Development of Impurity Influx Monitor (Divertor) for ITER

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Background and Objectives

- The main function of the Impurity Influx Monitor (divertor) is to measure the parameters of impurities and isotopes of hydrogen (tritium, deuterium and hydrogen) in the divertor plasmas by using spectroscopic techniques in the wavelength range of 200 - 1000 nm.
- The Japan Home Team (Japan Participant Team) had designed the Impurity Influx Monitor (divertor) during the EDA and CDA phases.
- Because the machine size of ITER was reduced after EDA phase, interfaces between ITER and the monitor changed. In order to install in the present ITER, changes in the design of the monitor are required.
- Optical design of this monitor and mechanical design of front end optics are carried out to realize the measurement in the harsh environment for diagnostic components such as high temperature, high magnetic field, high vacuum condition and high radiation field.

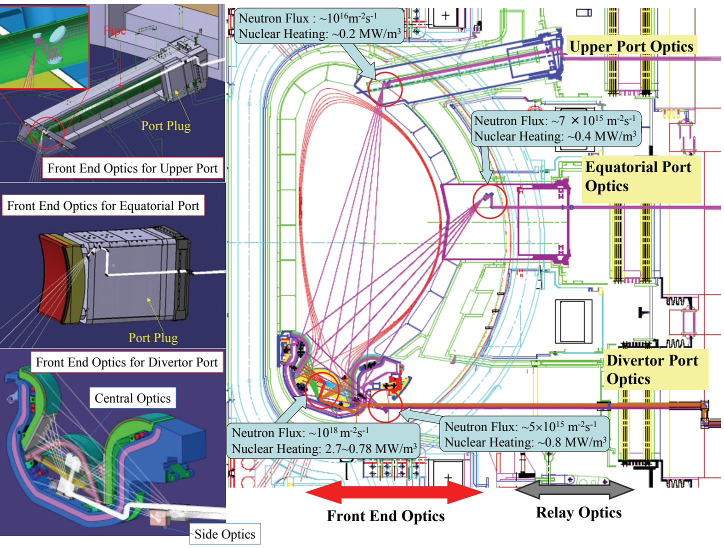
ITER Environment

- Neutron Flux : 10^{12}~10^{18}/m^{2}s^1
- Nuclear Hearting Power Density: 0.2 ~ 2.7 MW/m^3 (for stainless steel)
- Temperature: Operating Temp.: 100 °C (in) / 150 °C (out); Baking Temp.: 200 °C (Vacuum Vessel), 240 °C (in Vessel Components)
- Vacuum: Leak Rate < 5.0x10^{-9} Pam^3/s; Base Pressure <10^{-5} Pa
- Magnetic Field: 3~5 T near Shutter; 0.2~0.7 T at Vacuum Flange; 0.012 T at Diagnostic Room

Design Process

- Optical Design for Each Viewing Fan
- Mechanical Design of Optical Components
- Heat Analysis for Nuclear Heating
- EM Analysis for Plasma Disruption
- Nuclear Analysis for Shielding

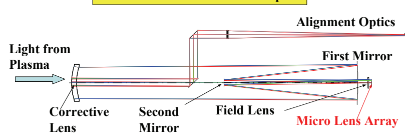
Results of analysis is feedback to the mechanical design and/or the optical design.



Optical Design

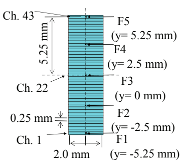
- Ray trace analysis of each viewing fan has been carried out by using optical design code Code V and ZEMAX.
- As a collection optics, simple Cassegrain telescope with optical alignment optics is used in each viewing fan.
- Micro lens array is placed on the imaginary plane of Cassegrain telescope (before fiber bundle).
  - Extend the image of fiber to toroidal direction to increase the detected light
  - Reduce the coupling loss to fibers
- The optics designed here will meet the ITER requirement for spatial resolutions (< 50 mm).

Schematic View of Collection Optics

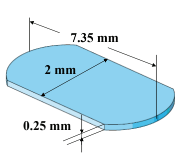


- A Cassegrain telescope system is composed of simple spherical mirrors and lenses.
- The collection optics for each viewing fan has same optical parameters.
- The alignment optics is also installed behind the second mirror.

End View of Micro Lens Array

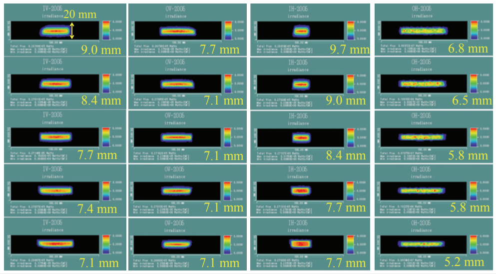


Schematic View of Micro Lens



- The micro lens array is made of silica.
- This micro lens array is piled up many micro lenses, which is thin spherical lens with height of 0.25 mm, thickness of 7.35 mm and effective width of 2 mm.

Spatial Resolution of Central Optics in Divertor



Spatial Resolution of Other Optics

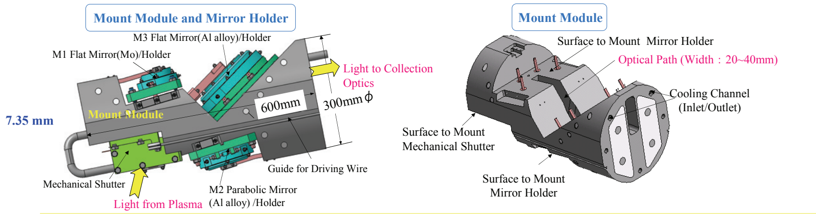
Viewing Fan	Sight Line	Spatial Resolution (mm)
ii) Side Optics	F1	33
	F2	27
	F3	25
	F4	22
	F5	22
iii) Equatorial Port Optics	F1	46
	F2	45
	F3	48
	F4	44
	F5	46
iv) Upper Port Optics	F1	36
	F2	35
	F3	36
	F4	35
	F5	35

Mechanical Design of Front End Optics

- Conceptual design of the mirror folder on the upper, the equatorial and the divertor ports.
- Conceptual design of the cooling channel for the optical components.
- Estimation of the temperature rise of the cooled optical components by a simple model calculation.
- Studies of productivity and integration of optical components.

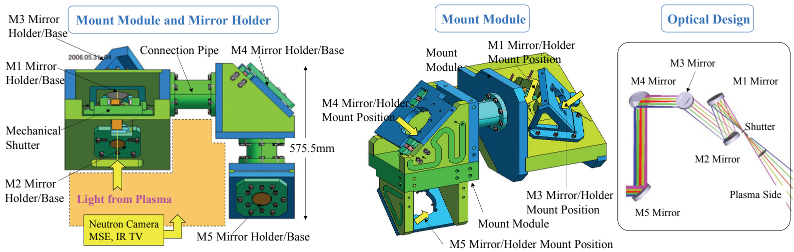
Mechanical Design of Front End Optics of Upper Port

- As a result of the integration in the upper port, optical components of the front-end optics were installed inside the pipe (ID: 300 mm) replaced with that for the remote-handling of the port plug.
- Three mirrors can be installed on the mount module with 300 mm diameter. It is also used for a neutron shielding and cooling the mirror. It is manufactured by machining and drilling the solid bar steel.
- The mount modules are made of stainless steel 316 and mirror holders are made of copper alloy.
- The M1 mirror (plasma facing mirror) is made of Mo and other mirrors are made of Al alloy.
- Cooling channel is made by drilling the mount module and welded the closure plate except of the inlet and the outlet of a cooling water.
- The kinematic mount type optical alignment is used to adjust tilt angel of the first mirror before the installation in the port.
- The copper mesh belt is connected from the first mirror to mount module to remove the heat load by nuclear heating.



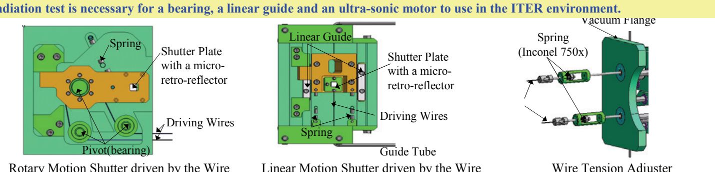
Mechanical Design of Front End Optics of Equatorial Port

- Five mirrors are necessary to avoid the interaction with other diagnostic equipments such as radial neutron camera, MSE and IR TV.
- Three Mirrors (M1 to M3) are mounted in the one mount module, and M4 and M5 have another mount module. They are manufactured by welding the solid plate.
- Two mount modules are connected by the pipe.
- The mount modules are made of stainless steel 316 and mirror holders are made of copper alloy.
- The M1 mirror (plasma facing mirror) is made of Mo and other mirrors are made of Al alloy.
- Each mount module has many cooling channel to remove the heat load by the nuclear heating. They are constructed by machining the groove on the plate and welding a closure plate except for the inlet and outlet of the cooling water.
- The neutron shield is not considered in the present design to install in the narrow space.
- The kinematic mount type optical alignment is also used to adjust tilt angel of the first mirror before the installation in the port.



Mechanical Design of Shutter for Upper and Equatorial Port Optics

- Three type of shutter were designed.
- The shutter plate has a micro retro-reflector array for the in-situ calibration.
- This shutter is mainly used during the discharge cleaning.
- The silicon nitride (Si_3N_4) ceramic is a candidate for a material of the bearing and/or the linear guide.
- The ultra-sonic motor is a candidate for an actuator.
- Shutter plate is made of titanium alloy and others are made of stainless steel 316.
- To compensate the thermal expansion of driving wire, the wire tension adjuster is also designed.
- The irradiation test is necessary for a bearing, a linear guide and an ultra-sonic motor to use in the ITER environment.



Rotary Motion Shutter driven by the Wire
Linear Motion Shutter driven by the Wire
Wire Tension Adjuster

Heat Analysis

- **Analysis Code : ANSYS Design Space Ver.9.0 (Steady State Analysis), Ignore Radiation and a Slip on the Boundary of Each Component**
- **Assumption**
  - **Nuclear Heating : Constant for Different Materials : 0.2MW/m³ (Upper Port) : 0.4MW/m³ (Equatorial Port)**
  - **Initial Temperature : 150℃**
  - **Cooling Water Pressure/Flow Rate : 4MPa Constant、Pressure Difference : 0.05 MPa、 3~5ℓ/min**
  - **Cooling Water Temperature : 150℃ Constant**

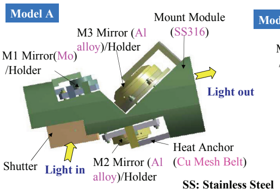
Materials

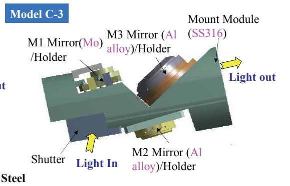
- **M1 (plasma Facing Mirror) : Mo**
- **Other Mirrors : Al Alloy (the tendency of the metal to creep under these stresses tends to result in delayed distortions when temperature is up to 300 ℃)**
- **Mount Module : SS 316**
- **Mirror Holder : SS 316/Cu Alloy (Young's module of copper decreased as increasing temperature up to 200 ℃)**

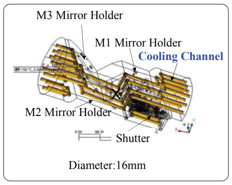
Temperature Profile on the Mirror and Mount Module in Upper Port

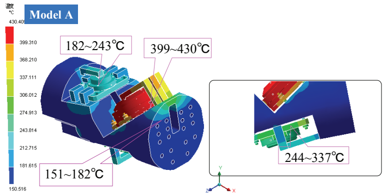
Model for Analysis

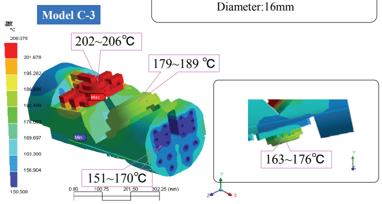
	Cooling Method of Mirrors
Model A	● The kinematic mount type optical alignment system is installed on all mirror holders. ● Mount module and mirror holders are made of SUS316. ● The heat anchor (Cu mesh belt) is connected from mount module to all mirror holders.
Model B	● The kinematic mount type optical alignment system is installed on M1 mirror holders only.
Model C-1	● Remove the heat anchor from M2 and M3 mirror holders
Model C-2	● M2 and M3 mirror holders are made of the copper alloy
Model C-3	● All mirror holders are made of the copper alloy.





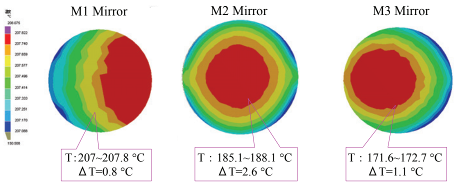


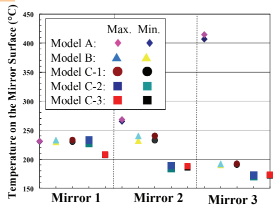




- **Model A : The thermal conduction through the heat anchor and several bolts connected to the mount module is insufficient to remove the large amount of nuclear heating.**
- **Model C-3: By using mirror holders made of copper alloy and contacting on the mount module tightly, the temperature on the all the components is reduced to less than 210 °C**

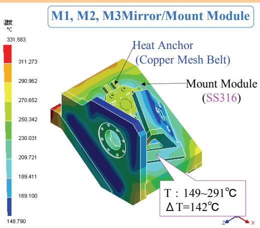
Temperature Profile on the Mirror Surface in Upper port in Model C-3

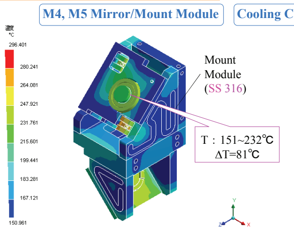


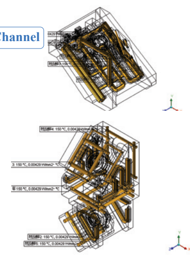


- **By using mirror holders made of copper alloy and contacting on the mount module tightly, the temperature on the mirror surface is also reduced to less than 210 °C**
- **The temperature difference on the mirror surface is 0.6 ~ 8 °C. It is not deepened on the model.**

Temperature Profile on the Mirror and Mount Module in Equatorial Port







- **Mirror Holder (Cu alloy) M1 : 169~290 °C M2 : 210~250 °C M3 : 149~230 °C M4 : 216~232 °C M5 : 216~248 °C (ΔT Large)**
- **Mirror (M1:Mo, M2~M5:Al alloy) M1 : 257~263 °C M2 : 212~214 °C M3 : 199~200 °C M4 : 233~233 °C M5 : 232~233 °C (ΔT Small)**
- **The temperature difference on the mirror holders and the mount modules exceeds 100 °C which is two times larger than that in the upper port.**
- **In the point of view of the cooling, monolithic structure such as the front end optics of the upper port is favorable**

Summary

(1) Ray trace analysis for each viewing fan indicates that the optics designed here will meet the ITER requirement for spatial resolutions (< 50 mm).

(2) The mechanical design of front end optics in the upper and equatorial port is carried out based on the optical design mentioned above.

(3) The heat analysis indicates that it is possible for mirrors to be cooled by the thermal conduction using the mirror holders made of a copper alloy and making many cooling channels on the mount module.

(4) The effect of thermal deformation to the optical properties is also calculated by using the optical design code ZEMAX. In the optics on the upper port, it is small. But in the equatorial pot, the measured position near the divertor region is displaced about 150 mm by the thermal deformation.

(5) In the point of view of the cooling, the monolithic structure such as the front end optics of the upper port is favorable.

Future Plan

(1) Design of mount module and mirror holder in the divertor port

(2) Design of the interface between a mount module and a pipe and/or a port plug (mounting method, route and connection of cooling water, etc)

(3) Design of the remote mirror adjustment system including the actuator and the driving method

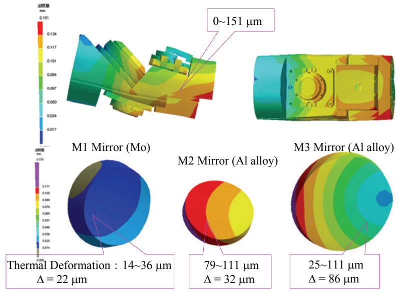
(4) Design of the actuator for shutter

(5) Electro-Magnetic analysis to protect the front end optics during disruption

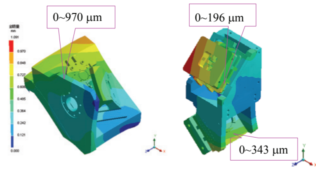
(6) Neutron analysis to determine the thickness of the neutron shield after the front end optics

Heat Analysis – Heat Distortion

Thermal Deformation of Front End Optics of Upper Port



Thermal Deformation of Front End Optics of Equatorial Port



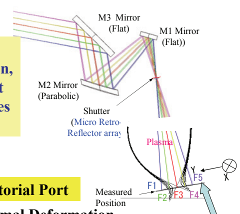
	Thermal Deformation	Difference
M1 Mirror	424 ~ 552 µm	128 µm
M2 Mirror	348 ~ 526 µm	178 µm
M3 Mirror	322 ~ 475 µm	153 µm
M4 Mirror	31.5 ~ 211 µm	179.5 µm
M5 Mirror	9 ~ 211 µm	202 µm

- **It seems that the mirrors are deformed to the concave mirror by the heat distortion. (The deformation is enhanced because that the sliding between the mirrors and mirror holders and/or a mount module is not considered in this analysis)**

Heat Analysis – Effect on the Optical Properties

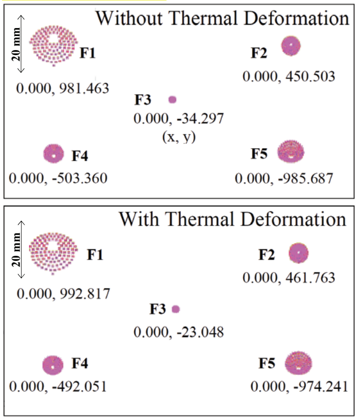
- **In order to estimate the effect of the heat distortion to the optical property, ray trace calculation is carried out by using ZEMAX code. In this calculation, it is assumed that the thermal deformation of mirror surface changes the tilt angle of each mirrors and thermal deformation of the mount module changes the angle of the light to the vacuum window.**

Upper Port Optics



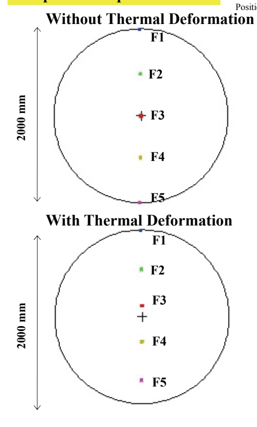
Footprint shows the positions of spot images on the measured position.

for Upper Port Optics



- **The displacement of the measured position is less than 20 mm by the thermal deformation, but the size and the shape of spot is almost same. This means that the effect of heat distortion to the optical property is small in this port**

Footprint of Equatorial Port



- **The measured position is displaced about 150 mm by the thermal deformation. This displacement is not small but it is possible to observe the measured positions by using the alignment optics installed on the collection optics and to adjust by using the optical alignment installed on the just behind the vacuum window**