CCD Camera Imaging of Plasma-Limiter Interaction in the Madison Symmetric Torus

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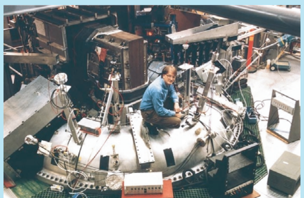
Abstract

A CCD camera has been used to observe reversed-field pinch plasmas in the Madison Symmetric Torus (MST) at a rate of 1.3 msec/frame. The resulting images consist mainly of Ha emission during the discharge, and heat from glowing carbon and ceramic limiter tiles after the discharge, both indicators of the region of plasma-surface contact. Typically the plasma footprint evolves from an even loading of an outboard toroidal limiter, into an intense interaction on the poloidal limiter which covers the break in the toroidal electrical continuity of the wall. The latter effect is attributed to growing error field at this poloidal gap toward the end of the discharge.

MST vacuum vessel also has the function of

1) flux conserver
2) single turn toroidal field coil



Madison Symmetric Torus (Reversed Field Pinch)

- major radius R = 1.5m
- minor radius a = 0.52m
- wall is 50mm thick aluminum
- small port holes (to minimize perturbation to vessel currents)
- most port holes 38mm diameter
- pulse length 70 msec

Plasma facing surface is primarily aluminum with some strategically located graphite & ceramic protection tiles

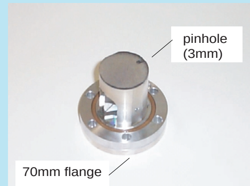
Installation of tiles covering poloidal gap

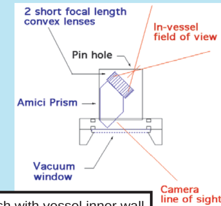
Limiters

- toroidal belt limiters on inner and outer walls at the midplane
- poloidal limiter covering the break in the toroidal electrical continuity

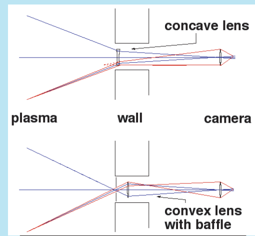
Inner wall portion of poloidal limiter:
- central ceramic tiles cover the gap
- these are flanked by carbon tiles

Wide angle view of vessel interior requires optical elements within a few centimeters of the plasma

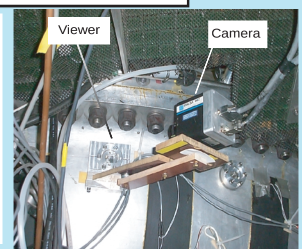




Viewer for a 38mm porthole. Pin hole flush with vessel inner wall.



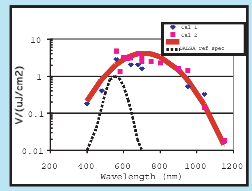
- Viewer with concave lens rapidly coated by plasma impurities
- Convex lens only exposed to plasma through pinhole: long lasting & no shutter



Camera focussed on vessel-mounted viewer

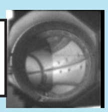
CCD camera

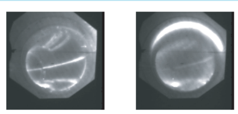
- camera spectral sensitivity broader than eye: sensitive to near infrared
- 128 x128 pixel images
- maximum frame rate: 800 frames/sec



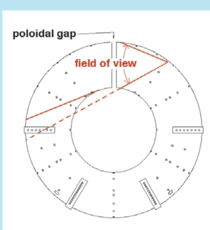
Camera view from outer wall sees whole cross section at the poloidal gap plus 90 degree segment of outer wall

reference image without plasma (artificial lighting)

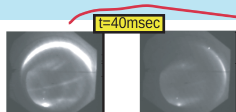




- early in discharge, toroidal limiters uniformly illuminated
- Later in discharge, interaction is mainly at poloidal limiter covering gap



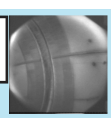
Plan view of torus: viewer on outer wall, just below midplane

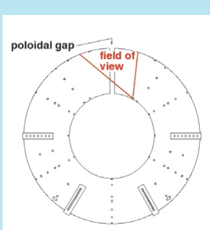


- 2 discharges at the same time slice
- appling external horizontal radial field at the gap reduces interaction with limiter

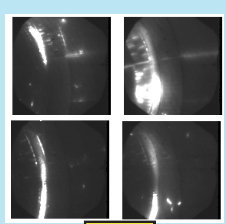
Camera view from inner wall sees details of outboard interaction with poloidal limiter

reference image without plasma (artificial lighting)



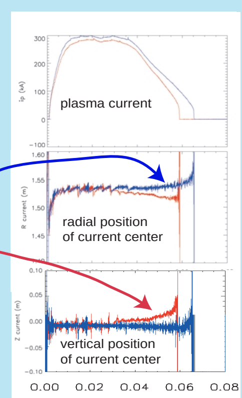


Plan view of torus: viewer on inner wall, just above midplane



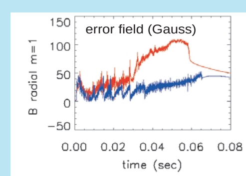
- 4 discharges at the same time slice
- different vertical and horizontal radial field at the gap determines plasma interaction footprint

Interaction with poloidal limiter is the result of growing error field at the poloidal gap



- lack of conductor at poloidal gap allows radial field their. External coils are used to null our error field
- compare 2 discharges with and without programmed error field correction
- the current center of the discharge without error field correction moves upward at the end of the discharge, consistent with CCD images
- difference in radial excursions also consistent with CCD image of plasma boundary

- applying Br to reduce error field equivalent to re-centering plasma at the gap with Ip x Br force.



magnitude of m=1 component of radial field at the poloidal gap

Tile Temperature

- immediately after discharge light is due to thermal radiation only
- camera calibration gives hot spot temperature > 1000 deg. C

Image Spectrum

- for a limited series of discharges, an H-alpha filter (656nm) was inserted betwee camera &viewer
- light during discharge predominantly due to recycling of hydrogen

Conclusions

- Main plasma surface interaction is on the toroidal limiter. This is consistent with the fact that the field is predominantly poloidal at the plasma boundary in an RFP; the toroidal limiter therefore intercepts more flux.
- Late in the discharge the plasma contact region moves to the poloidal limiter. This is due to growing error fields at the gap in the conducting shell
- Unless steps are taken to compensate the error field at the gap with applied external fields, the surface temperature at the poloidal limiter can exceed 1000 degrees Celcius.