TESTING OF A FULL-SCALE PROTOTYPE IN-VESSEL VIEWING SYSTEM WITH HYBRID LiDAR DESIGNED FOR NUCLEAR COMPATIBILITY

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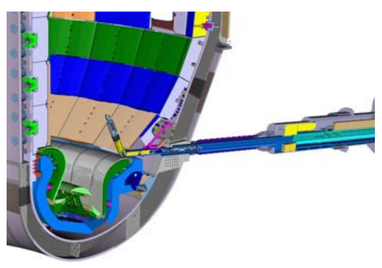
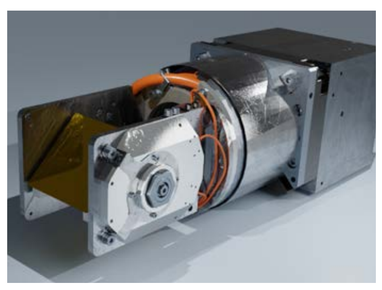
INTRODUCTION

The In-Vessel Viewing and Metrology System (IVVS) is a key ITER diagnostic for inspection of the plasma facing surfaces. The specified resolutions are in the range of 1mm for viewing and 0.1mm for depth measurement for distances from the system from 0.5m to 10m.
During ITER operations (between plasma pulses), the IVVS will be used to monitor more than 95% of the tokamak first wall surfaces for damage and erosion. Therefore, the IVVS must be radiation (up to 2.5MGy) and vacuum (down to 5 10-4Pa) compatible, with distant control cubicles (more than 295m long cabling) and a restricted space envelope. The small size, and harsh operating environment of the IVVS have required extensive technological development of components.
This new full-scale prototype is the first where all main sub-assemblies use technologies compliant with the challenging Tokamak environment and compatible with the available space.

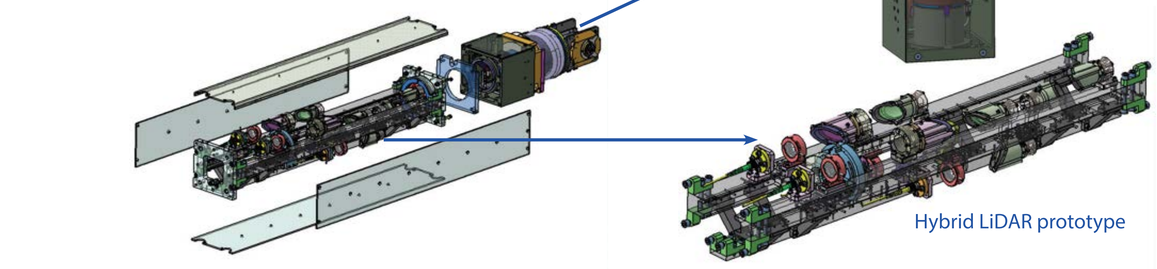




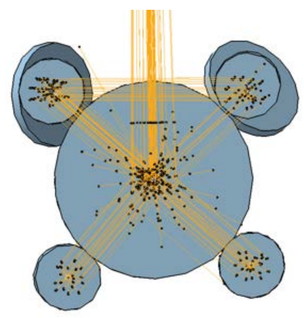
DESIGN OF FULL SCALE PROTOTYPE OF IVVS

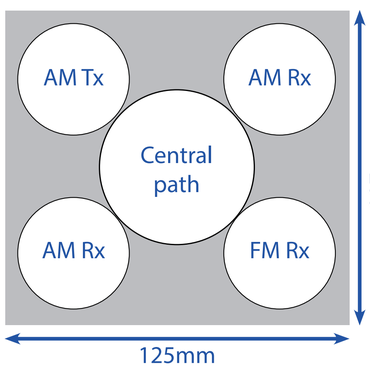
At Bertin Technologies, we developed a novel opto-mechanical hybrid design that allows both Amplitude Modulated viewing and Frequency Modulated metrology LiDAR systems to be used simultaneously.

We also succeeded in the development and integration of a scanning system with piezo actuators and optical encoders compatible with the environment.



The optical layout is based on two bistatic measurement systems with 18 optical components. A total of 4 linear stages is used to do the focusing. The innovative design includes both transmission and collecting optical path for each LiDAR systems (AM and FM) and a separate optical reference pathway for the LIDAR metrology system to compensate for the lack of a standard fibre-optic circulator. The optical probe is designed to do measurement with power range down to 80pW for the vieiwing channel & 3.8pW for the ranging channel (considering input powers of 100mW for the AM and 60mW for the FM).

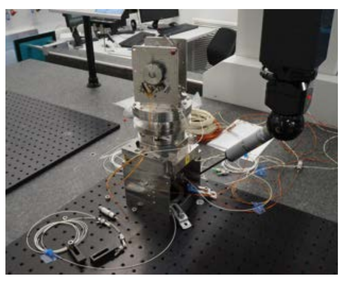




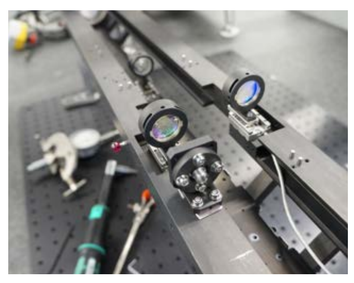
The optomechanical design is divided into five pathways: FM Tx, AM Tx, FM Rx, AM Rx and central. Each pathway is placed on a separate axis in a quincunx shape to limit obscuration of the return beam.

ASSEMBLY AND INTEGRATION OF A FULL SCALE IVVS MEASUREMENT PROBE

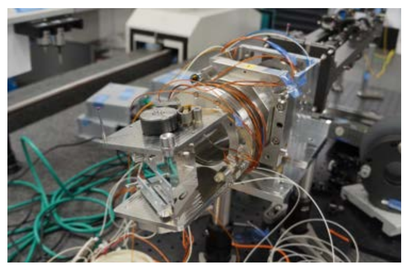
The assembly and alignment of both subsystems was done in Bertin's clean room using high repeatability and precision metrology systems (including a coordinate measuring machine, a laser tracker and a wavefront sensor). The assembly of the IVVS measurement probe in a clean room validates the vacuum compatible assembly process.



Scanning system assembly



Hybrid LiDAR prototype assembly



Full scale IVVS measurement probe prototype integration

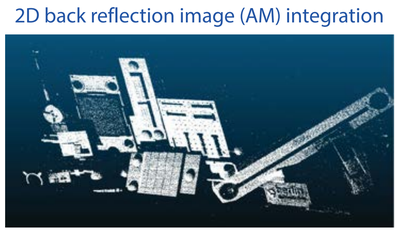
PERFORMANCE STUDY

A thourough study of the performances was done for focus distances from 0.5m to 11m with generation of three-dimensional images (AM & FM). This test campaign was set to check performances using simulaneously both LiDAR systems while scanning at speeds up to 0.63rad/s (at 10m it corresponds to a displacement on target of approximately 7.25m/s) with a sampling frequency of 5kHz.

Example of measurement taken at 4.5m:

Photo of the test setup

2D back reflection image (AM) integration



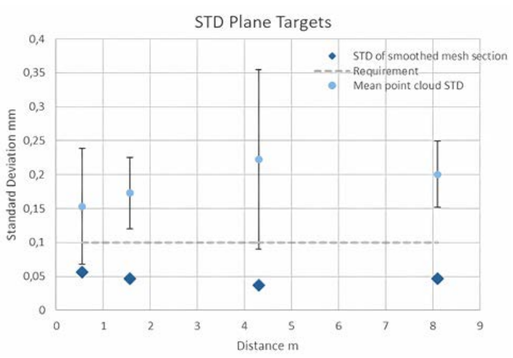
3D image (FM)

Overlapping of AM & FM

Main results of the test campaign:

Ranging performance (FM)

A study of the standard deviation on planes for different distances has been done.



Standard deviation study on planes for distances going from 0.5 to 8.1m show good performances with a mean value around 0.2mm before post processing and down under the 0.1mm specification after post processing (Point clouds meshed followed by 10 iterations of laplacian smoothing).

Vieiwing performance (AM)

A study of the spatial resolution of the viewing channel been done by scanning several bolts size giving a wide range of spatial resolution (from M10 to M24)

At 1.5m | At 4.5m | At 8.5m

Vieiwing Analysis					
		Thread pitch			
Distance	Direction of visibility	1,5mm	2mm	2,5mm	3mm
1,5m	Horizontal	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests
	Vertical	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests
4,5m	Horizontal	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests
	Vertical	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests
8,5m	Horizontal	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests
	Vertical	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests	Spec Limit Tests

Visible
Partially visible
Not visible

Vieiwing resolution is defined by:

- Optical resolution (MTF resolved at 50% when modulation period > 2*sigma)
- Sampling resolution (MTF resolved when modulation period > 2*sample spacing

Test campaign study of performance shows that the innovative optomechanical design works. The tests results of the prototype validate the new measurement probe arrangement and serve as a first proof of final performance.

NEXT STEPS TOWARD FOAK

From design to assembly and test of this novel optical design, clear steps have now been identified to deliver the final version of the system:

- Measurement on one of the first full scale Inner Vertical Target (IVT)
- Comparison of the test campaign scans with simulated scans
- Upgrades of the scanning head mechanical designs
- Validation of the components and subsystem under gamma radiation and validation of the outgassing rates.

ACKNOWLEDGEMENTS

This work was done under contract with F4E (contract number F4E-OMF-383-01-04). The authors would like to thank all the contributors taking part to the activities touched upon in this paper. The views expressed in this publication are the sole responsibility of the authors and do not necessarily reflect those of Fusion for Energy (F4E) or of the ITER Organization (IO). Neither F4E nor any person acting on behalf of F4E is responsible for the use which might be made of the information in this publication.

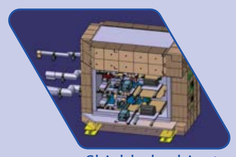
MORE ABOUT BERTIN

Bertin Technologies develops and installs plasma diagnostics for inertial and magnetic fusion:

- DP7-DP8: Visible optical diagnostics
- DP5: Visar diagnostic
- X-ray streak cameras

Rhodium coated mirror for In-vessel First Mirror

Dual reflector for in-vessel photometry calibration



Shielded cabinet for radiation protection

Laser Megajoule Common Reference

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