EUROPEAN FUSION DEVELOPMENT AGREEMENT

The new TAE - Alfvén Wave Active Excitation System at JET

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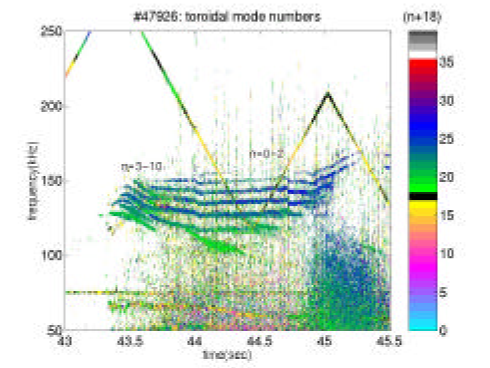
INTRODUCTION

After many years of successful operation, the JET saddle coil system will be dismantled during the 2004-2005 shutdown. A new antenna system has been designed and is being installed to replace it and excite MHD modes in the Alfvén frequency range (10→500kHz), keeping similar operational capabilities (I_{ANT}~30A, V_{ANT}~1kV, power ~5kW). The new antenna system comprises two assemblies of four toroidally spaced coils each, situated at opposite toroidal locations, protected by CFC tiles.

Why Study Alfvén Waves?
Why Replace the Saddle Coils?

1. fusion-born alpha particles (α's) resonate with Alfvén Waves (AWs) if $\omega = k_{||}\upsilon_A$;
2. AW spectrum unstable if large-enough free energy in the fast ion pressure gradient;
3. an unstable AW spectrum can lead to direct α's losses, possibly quenching the ignition process and damaging the first wall;
4. due to their geometry, the saddle coils only drive low toroidal mode numbers, |n|<2;
5. predictions for ITER: most unstable modes have n~5→20 (already observed in JET).



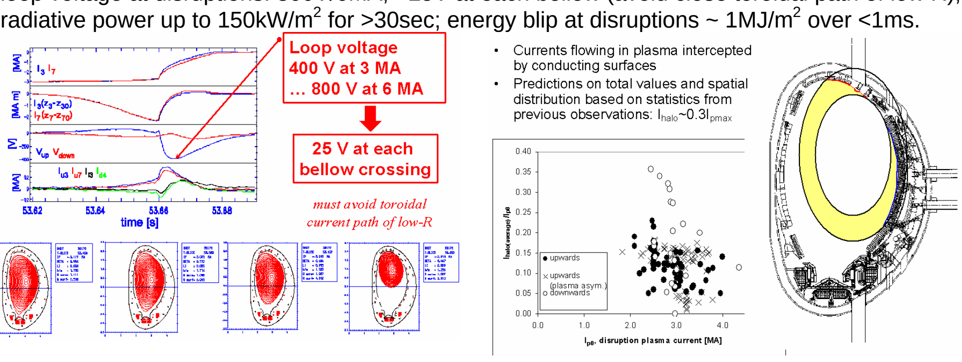
ENGINEERING CONSTRAINTS AND ANALYSIS

In addition to the constraints imposed by halo current and disruption-induced voltages and currents, the design must comply with the requirements of a remote handling installation:

Location	$B_{\|\|}$	$B_\perp$	$\partial B_{\|\|}/\partial t$	$\partial B_\perp/\partial t$	$\tau_{\|\|}$	$\tau_\perp$	B_ϕ	J_{HALO}	Φ_{HEAT}
Antennas	1.2T	0.4T	120T/s	80T/s	3ms	5ms	3T	600kA/m^2	225kW/m^2

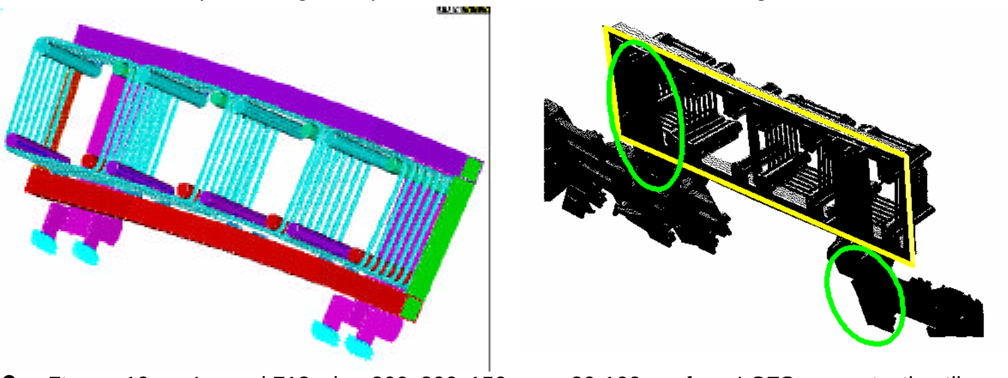
Table 1. Specification for halo currents and magnetic field variations during disruptions.

- total halo current integrated over the antenna surface = 90kA (I_{p0}=6MA, I_{HALO}/I_{p0}=30%, TPF=1.4);
- loop voltage at disruptions: 800V/6MA, ~25V at each bellow (avoid close toroidal path of low R);
- radiative power up to 150kW/m^2 for >30sec; energy blip at disruptions ~ 1MJ/m^2 over <1ms.

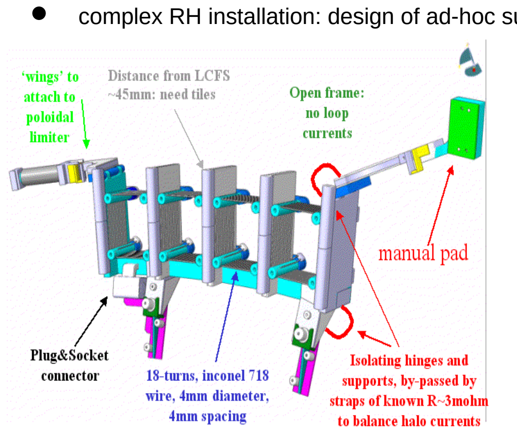


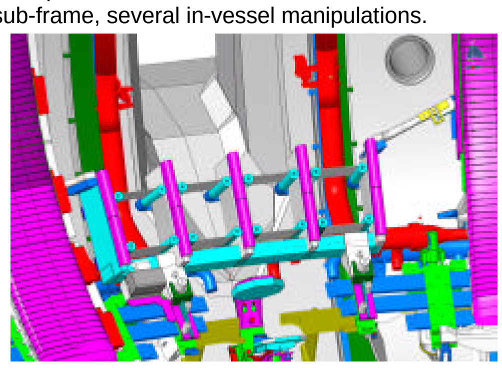
EVOLUTION OF ANTENNA DESIGN

First antenna conceptual design completed in December 2002 based on original total I_{HALO}~1kA.



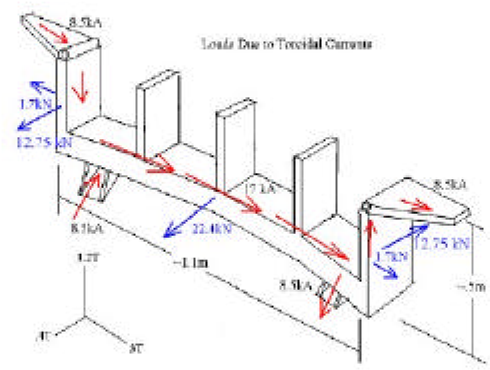
- 7turns, 10mm Inconel 718 wire, 200x200x150mm, ~80-100mm from LCFS, no protection tiles;
- Inconel 600 frame, total weight <50kg, simple ~one-step RH installation using MASCOT;
- MAIN PROBLEM: CONTINUOUS FRAME:
  - large induced currents, radial displacement of 1.3cm;
  - some areas at yield, bottom brackets not strong enough;
  - antenna-plasma coupling is marginal.
- ALSO: REVISED DESIGN CONSTRAINTS INCREASING I_{HALO} TO 90kA FROM I_{HALO}=1kA:
  - need limiters, protection tiles, wing supports to poloidal limiter, over MASCOT weight limit;
  - now need to isolate antenna block from vessel, provide link of known resistance;
  - complex RH installation: design of ad-hoc sub-frame, several in-vessel manipulations.





(above) front view of one block of four antennas.
(left) close-up with various engineering details.

FINAL ANTENNA LAYOUT DESIGN AS COMPLETED IN JUNE 2003

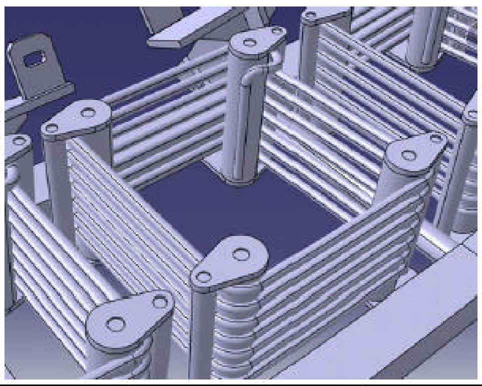


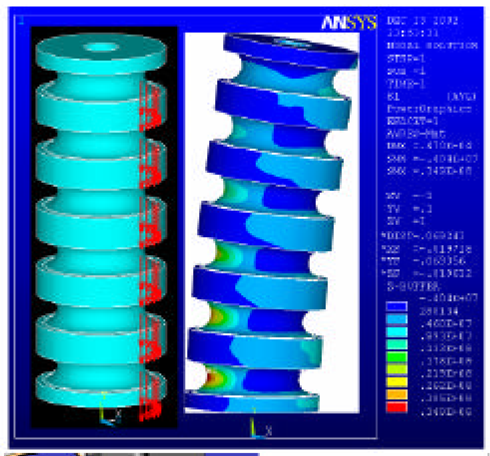
Mechanical loads due to toroidal current flowing in the antenna frame during a typical disruption, balanced up/down with the 3mW resistive straps.

Each coil is made using 18 turns of 4mm Inconel 718 wire, covers a toroidal and poloidal extent of ~25cm, and is individually insulated from the supporting frame with Shapal-M spacers. The first turn sits ~45mm behind the poloidal limiters, to achieve good coupling with adequate ωL.

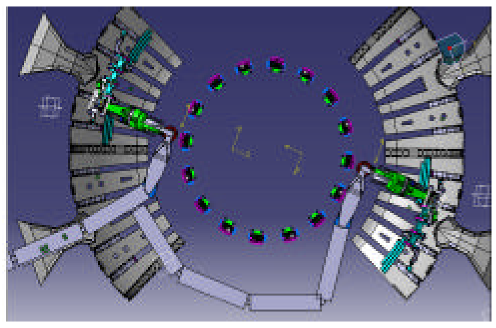
The coils are mounted on a 3mm-thick Inconel 625 open structure, to avoid a closed path for disruption-induced currents.

This structure is attached to the poloidal limiters and the remains of the saddle coils via 4 points isolated with Shapal-M spacers, bypassed with 3mΩ resistive straps to provide a reliable current path and optimise the load distribution.

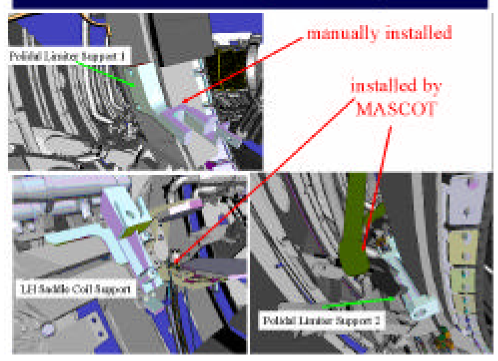




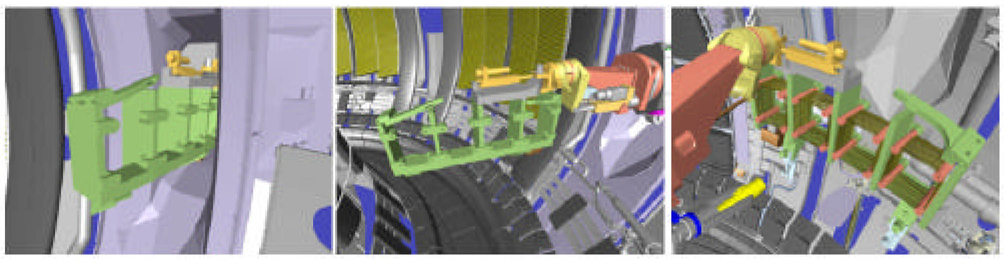
(above) close-up of one 18 turns coil.
(right) stress deformation of ceramic posts.



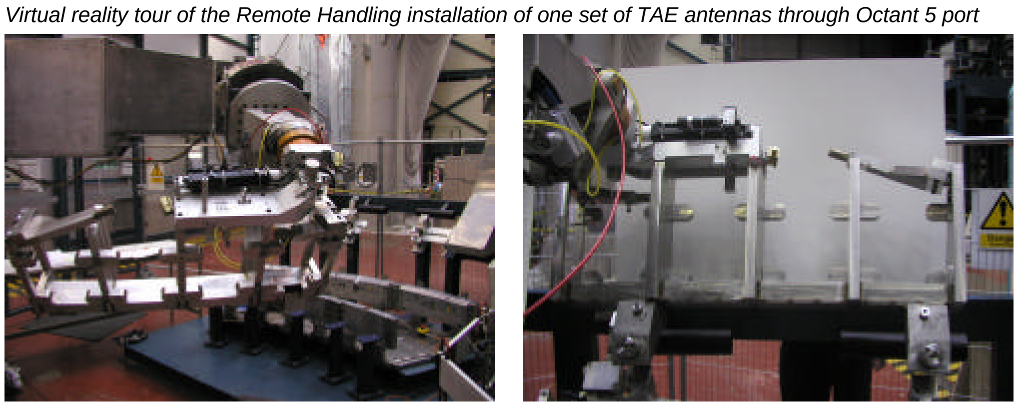
The BOOM is used to position MASCOT inside the vessel and carry heavy loads.



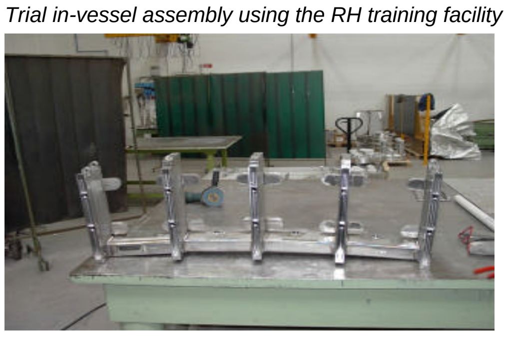
MASCOT is a force reflecting servo-manipulator (computer linked) operating as Master-Slave.



Virtual reality tour of the Remote Handling installation of one set of TAE antennas through Octant 5 port



Trial in-vessel assembly using the RH training facility



Detailed engineering work, the adaptable remote handling JET capability and virtual reality models were used to develop the installation procedure, successfully demonstrated in full mock-up trials.

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§ See annex 1 of J.Pamela et al., "Overview of Recent JET Results", OV-1/1.4, Fusion energy 2002 (Proc. 19th International Conference, Lyon, 2002) IAEA, Nuclear Fusion 43 (2003), 1540.