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Conceptual Design Studies of the KSTAR Bay-Nm Cassette and Thomson Scattering Optics

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***Abstract*— A Multi-Channel Thomson Scattering System viewing the edge and core of the KSTAR plasma will be installed at the midplane port Bay-N. An engineering design study was undertaken at PPPL in collaboration with the Korea Basic Science Institute (KBSI) to determine the optimal optics and cassette design. Design criteria included environmental, mechanical and optical factors. All of the optical design options have common design features; the Thomson Scattering laser, an in-vacuum shutter, a quartz heat shield and primary vacuum window, a set of optical elements and a fiber optic bundle. Neutron radiation damage was a major factor in the choice of competing lens-based and mirror-based optical designs. Both the mirror based design and the lens design are constrained by physical limits of the Bay-N cassette and interference with the Bay-N micro-wave launcher. The cassette will contain the optics and a rail system for maintenance of the optics.**

I. INTRODUCTION

The Bay-N Midplane port cassette on KSTAR has been designated to house Thomson Scattering optics with a broad field of view of the Thomson Scattering laser along the midplane of the machine. Figure 1 is an illustration of the baseline coordinates defined for the diagnostic view [1] [2]. These baseline coordinates were the starting point for the optics design studies and the cassette design.

The optics and cassette structure design were interdependent. Any useful optics concept was required to fit

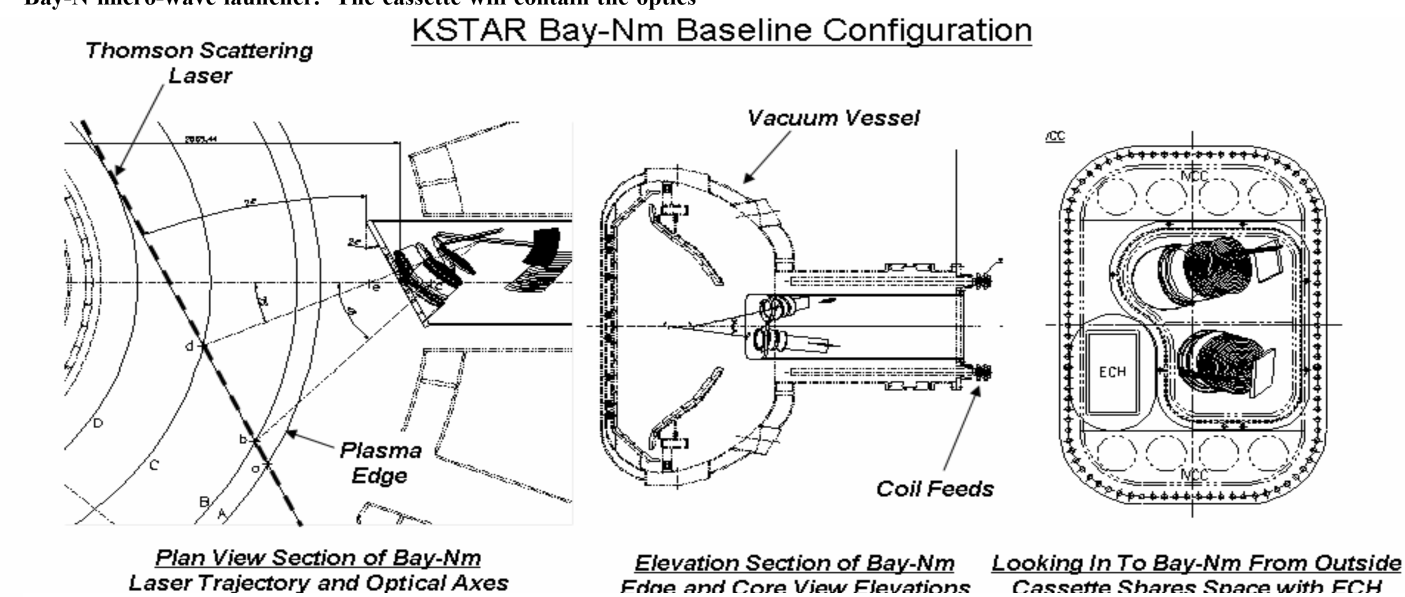

Figure 1: KSTAR Bay-Nm Baseline Configuration and Optics Coordinates

Optical Design Parameter	*Target Value*	*How Controlled*
Field of View	*Edge View:* *Core View:* *Note: Mirror System views entire field of view*	*1. Orientation of Cassette Face* *2. Sizing of Vacuum Window and Optics*
Spot Size	*For the conceptual design process, spot size was merely minimized. Consistent spot sizes of about .3 mm were achievable.*	*1. Optimization of lens or mirror spacing, curvature and material in OSLO* *2. Field of View and F-number constraints*
Etendue	*The Polychrometer for KSTAR will have an Etendue of .017 cm2-steradian. Core and Edge fiber array designs will attempt to efficiently match this.*	*1. Polychrometer Etendue* *2. F-number constraints* *3. Fiber Bundle and Laser Sample Size*
Spatial Resolution	*Core: 3 cm Edge: 3 mm* *The core optics concepts meet the 3 cm requirement. The edge concepts exhibit ~6 mm resolution and will need further study.*	*1. Fiber bundle and array design*

Table 1: Optical Design Parameters

neatly inside the cassette. The size of the vacuum window which defines ultimately how much light the system can collect is constrained by the shape of the cassette. Similarly, the shape of the cassette was driven by the optics. The front face of the cassette must be arranged to allow for efficient edge and core views.

II. THOMSON SCATTERING OPTICS DESIGN STUDIES

A. Optical Design Parameters

The primary goal for the optics design was to provide edge and core views of the Thomson Scattering laser with adequate optical performance. OSLO optical design software was used to design and optimize the optics based on spot size. Etendue and spatial resolution are also critical optical design parameters. Table 1 lists target values for field of view, spot size, Etendue and spatial resolution.

Spot size performance is purely a function of the lens or mirror design. Optimization of Etendue and spatial resolution depend on the optics design as well as the choice of fiber optics spacing, the size of the laser beam along the field of view and how well the Polychrometer collects light. The conceptual lens and mirror designs presented in this paper were optimized for minimum spot size. During the next design phase, as the fiber optics design matures, spatial resolution and Etendue will be considered more carefully.

Figure 2 illustrates the three design concepts and features.

B. Triplet Lens Design

The triplet lens Core and Edge view design is a form of the classic Cooke Triplet with a fourth element added to enhance performance. Schott Glass LAFN21 was used for the positive elements and Schott SF53 for the negative element. The optimized design object f-number ranges between *f/5* and *f/9* while holding the image f-number to *f/2* for 200 mm optics and windows. The conceptual design exhibits a uniform .4 mm spot size.

C. All Quartz Lens Design

The All-Quartz lens Core and Edge view design was derived from the triplet concept. All negative and positive elements are quartz. The fourth element is aspheric. The optimized design object f-number ranges between *f/5* and *f/9* while holding the image f-number to *f/2* for 200 mm optics and windows. This is similar to the triplet design because the dimensions of the two are almost identical. With the aspheric element this conceptual design exhibits a uniform .3 mm spot size. Depending on the available capabilities to machine aspheric elements, even better performance is achievable.

D. Spherical Mirror Design

The mirror design covers the full Edge and Core field of view. A 500 mm radius spherical mirror is centered on the vacuum window. The fiber array is placed between the window and mirror and will obscure about 10% of the incoming light. The optimized design object f-number is a constant *f/7* with the same image f-number of *f/2* for a 200 mm window. The conceptual design exhibits a uniform .3 mm spot

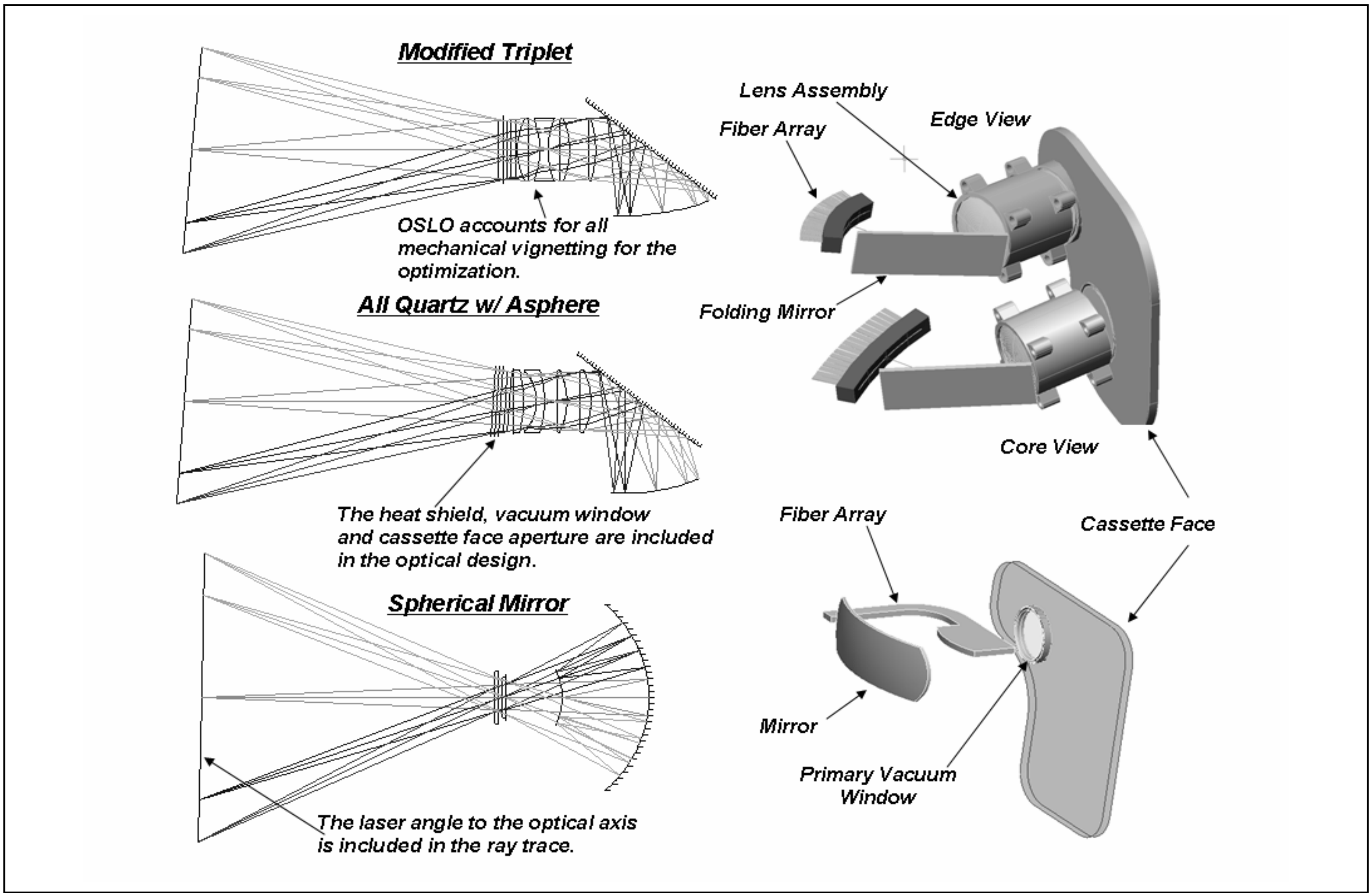

Figure 2: Competing Conceptual Thomson Scattering Optical Designs

size.

E. Preliminary Design Phase

The All-Quartz lens design will be used for the preliminary design phase. With the availability of aspheric lens machining technology the design performance can be greatly enhanced over the Triplet and Mirror designs. The All-Quartz system is brighter than the mirror based system and is cheaper than the exotic glasses used in the triplet.

Another important factor in choosing the All-Quartz design is the radiation resistance of the quartz elements. Quartz elements will stay color-free for longer during KSTAR long pulse operation.

III. Bay-N Mid-Plane Cassette Design

Figure 1 illustrates how the cassette concept is arranged in the Bay-Nm port. The cassette is a re-entrant stainless steel plate welded structure for housing the Thomson Scattering optics. The optics, rails and shutter actuators are mounted on the atmosphere side of the cassette. Figure 3 highlights the main components of the cassette design.

A. Cassette Face

The cassette face is oriented for optimal optical performance and manufacturing ease. The Core View axis is normal to the face which allows for a large window and aperture. The Edge View window is aligned to the edge optical axis and mounted on a re-entrant stub off of the face.

The shutters and heat shields are mounted on the vacuum side of the cassette face. Quartz heat shields are needed to prevent the primary vacuum windows from over heating. The primarily UV radiation heating would take the primary windows above allowable temperatures for the vacuum seal braze. As the heat shield temperature elevates infrared radiation could be re-radiated in to the optics and compromise the Thomson Scattering data. A preliminary design challenge will be to study this and find ways to keep the heat shield cool for long pulse KSTAR operation.

The shutters are sturdy 4-bar mechanisms. A rotary pendulum motion is achieved with linear air-side actuators and links that will feed through to the vacuum side. The shutters will help to keep the heat shield and widows clean during vacuum conditioning.

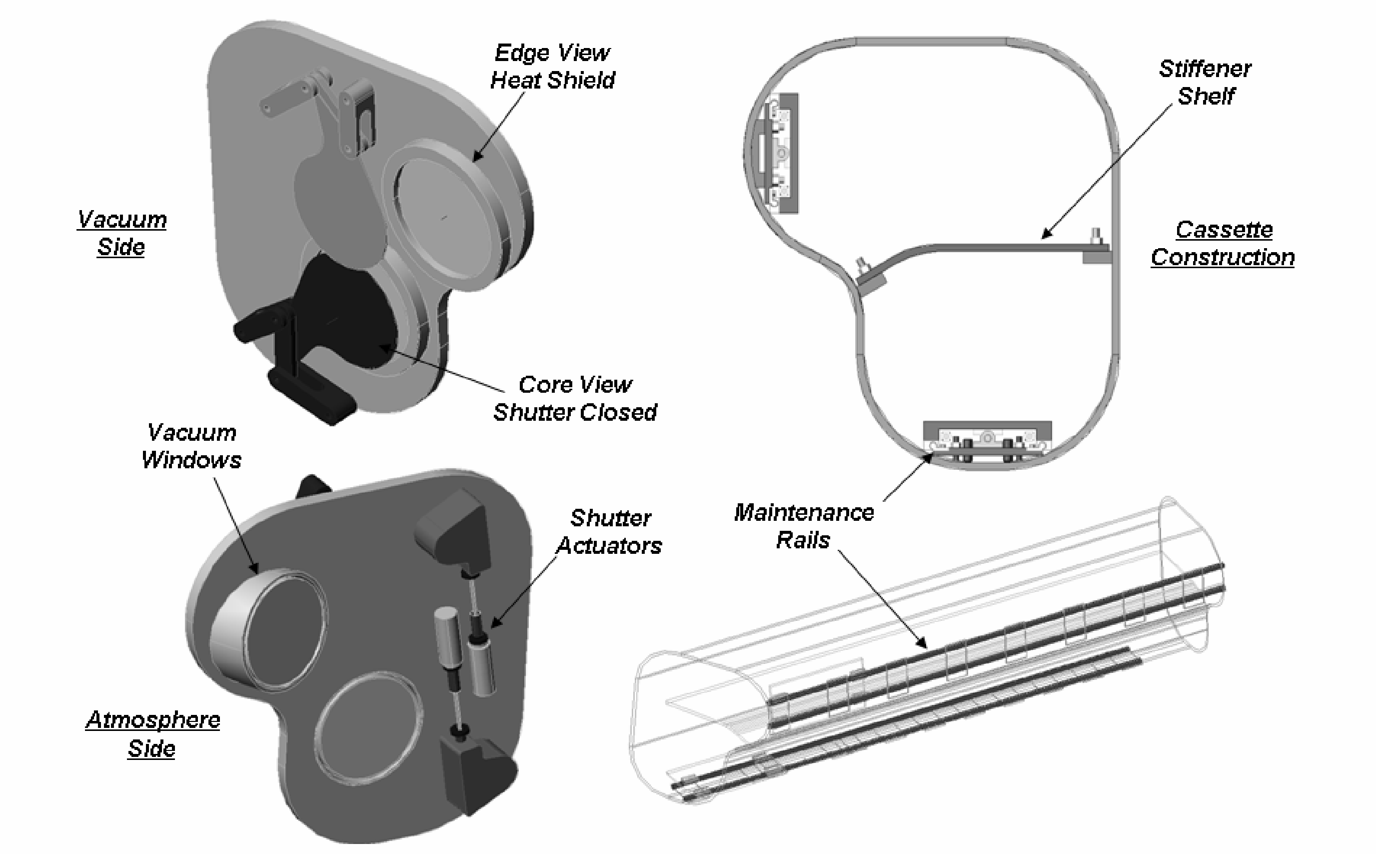

Figure 3: Bay-Nm Cassette Design Features

B. *Cassette Body*

The cassette body will be a welded construction of ½" thick 300 series stainless steel. KSTAR requires a maximum deflection of 1 mm across any cassette face. A central stiffener plate and the ½" body plates hold the conceptual cassette to .82 mm deflection under 1-atmosphere of internal pressure. A refined structural analysis during the preliminary design phase will include electromagnetic and thermal effects for a full stress and deflection study.

The rear end of the cassette will have a flange that can support the cantilevered weight of the cassette, optics and rails as well as provide a vacuum tight seal. The front end of the cassette body will be machined at a compound angle to mate the face assembly. All parts of the structure had to be arranged to share space with and allow for independent installation of the ECH launcher antennae.

A rail system for transporting the edge and core optics in and out of the 2 meter long cassette is also part of the design effort. The large optics and optics housing will weigh approximately 100 lbs or more. The rails will need to be strong enough to withstand this load and provide smooth motion. Since the rails are on the atmosphere side, some kind of lubrication can be used. It is anticipated that the cassette will be constructed and installed before the optics are ready. The rails will allow later installation and alignment of the optics.

Acknowledgment

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[1] H.G. Lee, J.H. Lee *et al*, "Design of core and edge Thomson scattering systems for Korea Superconducting Tokamak Advanced Research tokamak," Review of Scientific Instruments, vol. 75, no. 10, pp. 3903-3905, October 2004.

[2] KSTAR Baseline Coordinates figure reproduced from KBSI drawing 050225 T516-000-S00 R2.dwg

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