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WEST advanced wall protection achievements toward long pulse operation

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ABSTRACT

- Artificial intelligence and physics/engineering model-based wall protections are used at WEST, to remain within the safe operation domain of the divertor and main wall during long pulse operation.
- No critical divertor and wall power event during campaigns C9 to C11, cumulating 13 hours of plasma with single plasma duration up to 1337s.
- While it cannot be demonstrated that the active & intelligent wall protection enabled avoiding accidents, it is bound that the wall protection system as a whole helped significantly by preventing wall hot spots to deteriorate to the point of becoming critical during the campaigns.

BACKGROUND

- Infrared viewing system is a key tool for divertor & wall health monitoring, but with limitations.
- Infrared radiance conversion to armor surface temperature is hindered by possible surface layers with added thermal resistance, emissivity and reflective effects, diffuse or specular (especially in metallic environment).
- Even if surface temperature becomes eventually available with sufficient precision, further key wall component indicators such as the surface heat flux are needed for effective plasma control.
- In addition to heat fluxes and power, relevant wall health information is available in hot spots shapes and textures, and should be exploited toward documenting wall behavior evolution.

IMPLEMENTATION

Model-base heat divertor heat flux estimation (Fig. 1)

Uses real time control data : magnetics, power and bolometry to estimate divertor heat flux from physical models.

Thermal event detectors (Fig. 2)

Detects and classify hot spots according to shape and texture. (Yolo). Time tracking algorithm to convert hot spots to thermal events (add time feature) → phenomenological analysis.

Large language model for discharge thermal scene analysis (Fig. 4)

Automatic forensic analysis of discharge summary. Normal / abnormal behavior. Available within minutes to the wall health expert in charge between discharges. Draw attention on key events of thermal scene time sequence.

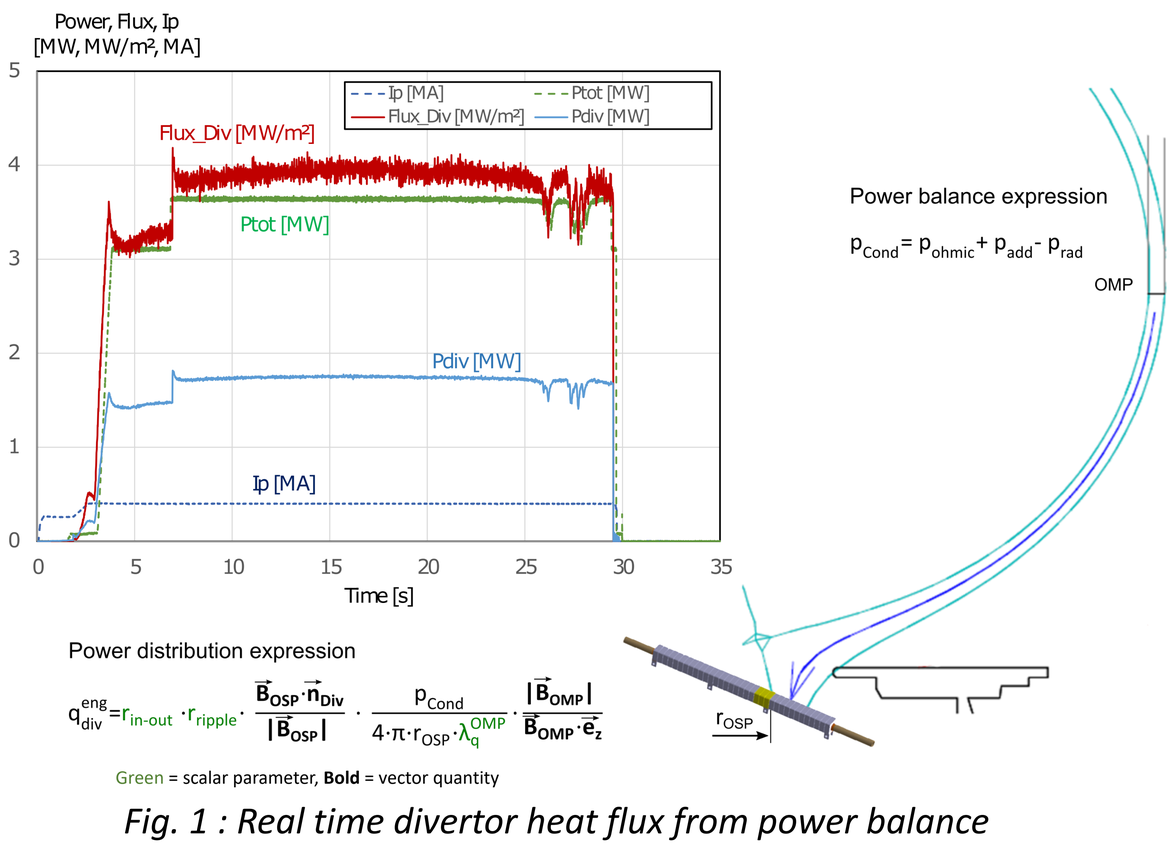


Fig. 1 : Real time divertor heat flux from power balance

CHALLENGES & OPPORTUNITIES

CROSS MACHINE DEVELOPMENT FRAMEWORK

Thermal events formats (instances, categories, annotations) are developed in the framework of EUROfusion consortium, through open source libraries.

Formats and framework accessible to third party users.

Data privacy and security are enabled by proprietary front-end layers.

THE CHALLENGE OF PERFORMANCE INDICATORS IN MATTERS OF SAFETY

Quantifying performance for matters of operation safety and machine protection is multifaceted. Several classes of metrics.

- **Loss functions** (numerical distance between data sets) : used for training and qualification.
- **Precision, recall, MAE, MSE, F1 Score** : enable cross process comparisons.
- **User's metrics** : example polling test : quantify user's satisfaction with the data process.

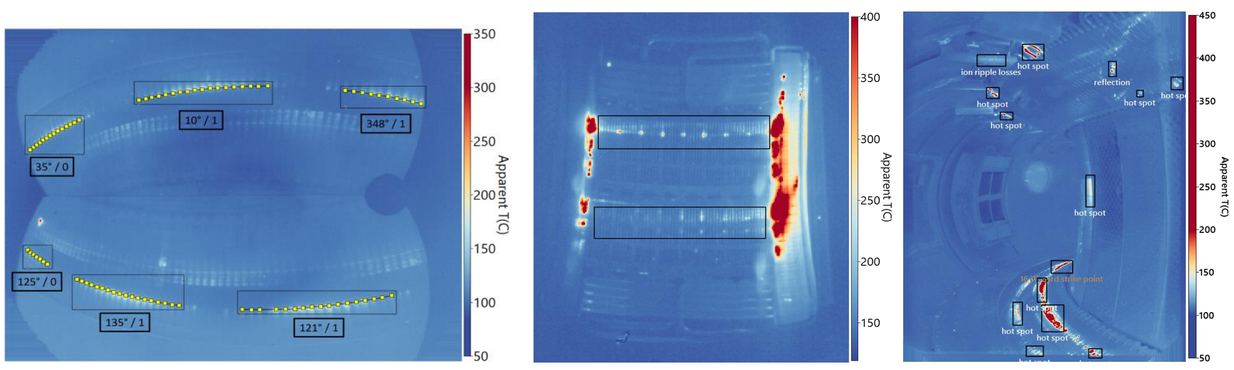
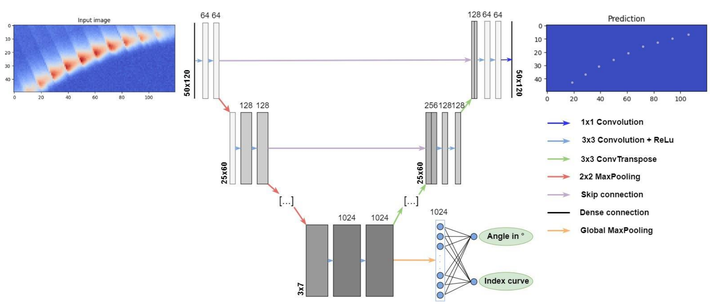


Fig. 2 : Strikeline characterization (angle/curvature), arc and thermal event detectors



Metric	Constrained U-Net
1 - T(α,β=1)	0.034
MSE(y_2,$\hat{y}_2$) + MSE(y_3,$\hat{y}_3$)	0.699
Precision (threshold 0.5)	0.985
Recall (threshold 0.5)	0.980
F1-Score (threshold 0.5)	0.983
MAE Angle (in °)	0.667
MAE Curvature	0.023
Inference time (ms)	5.26

Fig. 3 : Neural network and performance metrics for the strikeline characterization tool

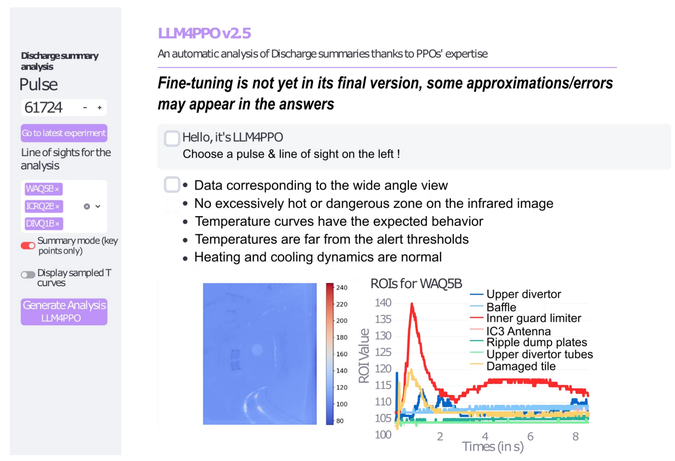


Fig. 4 : Screen copy of the interface available to wall health expert in charge

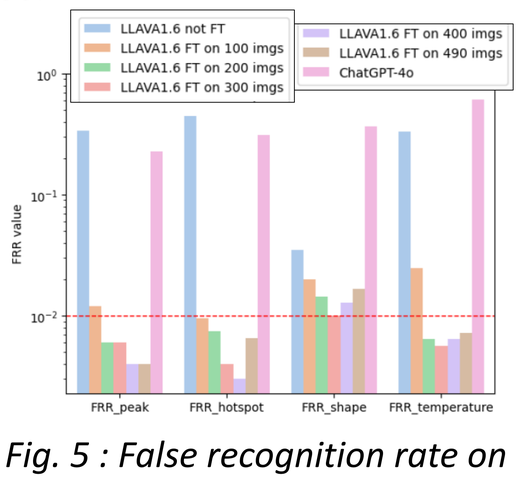


Fig. 5 : False recognition rate on a synthetic image dataset for fine-tuned and non fine- tuned language models

CONCLUSION

- WEST wall monitoring system is strengthened by adding advanced processes that use intelligence and / or physical models, working either in real time, or for post discharge automatic analysis.
- Availability of the wall protection is of 94.1% during campaign C9 (Jan-Apr 2024). Only 1 discharge out of 1389 is lost as a result of the hard-wired wall protection system, indicating the automatic feedback control failed.
- Future plans is to integrate wall safety with synthetic diagnostic models.

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