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Abstract. The Motional Stark Effect (MSE) diagnostic will be essential for the study of advanced scenarios on ITER and its design is currently underway. In order meet the ITER MSE diagnostic design requirements, two approaches for the measurement are under consideration. The first is based on standard polarimeter techniques to measure the polarization of the emitted light, whereas the second measures the Stark splitting from which |B| can be inferred, where |B| is the magnitude of the total magnetic field. The baseline design of the optical system is centered on the first approach. Emphasis in this case is placed on minimizing the polarization aberrations of the optical relay system. Motivation for the second method results from concern that the optical properties of the plasma-facing mirror, particularly its diattenuation and retardance, will degrade with plasma exposure. The second approach, while less sensitive to aberrations induced by plasma exposure effects, requires greater optical throughput in order to measure the complete Stark spectrum. We have developed optimized designs for both techniques and will present a comparison of them and discuss the associated design trade-offs.

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I. INTRODUCTION

The Motional Stark Effect (MSE) diagnostic will be essential for the study of advanced scenarios on ITER and is part of the required diagnostic set for these discharges. The standard version of the MSE diagnostic [1] measures the local value of the magnetic field line pitch angle through the use of polarimetry. From this information, the current density and safety-factor profiles may be deduced when combined with other measurements in an equilibrium code such as EFIT[2]. In order to apply this technique, the polarization characteristics of the entire optical train must be accurately known. This is challenging in current experiments, but will be more so in ITER as access to the optics will be extremely limited making *in-situ* calibration of the diagnostic difficult. The primary concern, though, is with the first, plasma-facing optic, which is subject to heat and particle fluxes from the plasma that may alter its optical properties in an unpredictable manner. Effects on the first optic include erosion due to sputtering by energetic plasma particles, and coating by material sputtered from plasma-facing components that is then transported about the plasma periphery and deposited on the optic. Thus the reflectance, diattenuation, and retardance of the first optic are expected to vary on long time scales (10s to 100s of shots) and possibly even during a single shot.

In order to diminish the impact of these effects, a second approach is also being considered in which the full Stark spectrum is measured at each observation point [3, 4]. The Stark-splitting is proportional to the total local magnetic field and is thus related to the magnetic field line pitch angle. This information can also be input to equilibrium codes to generate current density and safety-factor profiles analogous to the standard method [5]. Since this method is independent of polarization, it is more tolerant to degradations in the optical performance. However, much more light throughput is required in order to measure the complete Stark spectrum. This increases the demands on the optical system, particularly in terms of the size of the optics.

The ITER MSE system will consist of two modular systems, each viewing different heating neutral beams, and installed in different equatorial port plugs. One system will view the core of the plasma and the other the edge, thereby providing complete coverage of the plasma from the magnetic axis to the separatrix. The two systems have similar designs, but the edge system is more demanding due to the larger angle of incidence and it employs a final lens to obtain an image that fits within a 100 mm spot. The system design has evolved in step with the maturing design of the port plug and the need to satisfy the requirements of both types of MSE measurements as outlined above. The design is compliant with the mechanical constraints of the current modular “drawer-type” port plug concept (discussed below). At each successive design change, the optical system has been optimized to meet the following goals:

- minimize the size of the optics,
- keep the surface figure as simple as possible,
- minimize the polarization aberrations,
- maximize the étendue.

Together, these goals minimize the neutron streaming through the system, reduce the cost of the optics, and result in a system that achieves the physics requirements. So far it has been possible to achieve the required system performance without significant trade-offs in any of the primary optical parameters. However, the design is very close to its performance limits, and as the engineering constraints continue to evolve (and generally tighten), some performance trade-offs will likely be necessary.

II. OPTICAL DESIGN

A. GEOMETRY

An overview of the core system is shown in Fig. 1. It depicts the heating neutral beam (yellow cylinder) that together with the radial and vertical resolution of the optics define the emission volume for the MSE measurement. Typical rays are shown for the two extreme channels and one in the center. The rays pass through an aperture in the shield-blanket module mounted on the front of the port plug assembly. The first mirror is located behind the shield-blanket. The layout of the edge system is similar. The main difference is that in order to accommodate the large angle of incidence, the first two optics in the edge system are mounted on an extension of the drawer that projects into a region normally occupied by the shield-blanket module. Thus a cutout on the backside of the shield-blanket will be needed to accommodate this system (see Fig 2b below).

Figures 2a and 2b show plan views of the core and edge systems. The z-shaped optical path is a key part of the neutron shielding. Such a configuration prevents direct neutron streaming though the port plug, minimizing the neutron flux at the back of the port plug. Four reflective optics are used in each system together with a final focusing lens for the edge system. The first two optics will be metal mirrors as these are exposed to the highest heat fluxes and must be actively cooled. Dielectric mirrors are being considered for the remaining two reflective surfaces. The lens in the edge system is the final optical element and is located at the rear of the port plug, minimizing the neutron flux it is exposed to.

The initial design of the MSE system was optimized only for the polarimetric MSE measurement. This design then served as the basis for a design with increased étendue in order to maximize the photon throughput for the measurement of the full Stark spectrum. It has been possible to increase the étendue of the initial system without significant increases in the polarization aberrations. Thus a single design works for both types of measurements. Table 1 summarizes the design parameters of the optics for both the core and edge systems and is applicable to both measurement options.

Figure 3 shows spot diagrams for the core and edge systems. A 1.4 m by 0.4 m region is mapped to an area less than 100 mm in diameter. The mapping of object to image planes corresponds to a demagnification of 8 (7) vertically and 20 (23) horizontally for the core (edge) system and preserves the shape of the image with minor aberrations. The depth of field for the core and edge system is approximately 400 mm and 150 mm respectively.

B. POLARIZATION PERFORMANCE

Minimization of polarization aberrations is essential for the polarimetric measurement. The use of dielectric mirrors aids considerably in achieving this requirement, as such mirrors can be fabricated with essentially identical optical performance for both the s- and p-polarizations over the full range of angles of incidence. Table 2 lists data characterizing the polarization performance of both the core and edge systems. The column labeled "Ideal" presumes ideal mirrors that result only in polarization rotation without retardance as the light propagates through the optical train. The polarization aberration is characterized by the standard deviation of the polarization orientation, which measures the variation across the full image field. The second case is for a system in which M1 and M2 are both Rh coated, giving rise to both added depolarization and retardance. However, the deviation from ideal, as measured by the relative standard deviations, is quite small. Thus, use of metal mirrors of this type in the optical system does not result in a significant performance penalty.

C. INCREASED ÉTENDUE DESIGN

The goal of the increased étendue design was to increase the height of the viewing volume by a factor of 6, from 66 mm to 400 mm (symmetric about the beam centerline), without impact on the radial resolution or significantly increasing the polarization aberrations over that of the baseline design. The increased height effectively increases the étendue by a factor 6, from 1.1 to 6.4 m^2-str. The new design achieved all the goals with only modest increases in the size of the optics over that of the initial baseline design. Further it proved possible to produce an image that still fits within a 100 mm diameter circle commensurate with the clear aperture of commercial photo-elastic modulators. Thus the increased étendue design is fully consistent with polarimetric measurement technique.

III. MECHANICAL DESIGN

Design of the equatorial port plug has evolved in parallel with the optics design and the optics design has been updated accordingly. Most recently, a diagnostics drawer design has been adopted in which each diagnostic is confined to a modular section of the port plug. The drawer design concept as applied to the MSE system is depicted in Fig. 4. which shows the edge drawer with front-end extension and viewing cone, and the port plug with drawers extending from the rear of the plug. However, this design reduced the available space, particularly in the horizontal direction (width of the module) and necessitated a design iteration. Up to this point it has been possible to accommodate the changes required to remain within the defined boundaries. However, with the latest changes, the optical design is currently very near the limits of its design margins. Further changes will likely force performance trade-offs in the optical design.

IV. CONCLUSION

Optical design of the core and edge ITER MSE diagnostics is advancing in step with the mechanical design. After a number of iterations it has been possible to achieve an optical design consistent with a polarimetric based measurement, as all current MSE systems now employ, as well as a design with greater étendue for measurement of the full Stark spectrum. The optical designs also conform to the mechanical constraints imposed by the modular “drawer” concept currently under consideration for port plugs.

Acknowledgment

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List of Tables

Table I. Optical Parameters for Core and Edge Systems

System	Optical Element	Size x (mm)	Size y (mm)	Focal Length x (mm)	Focal Length y (mm)	Shape
Core	Object	1400	400	-	-	-
	Stop	93	93	-	-	Circle
	M1	250	175	750	750	Spherical
	M2	180	115	1250	-	Cylinder
	M3	365	205	1420	1420	Spherical
	M4	320	120	1040	835	Biconic
	Image	80	70	-	-	-
Edge	Object	1400	400	-	-	-
	Stop	80	160	-	-	Ellipse
	M1	180	210	1750	-	Cylinder
	M2	230	230	1100	-	Aspheric
	M3	420	200	1800	-	Spherical
	M4	390	250	2250	750	Biconic
	L1	130	120	305	305	Plano-convex
	Image	60	50	-	-	-

Table II. Polarization Performance of the Core and Edge Systems

System	Parameter	Ideal Orientation	Ideal Retardance	Rh Coated Orientation	Rh Coated Retardance
Core	Minimum	43.2°	0°	42.7°	-3.6°
	Maximum	45.5°	0°	45.1°	-2.5°
	Average	44.3°	0°	43.8°	-2.9°
	Standard Deviation	0.59°	0°	0.60°	0.28°
Edge	Minimum	39.6°	0°	37.2°	-14.6°
	Maximum	41.5°	0°	39.2°	-12.1°
	Average	40.6°	0°	38.3°	-13.2°
	Standard Deviation	0.44°	0°	0.48°	0.66°

List of Figure Captions

Fig. 1. Isometric view of the core MSE system showing several ray paths originating in the heating neutral beam (yellow cylinder) and propagating through the optical system.

Fig. 2. Plan view of core (upper) and edge (lower) designs with in the port plug. The core and edge optical designs are fundamentally the same. The edge system requires an extension for mirrors 1 and 2 to accommodate the larger angles of incidence involved with this view and also employs a lens. The optical elements are indicated on the edge diagram.

Fig. 3. Spot diagram for core (a) and edge (b) systems. The core system does not incorporate a lens. Note the different scales on the various diagrams.

Fig. 4. Port plug drawer concept. The upper figure depicts the drawer for the edge MSE system. An extension at the front of the drawer holds mirrors 1 and 2. The drawer is one of several contained in the port plug at the lower right. The drawers are removed from the rear of the plug

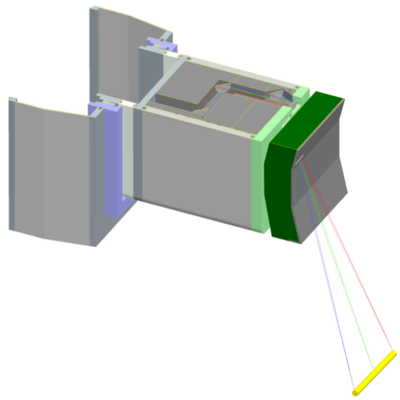

Fig. 1

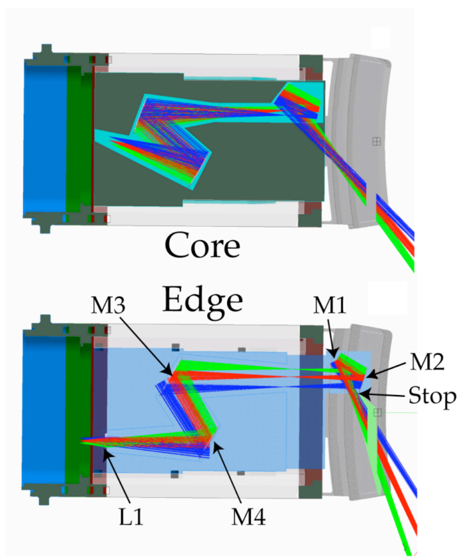

Fig. 2

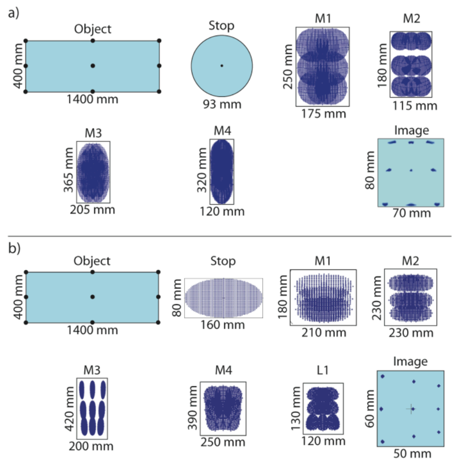
a)
Object
400 mm
1400 mm
Stop
93 mm
M1
250 mm
175 mm
M2
180 mm
115 mm
M3
365 mm
205 mm
M4
320 mm
120 mm
Image
80 mm
70 mm
b)
Object
400 mm
1400 mm
Stop
80 mm
160 mm
M1
180 mm
210 mm
M2
230 mm
230 mm
M3
420 mm
200 mm
M4
390 mm
250 mm
L1
130 mm
120 mm
Image
60 mm
50 mm

Fig. 3

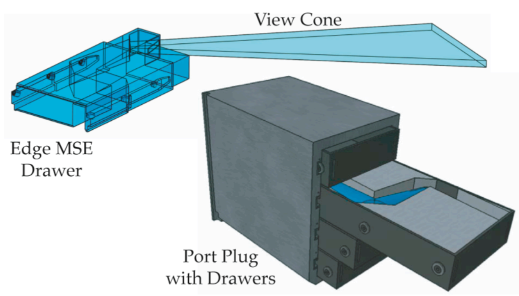
View Cone
Edge MSE
Drawer
Port Plug
with Drawers

Fig. 4