Development of a 3D printed water cooled bolometric camera for long pulse operation in WEST From design to manufacturing

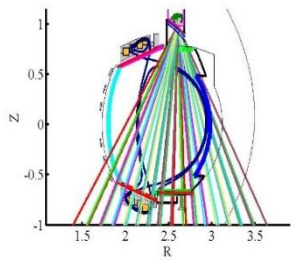
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INTRODUCTION

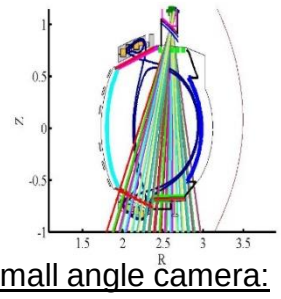
WEST is a full tungsten (W) superconducting, water cooled tokamak, targeted at mastering long pulse operation in a metallic environment. It is equipped with two divertors at the top and bottom of the machine. As the new holding structures of the top divertor are occupying most of the space in the vertical ports, it was necessary to redesign the vertical bolometer and install it in-vessel to recover the view of the full poloidal section. We present here the solutions which were adopted to fulfill this goal.

Geometry of the lines of sight



Large angle camera:

16 LOS, maximum covering of the poloidal section. Radial resolution of LOS at divertor 8 cm



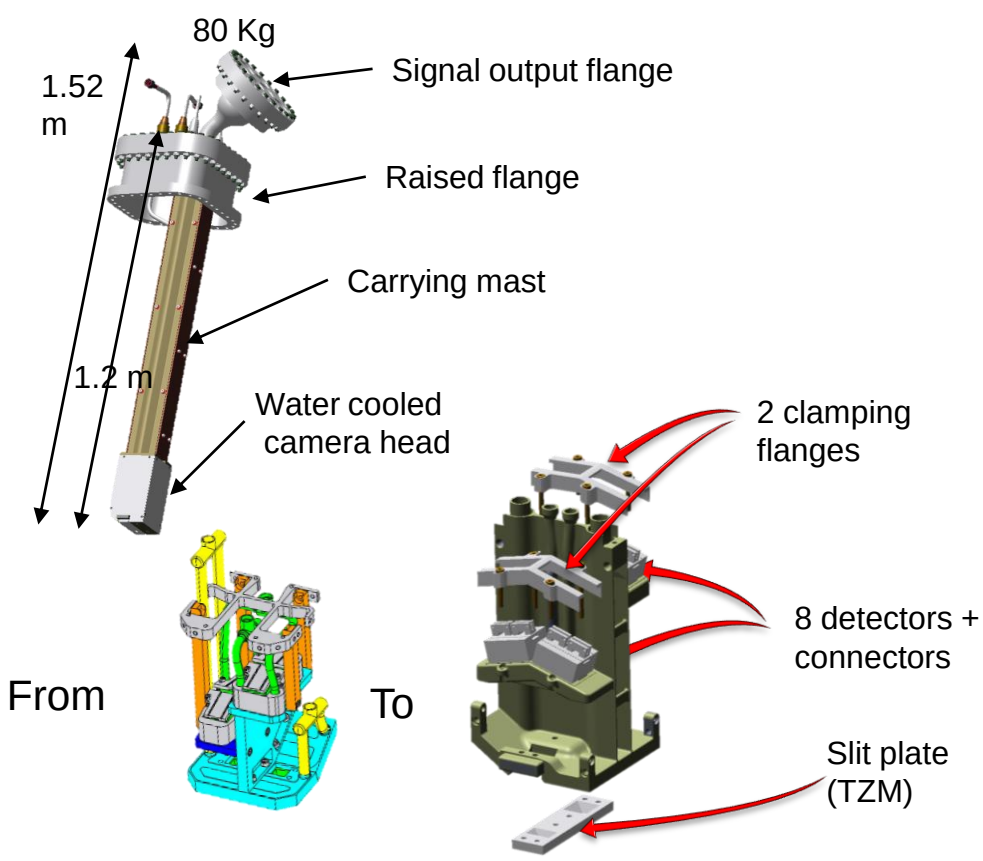
Small angle camera:

16 LOS, better resolution in plasma center and in lower divertor zone. Radial resolution of LOS at divertor 5 cm

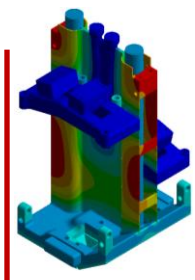
Technical requirements

- The 2 cameras are in the same holding structure
- The camera head is lowered in the vertical port to recover a maximum view of the poloidal cross section.
- It is shielded from the fast particles created by the plasma.
- The resistive metallic bolometer detectors are cooled down continuously with a 6 Bars, 20 °C water loop.
- The bottom plate of the camera is cooled down by a 30 bars water loop whose temperature can be raised above 200 °C during machine baking.
- Except the detectors which must remain under 50 °C, the whole camera head can be heated up above 200°C.
- Low cobalt and amagnetic material.

Camera head: Using additive technology

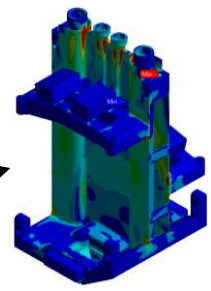


Thermo-mechanical and hydraulic calculations



Bolometers
33°c during shot
20°c during machine baking

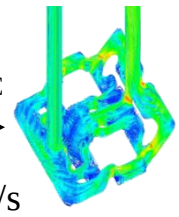
Inconel 625 at 300°C
Vertical displacement: 0.3 mm
Stress:140 Mpa (max tol. 240 Mpa)



30 Bars, 200°C

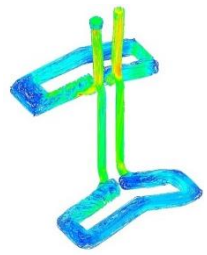
Water flow →

V ~ 3m/s



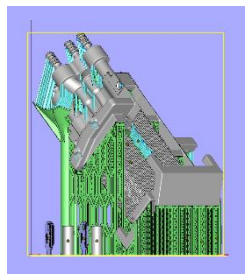
6 Bars, 20 °C

V ~ 2m/s



List of Manufacturing Operations and Control

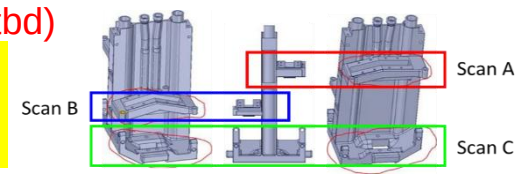
Printing of the camera head by LBM process (Laser Beam Melting) in inconel 625 with test specimens by POLY-SHAPE*.



- Ultrasonic cleaning in water
- Relaxation treatment
- Removal of holding structures
- Finishing by sandblasting and micro balling
- Hot isostatic compression

- Dimensional control: √
- Hydraulic test: Bottom plate (18 bars)/detectors (10 bars)√
- He sealing test: √
- Welding test: Inconel 625/SS316L water pipes connection √
- Traction tests on sample tubes:√
- X-ray Tomography: To be done (tbd)

Scan critical areas to detect porosities or particulate inclusions (Resolution of the order of 50µm)



- He cold pressure test: 10 bars detectors, 40 bars bottom plate:tbd
- He pressure tests with thermal cycles at 200 °C after welding pipes: 10 bars detectors, 40 bars bottom plate tbd

Feedback from additive technology

- Accuracy of the additive process about 0.1 mm
- Cooling optimized: No more soldering, water closer to cooled surfaces.
- Decreased weight and more compact.
- Integration of complex functions (striations, grid holder)
- Number of pieces reduced from 30 to less than10.
- Cost divided by 3.

The printed camera head







will be installed on WEST for the next campaign in 2020