] for experimental spectra processing.

III. PROJECTED MSE DIAGNOSTIC AT GDT

The layout of projected MSE diagnostic is shown in Fig. 2. The energetic hydrogen atoms from the diagnostic injector RFX-DNBI [8] move horizontally through the recombination spectroscopy (or CHERS for short) in medium-size devices for magnetic plasma confinement. The injection energy is increased up to 50 keV in comparison with 40 keV of DINA-5M allowing to obtain a more clear separation of MSE spectrum components [3,7]. The main operational characteristics of this injector are listed in Table 1. As a result of several engineering enhancements introduced into the injector design, the angular divergence of the neutral beam is reduced to about 0.5° [8]. Together with higher beam velocity, this

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of ion optic system (IOS)</td>
<td>Focusing</td>
</tr>
<tr>
<td>IOS diameter</td>
<td>110 mm</td>
</tr>
<tr>
<td>Injection energy</td>
<td>50 keV</td>
</tr>
<tr>
<td>Beam current</td>
<td>5 atom Amperes</td>
</tr>
<tr>
<td>Beam radius in the focus</td>
<td>2 cm</td>
</tr>
<tr>
<td>Percentage of full energy component</td>
<td>87 %</td>
</tr>
</tbody>
</table>

plasma volume and emit statistically mixed radiation due to excitation by collisions with plasma particles. Eight observation chords are used to collect the beam radiation, which then is recorded and digitized by the CCD spectrometer (see Fig. 2). Fig. 3 shows the layout of the RFX-DNBI neutral beam injector recently developed in the Budker INP for application in such particular fields as motional Stark measurements and active charge-exchange

Fig. 2 The layout of the projected 8 chord MSE diagnostic for GDT.

Fig. 3 The layout of the RFX-DNBI diagnostic neutral beam injector
characteristic is important for projected experiments since it allows to reduce broadening of Stark spectrum components [3].

The registration system of the upgraded MSE diagnostic is comprised of eight separate light collection telescopes (Fig. 2), optical shutter and the 0.5 m Ebert-Fastie spectrometer with the digital CCD detector. Recorded and digitized signal from the CCD is transmitted to the main GDT data storage for further processing and calculation of $\beta$. Comparing to the single-chord instrumentation reported previously in Ref. 3, we plan to use the Apogee Alta E47+ CCD detector. The outputs of eight fiber bundles are stacked vertically along the entrance slit of the spectrometer. The spectrometer disperses the light horizontally, but preserves this vertical mapping. Thus the CCD detector records eight separate motional Stark spectra, corresponding to the eight spatial measurement points in the plasma. According to the estimates made, the signal-to-noise ratio for each channel will be increased up to 7-10 mostly due to the better performance of the Apogee Alta detector.

Analysis of the spectrum obtained from the CCD in a GDT shot is performed using the quantum mechanical model, which considers also Zeeman splitting, fine structure of hydrogen atom energy levels and Lamb shift besides the motional Stark splitting. The detailed description of the model can be found in Ref. 7. Spectrum simulation is made for the actual geometry of MSE measurements in GDT plasma as it is shown in Fig. 4. Note that polarisation direction $e_2$ corresponds to the recorded beam signal. Introducing a finite broadening of each line of the $H_\alpha$ multiplet, we simulate the observed spectrum. Fig. 5 shows the example of simulation of this kind. Parameters of calculation are the following: atom energy 40 keV, magnetic field 0.2 T, angle between the beam velocity and the observation line 22.5°. They reflect conditions of planned MSE measurements in the GDT midplane. Fine structure splitting is significant here leading to the deviation from symmetry of the spectra in Fig. 5.

III. SUMMARY

The projected MSE diagnostic for the GDT mirror system provides the capability to measure the radial profile of magnetic field on a single-shot basis. Several improvements introduced into the design of upgraded diagnostic injector, allow to increase the beam energy and current density. The signal-to-noise ratio is expected to be about 7-10 for an individual spatial channel of the diagnostic. Precise calculation of plasma magnetic field is provided by the quantum mechanical model of the H-alpha spectrum.

ACKNOWLEDGMENTS

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REFERENCES

Abdrachitov et al.  DEVELOPMENT OF MSE DIAGNOSTIC FOR GDT


