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MAGNETIC PITCH ANGLE MEASUREMENTS ON TEXT USING LASER-ENHANCED ATTENUATION OF A Li BEAM

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Magnetic pitch angle measurements on TEXT using laser-enhanced attenuation of a Li beam

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ABSTRACT. The polarization of the π component of the Zeeman split $\text{Li}2\text{P}-2\text{S}$ transition allows a direct spectroscopic measurement of the local magnetic pitch angle. Li atoms are injected radially into TEXT as a 95 keV beam, and the intensity of the transmitted beam is detected. A polarization-modulated, cavity-dumped dye laser, tuned into resonance with the π line, is injected collinearly with the beam. Laser excitation of the beam results in an enhanced beam attenuation. Time-resolved detection of the transmitted Li beam allows determination of the local magnetic pitch angle. Details of the system and results of recent measurements will be discussed.

INTRODUCTION

An adequate current profile diagnostic system suitable for the wide variety of tokamaks in the community remains elusive. While many techniques have been demonstrated to work under limited conditions (too many to reference in this brief paper), a generally applicable diagnostic tool has not yet been demonstrated. We are developing a system for the TEXT tokamak that promises to be applicable to most tokamaks of similar or smaller size and promises to obtain complete profiles with reasonable time resolution. This system design stems from previous work on TEXT, using a Li beam and laser-induced fluorescence (LIF) to measure magnetic pitch angle profiles.^{1,2} During the course of the previous work, it was discovered that laser excitation of the Li beam atoms led to an enhancement of the Li beam attenuation, resulting in reduced fluorescence and limiting the density range of applicability to $< 1 \times 10^{13} \text{ cm}^{-3}$. The present system³ takes advantage of laser-enhanced attenuation (LEA) to measure magnetic pitch angle profiles.

An injected atomic Li beam allows magnetic pitch angle measurements because of the resonance line splitting and polarization resulting from the interaction with the magnetic field. Because both the Li ground 2S and first excited state 2P are energetically isolated from each other, and from all other excited levels, the motional Stark effect is negligible and the Zeeman effect dominates the splitting and polarization of this transition. This transition is split into three components, usually labeled σ and π . The π component has a transition energy that is nominally independent of the magnetic field strength and is separated from the sigma lines by $>15 \text{ GHz}$ in TEXT. Since the π line is polarized parallel to the local B field direction (when viewing perpendicular to B), laser excitation can be used to determine the local direction of B.

I. DIAGNOSTIC SYSTEM

The system is shown schematically in Fig. 1. The Li beam consists of a Li ion gun, acceleration and focusing optics, a steering magnet, and a Na vapor neutralization cell. Typically, the ion source is operated at about 4 mA emission, producing an ion beam current of 2.5 mA at 95 keV. The neutralization efficiency is about 40%, resulting in an equivalent neutral current of 1 mA. The laser, a modified cw dye laser pumped by an Ar ion laser, uses an acousto-optic modulator as a cavity-dumper to produce a 9 ns pulse at repetition rates from 0 to 2 MHz. In the data shown below, a 1 MHz repetition rate was used. Peak pulse powers of over 20 W have been obtained. The laser beam is passed through a LiNbO_3 polarization rotator, which maintains the linear polarization state of the laser light, but rotates the plane of polarization at a frequency of 50 kHz. The laser is merged with the Li beam, and the two beams are directed collinearly into the TEXT plasma and onto a transmitted Li beam detector. As discussed previously,¹ the polarization rotation results in a laser excitation of the Li atoms that is modulated at 100 kHz, and the phase of this 100 kHz modulation is directly related to the pitch angle of the magnetic field at the point of excitation.

The transmitted beam detector consists of a thin carbon foil of about $20 \mu\text{g}/\text{cm}^2$ surface density and an ion collector plate. The incoming 95 keV Li atoms are stripped of an electron as they pass through the foil. The collected current is then amplified using a 100 MHz bandwidth transimpedance amp located adjacent to the collector and the signal is conducted out of the vessel using 50 Ω coax. The foil, about 2 cm in diameter, is supported by fine stainless steel mesh and is protected from the plasma by a 2 mm thick hexagonal collimator with 1 mm holes. The detector is insensitive to incoming photons (UV and X-ray) since secondary electrons are unable to escape from the collector due to the large ambient magnetic field.

Fig. 1. Schematic of the Li beam, dye laser, and detection system on TEXT.

The signal, after secondary amplification, is directed to 100 MHz bandwidth track and hold amps (T&H). Each T&H is triggered to hold the value of the signal at a precise delay time from the laser pulse. These delay times are related to the propagation time of the timing pulses, the signal, and the Li beam atoms from particular radial positions in the tokamak to the detector. The radial resolution of the measurement, determined by the pulse length of the laser, the bandwidth of the electronics, and the velocity of the beam atoms, is about 2 cm. After the T&H's, each signal is directed to a phase-sensitive detector, locked to the polarization rotator, to measure the relative phase of the effect of the polarization rotation on the Li beam at a localized position in the plasma. At present, we have operated with only one T&H.

II. EXPERIMENTAL DATA

Pitch angle measurements obtained using this system are shown in Fig. 2 along with a few relevant TEXT plasma parameters. These data have been averaged over 10 ms and over 19 similar shots. The pitch at $r = +15$ cm clearly follows the plasma current, as is expected. The observed change in the measured pitch during the initial plasma current ramp from 0 to 50 ms is reasonable for this radial position and plasma current. The pitch at $r = -4$ cm should not be correlated with the plasma current, since it is very near the magnetic axis.

Absolute pitch of B was not determined from this data because there was no LEA effect prior to the discharge initiation. In previous work using LIF, there was a strong signal just prior to the discharge allowing determination of absolute pitch. Due to lack of cross section information, we were unable to predict the size of LEA in the neutral hydrogen gas injected 50 ms prior to the discharge, but this data indicates that it is

GEOMETRIC RADIUS = 15.00

Fig. 2. Pitch angle data from TEXT: (a) T&H delay set to $r = +15$ cm, (b) delay set to $r = -4$ cm, (c) plasma current and density. Pitch angles are averaged over 10 ms and several shots as noted. (Sheet 1 of 3)

GEOMETRIC RADIUS = -4.00

Fig. 2. Pitch angle data from TEXT: (a) T&H delay set to $r = +15$ cm, (b) delay set to $r = -4$ cm, (c) plasma current and density. Pitch angles are averaged over 10 ms and several shots as noted. (Sheet 2 of 3)

Fig. 2. Pitch angle data from TEXT: (a) T&H delay set to $r = +15$ cm, (b) delay set to $r = -4$ cm, (c) plasma current and density. Pitch angles are averaged over 10 ms and several shots as noted. (Sheet 3 of 3)

quite small. As discussed below, we are developing a optical reference that will allow absolute pitch determination.

The signal-to-noise in this data was well below that initially expected due to two reasons: (1) the laser pulse peak power was only 5 W, significantly below the 20 W achieved in the past, (2) the major contributor to the observed noise was pickup from plasma fluctuations. As a result, as the plasma density was ramped above $1.5 \times 10^{13} \text{ cm}^{-3}$ (between 100 and 200 ms), the transmitted Li beam is too weak to observe the LEA effect.

Shown in Fig. 3 is an FFT power spectrum obtained by digitizing the output of the T&H at 500 kHz sample rate. The signal at 100 kHz is clearly observable, as well as artifacts at 50 and 150 kHz due too poor alignment of the polarization rotator. Also observable is a band of noise centered near 100 kHz that we attribute to pickup of edge plasma turbulence.

III. DISCUSSION

Several improvements to the system are suggested by the data presented here. First, to improve the signal-to-noise, the laser must be brought back to previous performance levels and the pulse rate can be doubled to 2 MHz. In addition, the effect of plasma turbulence can be reduced by improving the shielding of the detector and by moving the frequency of laser rotation to above 130 kHz. We expect an improvement in signal-to-noise by more than an order of magnitude. Increasing the Li beam current will also improve S/N, but is not a trivial change.

A phase reference suitable for determining absolute pitch has been designed. Directing the small percentage of the laser beam that is reflected from the vacuum input

Fig. 3. Power spectrum of transmitted beam signal after T&H amp.

window through a polarization beam splitting cube and onto a photodiode yields a signal that is directly related to the orientation of the cube. The cube is accurately aligned to the local horizontal using a precision spirit level. The signal is then directed to a T&H amp identical to those used for the transmitted beam signal. In order to avoid phase shifts usually found in analog electronics, the phase-sensitive detectors will be removed, and the signal from the T&H amps will be directly digitized in sync with their triggers. The phase comparison between the photodiode signal and the transmitted beam signals will be done digitally.

In conclusion, the initial magnetic pitch data obtained on TEXT using the LEA technique is very promising. We anticipate that following the shutdown for TEXT upgrade, we can implement the improvements discussed above and obtain complete radial profiles with good time resolution.

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