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Analysis of diagnostic cassette and development of divertor H-alpha monitor for KSTAR

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1. Introduction: The KSTAR vacuum vessel and its enveloping coil structures are contained within a cryostat that protects the coils from high heat gains. The interface flanges for the vacuum vessel exist at the radius of the cryostat's main cylindrical surface that is roughly 2.3 meters from the plasma. Re-entrant diagnostic port cassettes have been designed for Bay J allowing useful diagnostic access to the plasma. Front-end face of cassette is close to plasma, thereby maximizing the available view angles and includes 5 windows and shutter assemblies. Many diagnostic systems are installed inner side of re-entrant diagnostic cassette. Especially, divertor H-alpha monitor, locates on upper and lower side of center window, is fabricated to view divertor region, consisting of 10 channels of line of sight in each side. The structure and thermal analysis of diagnostic cassette is performed, and also collection optic system is developed and it shows good image quality.

2. Analysis of diagnostic cassette: The cassette structure consists of two different configuration as straight and flared section according to the port shape as shown in figure 1. Structure analysis for vacuum pressure is performed on the diagnostic cassette to understand displacement. Temperature rise of cassette by plasma radiation is below 63 ^{o}C in baseline operation(20sec), so the additional cooling system for cassette itself is not required during initial operation. Thermal analysis of diagnostic cassette is also performed for baking of vacuum vessel and PFC only, or otherwise using hot water for baking the cassette itself.

a) Structure analysis: Distortion under vacuum: Analysis is performed by ANSYS FEM analysis method (figure 1, left) by 3-D shell modeling, material SS316LN, cassette wall thickness 12. 7 mm, and applied vacuum pressure load. The results show that maximum displacement is 5.3 mm center of flared section of cassette, but other areas are below 0.5 mm as shown in figure 1(right), and so to limit the displacement within 1 mm the additional stiffener is required. Rib structures have been selected as the method for minimizing the deflection of the 12.7 mm skin under vacuum load. The 18mm gap between adjoining ribs is included for the routing of bake out water lines and for ease of shop assembly. 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 after installing ribs structure are in the range of 0.26-0.44mm[1].

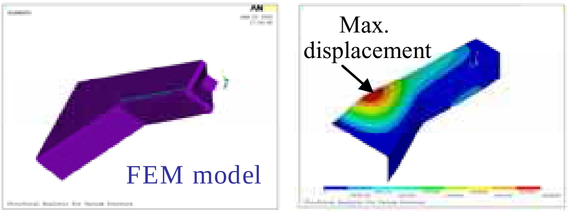

Fig.1 Structure analysis for vacuum pressure using FEM model(left), shows 5.3 mm maximum displacement in flared section(right) of cassette.

b) Thermal analysis of cassette and window : Assuming no baking and cooling in diagnostic cassette and no loss of heat flux from cassette by radiation and conduction, temperature of plasma facing side of cassette will be near 120 °C by baking and radiation from PFC and vacuum vessel baking only, but center of cassette stay about 34 °C, so it needs baking cassette itself. This report shows the temperature will be around 100 °C by additional baking tube inside cassette with 110 °C hot water of 0.5m/s flow rate. After baking the cassette the temperature ranges reaches at 93 - 110 °C as shown in figure 2(left). Windows will be brazed or bonded into viewports, which will be bolted to the cassettes. The heat loads and pulse lengths on KSTAR present a severe thermal environment. Uncooled, commercially available viewports cannot withstand the 300 second pulses ultimately envisioned for KSTAR, but will be adequate for the 20-second pulses of the initial configuration. In this document, the heat loads on the windows are defined conservatively, and maximum temperatures are calculated.

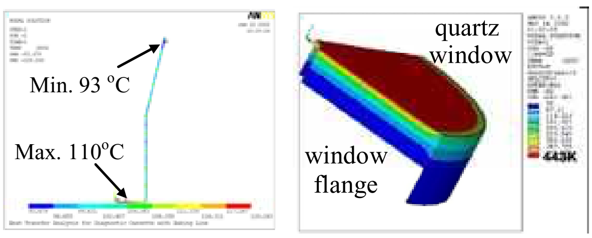

Fig. 2 Temperature distribution of 93-110 °C at cassette by 110 °C hot water with 0.5m/s flow rate(left), temperature distribution in 10cm diameter quartz window after 20sec operation by ANSYS analysis(right).

The results indicate that commercially available quartz viewports are, in general, only acceptable for use in the initial KSTAR operation. Figure 2(right) shows the thermal response of a quartz window to a 20sec pulse. The peak temperature, 443 K, is within the range of accuracy of the graphical solution for the one-dimensional analysis[2]. The allowable temperature is determined by the seal between the window and its mounting flange, and not by the window material itself. The use of alternate sealing techniques, in concert with a “ring baffle” which directly protects the seal area from radiation, should enable the use of silica based window materials even in long pulse operation. And while the temperature at the quartz/metal interface, around 20 °C, is significantly lower than the peak temperature, it should be noted that almost all of that transition takes place over the radial span of one element, and more detailed analysis, confirmed by testing, is required before such a window can be used in the long pulse operation of KSTAR.

3. Divertor H-alpha monitor : H-alpha light comes primarily from the plasma edge and divertor regions, and it is desirable to view this light at multiple locations to quantify plasma edge conditions, quantify recycling sources. Divertor H-alpha system locates at middle window of cassette to see divertor region, which consists of 10 viewing channels with optical fibers and collection optics.

a) Fabrication : Figure 3(left) shows optical line of sight with 10 channels viewing upper divertor region, angle between each channel is 4-5^{o}. Optical assembly for light collection consists of optical fibers and lens with adjusting stages as shown in figure 3(right). The optical stages consist of 5 axis fine tuning system, x-y-z-ϕ and rotation, to focus small optical image on the fiber(400 microns, quartz). Fiber holder has 500 microns small grooves to places fibers in every 1.5mm distance, and two kinds of Aluminum covers press the fibers softly as shown in figure 3. Two sets of optical assembly to view upper and lower divertor region places at center window of cassette. Fiber end surface locate at focal plane of lens, radius of 80 mm. Design considered the interference between viewing angle and the mechanical shutter opening which locates at outside of window flange.

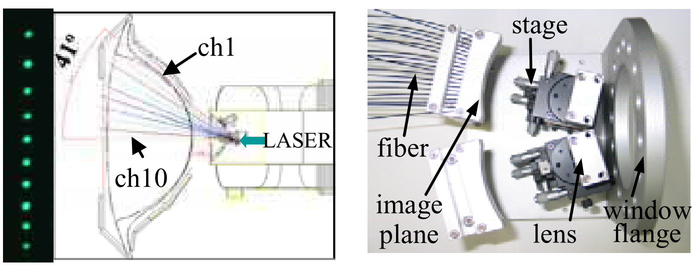

Fig. 3 Divertor H-alpha system which consists of 10 lines of sight and shows fiber images from laser(left), and two sets of optical assembly consist of fibers, collection lens, optical stages and window flange(right).

b) Optical system : Figure 4 shows fiber position is aligned with surface normal in order to make easy alignment and distance between each fiber is around 1.5mm, also fibers are aligned along curved image surface. Lens assembly consists of 3 small lens, total length of lens assembly is less than 20mm, and height of image surface is 48mm. Optical performance of the lens system is evaluated by spot diagram. Image quality by spot diagram for each position is shown in figure 4(right), the upper left diagram shows image for zero incidence angle to normal surface of lens, right is image for incidence angle of 16 degree to normal surface of lens, the most lower is for 21-23 degree with full half angle of lens system. Total acceptance angle of lens system for divertor H-alpha monitor is around 41 degree, and lens system is designed with symmetry configuration about normal surface of lens. The image quality with zero angle incidence is more better than full half angle. Diameter of quartz optical fiber is 400 micrometer. Spot size of image at fiber surface is as small as fiber diameter in order to maximize light intensity going through fiber. Total lines of sight are 10 channels and those are corresponded to each fiber. Most far distance from lens to plasma is 1800mm and shortest distance is 1500mm, this is criteria to make and evaluate lens system. Also design focused to minimize interference between rays from each line of sight. Design considered that gap between each lens element is more than 0.1mm. All lens material used for fused silica with refractive index 1.456368 at 656.3nm and 1.45866 at 587.6nm. Spatial resolution of each channel at plasma region is ϕ10.3-12.3 mm spot size measured by entering laser light backward at the end of fiber.

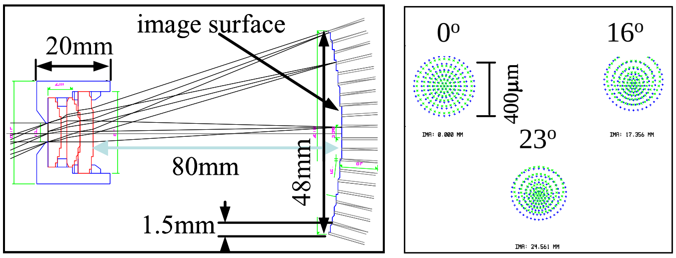

Fig. 4 Layout of lens optics by Code V ray tracing to make image at fiber surface(left), and spot diagram at image surface, spot size is within 400 microns, shows total field for each different incidence angle(right).

4. Summary : Diagnostic cassette is developed to easy access of plasma for long diagnostic port of KSTAR. The cassette consists of five quartz windows and mechanical shutter to protect the window. Under vacuum, thermal analysis of cassette shows that the maximum displacement is 5.3 mm, to limit the displacement within 1 mm the additional stiffener is required. The temperature rise of front face of cassette is around 120 °C when only vacuum vessel is baked, the minimum temperature is about 34 °C at center of cassette. The additional baking system is required to maintain the baking temperature 100 °C. The temperature ranges are 93 - 110 °C along the cassette, if the 110 °C hot water is used for baking. The window analysis has shown that commercial quartz viewports can be used for 20-second pulses of KSTAR. The divertor H-alpha monitoring system is developed to monitor the divertor region, and it has 10 channels viewing lines will be installed in upper and lower divertor region with 41° total viewing angle, spatial resolution of each channel at the plasma region is in the range of spot size ϕ10.3~12.3 mm. The optical lens system shows good image quality by analysis of spot diagram.

References

1. 31st EPS conference on plasma physics, London 2004 ECA Vol. 28B, P-5.180(2004)
2. Rohsenow, W. and J. Hartnett, ed, Handbook of Heat Transfer, McGraw-Hill, New York, 1973, pp.3-66 – 3-68