

Design of Re-entrant Cassette and Visible Diagnostics for KSTAR

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1. Introduction

KSTAR has very long diagnostic port because of cryostat with a large, ~9m diameter cylindrical vacuum vessel. So re-entrant cassette is developed to make easy access of diagnostic system to the plasma. This report describes engineering design and manufacture of diagnostic cassette, and also fabrication of a diagnostic system in the cassette. The cassette is made of stainless steel, its weight estimates about 1 ton, windows used for fused silica glass. Bay J is dedicated to a visible diagnostic including H α monitor, survey spectrometer, Bremsstrahlung array, visible TV. The clearance between main vessel and cassette is 20mm. The toroidal and poloidal Balmer H α monitor which locates tangential and central window of cassette, respectively, is especially fabricated for the first plasma of KSTAR. Visible Bremsstrahlung array shares 20 viewing channels with Balmer H α monitor in toroidal direction. Visible survey spectrometer and filterscope has 10 viewing channels in tangential direction, respectively.

2. Bay J Cassette

Bay J cassette is very large size capable of people entering inside of cassette for installation and maintenance of diagnostic system. This cassette design will be model case as prototype for some other similar port and it may be easily modified to a dedicated diagnostic system.

a) Vacuum Requirements for Cassette

(i) Bakeout: The design will accommodate both the operational scenario at full power for 20 seconds and bakeout at 150 °C. Water pipes to provide heating for the bakeout and for cooling during operation are attached to the inner walls of the cassette. The outside port flange, has been sized to meet the Helicoflex seal.

(ii) Distortion under vacuum: The cassette is designed so that in atmosphere at room temperature, there is a clearance of 20 mm at all points between it and the vacuum vessel. The distortion of the sides of the cassette box are limited by ribs to less than 1 mm.

(iii) Motion under disruption forces: Vacuum vessel motion resulting from electromagnetic forces during a disruption can be transmitted through the support structure and cryostat to the

mounting flange of the diagnostic cassette. Because the vacuum vessel vibrations must be transmitted through the vacuum vessel support, the floor of the test cell, and then through the wall of the cryostat in order to reach the cassette, it is expected that the acceleration of the cassette will be less than 1g.

b) Bay J Cassette Structure

The Bay J cassette is larger allowing easy human access. Rib structures have been selected as the method for minimizing the deflection of the 12mm skin under vacuum load. Figure 1(left) shows an exploded view of the cassette and provides a view of the ribs in the flared end. The 18mm gap between adjoining ribs is included for the routing of bakeout water lines and for ease of shop assembly. Figure 1(right) shows exploded view and the arrangement of the ribs with 12mm thick x 26mm deep elements installed in the straight section of the cassette every 165mm of length. 12mm thick x 38mm deep elements are placed every 75mm of length in the flared section of the cassette. The calculated deflections are in the range of 0.26-0.44mm.

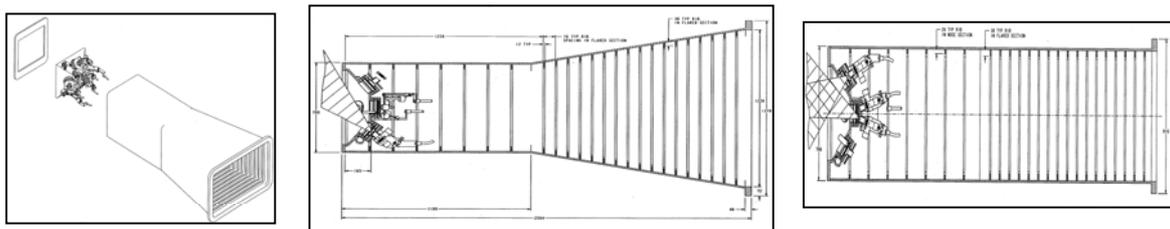


Fig. 1 Exploded view(left), and horizontal(center) & vertical section(right) of the bay J cassette showing stiffening ribs.

c) Window Type, Location and Heat Flux Analysis

In order to accommodate the tangential views, the optical components must be very close to the plasma-facing end of the cassette. Hence the windows will be in a region of high plasma-radiation and, perhaps, neutral particle fluxes. All the windows should be made from fused silica or sapphire. The central and surrounding window has ~100 mm clear aperture. For the initial, 20-second operation, the heating power is 16MW. An estimate from KSTAR, the heat flux gives $18.8W/cm^2$. The front surface temperature is given by $T - T_0 = \frac{q''\delta}{k}(Fo + 1/3)$, for $Fo \geq 0.50$, where q'' is the heat flux and k is the thermal conductivity, 0.014^1 for fused quartz.

$Fo = \frac{\alpha t}{\delta^2}$ is the Fourier number, and δ is the thickness of the window. For $Fo \leq 0.50$, the graphical solution presented in Rohsenow and Hartnett² can be used. For a window thickness of 1cm and a 20-second pulse, the Fourier number is 0.150 for quartz, 0.182 for sapphire, too small for the linear approximation above. From Rohsenow and Hartnett, we have 577K for

quartz, 340K for sapphire, sapphire windows can typically be baked to 450C, while quartz windows are only rated for bakeout to 200C. The bond between the window and metal determines the temperature limit. Aluminum sealed quartz windows have been used on JET, TFTR and NSTX, and can withstand temperatures of 400C for short durations. For providing window protection during discharge cleaning and when the diagnostics are not in use during normal discharges, shutters are provided for all windows.

d) Visible Diagnostics

Fig. 2. shows overview of KSTAR ancillary system. Basic diagnostics is dedicated for the first plasma of KSTAR, and next will be a baseline and mission oriented. H α radiation observes the particle recycling from the Balmer alpha emission at edge of the plasma, by combining the measured H α fluxes with 3D neutral transport codes. Visible survey spectroscopy measures line wavelength, width, and intensities to extract physics. Line wavelength determines plasma composition, electric field and magnetic field amplitude. Line broadening measures n_e, T_i. Line intensities measure population densities, electron density and temperature. The system shares line of sight with filterscopes in toroidal direction. Bremsstrahlung array measures background radiation due to bremsstrahlung, $\Phi_{Br}(\lambda)=gZ_{eff}^2N_e^2\lambda^{-1}T_e^{0.5}$, where g is Gaunt factor. With known electron density and temperature profiles it can be exploited to obtain a line averaged value for Z_{eff} or after Abel inversion a Z_{eff} profile can be produced. Visible TV monitors plasma shape and investigates inner wall & divertor region with viewing angle 45°. Filterscope observes impurity concentration near plasma edge region.

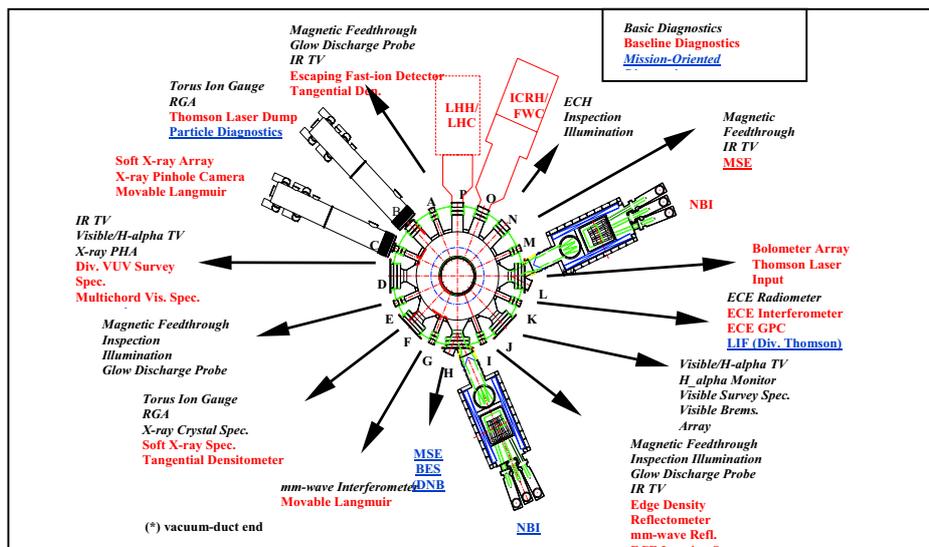


Fig. 2. shows overview of KSTAR ancillary system

e) Fabrication of H alpha Monitor

The toroidal & poloidal H α monitor is fabricated and tested its performance in laboratory using laser, which consists of 5 axis adjustable lens assembly and fiber which have 20 lines of sight in toroidal direction and 2 sets of 10 channels for viewing divertor region. Preliminary experiment shows that spatial resolution of each line of sight is good agree with the design parameter in the range of ϕ 10-27mm. Figure 3 shows fabricated H α system(left) with window flange, lens assembly and optical fiber array, and 20 lines of sight(right). The length of shortest line of sight is about 1.5m and the longest one is about 4.6m from collection optics.

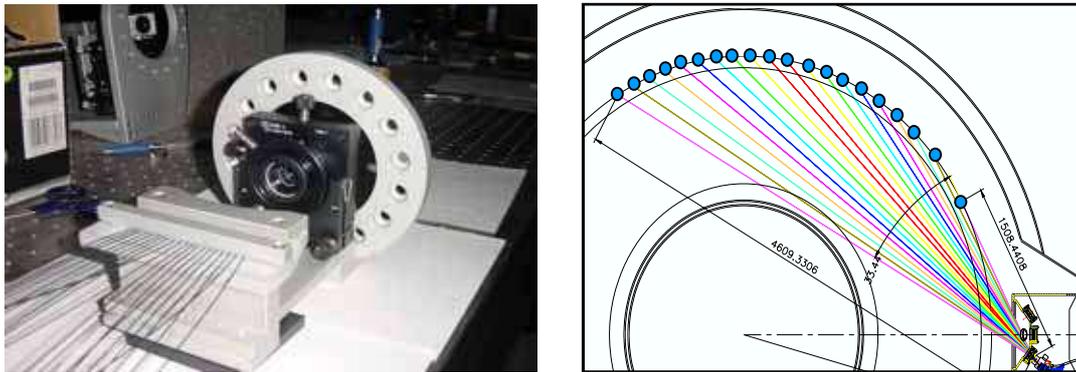


Fig. 3. shows toroidal H α monitor and line of sight.

3. Summary

Re-entrance cassette is developed to easy access of diagnostic system to plasma because of long diagnostic port of KSTAR. The shape of cassette is basically rectangular with 2.2m length, weight is about 1 ton with stainless steel. The cassette consists of five quartz windows and mechanical shutter to protect the window, all diagnostic components will be put into inside of cassette. Some visible diagnostics for KSTAR is designed with re-entrant cassette, especially toroidal & poloidal H α monitor is fabricated and its test shows good results. Heat flux analysis of window has shown that commercial sapphire viewports can be used for 20-second pulses of KSTAR, while commercial quartz viewport will exceed its rated temperature. An appropriate seal design, such as the aluminum-based mounting scheme developed at UKAEA Culham Lab, and the use of a ring baffle for the window edge, should enable the use of silica based windows where necessary.

References

1. Lide, D., ed., *Handbook of Chemistry and Physics, 75 edition*, CRC Press, Ann Arbor, 1994, pp.12-158 – 12-188.
2. Rohsenow, W. and J. Hartnett, ed, *Handbook of Heat Transfer*, McGraw-Hill, New York, 1973, pp.3-66 – 3-68.