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B30: Tore Supra WEST Cooling Water System for ITER-like conditions

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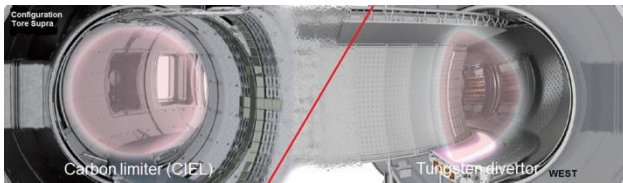
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The French Tore Supra tokamak is upgraded in an x-point divertor fusion device in the frame of the WEST (W-for tungsten-Environment in Steady-state Tokamak) project, launched in support to the ITER tungsten divertor strategy. The WEST project aims to test actively cooled tungsten Plasma Facing Components (PFC) under long plasma discharge. As the existing cooling loop B30 cannot ensure the cooling of the W divertor elements under ITER nominal conditions, a new pressurized water loop must be designed to exhaust all the heat coming from the plasma and transmitted to the in-vessel components. It includes additional piping networks of around 50m³ connected to the existing loop in order to cool components such as stainless steel vessel protection panels, upper and lower divertor coper coils, baffle, bumpers and ripple protection. During plasma operation, the water inlet temperature is 70 °C and the pressure at the inlet of the pump is 2.4 MPa while baking is performed at 200 °C and 2MPa to achieve the outgassing of components inside the vacuum vessel. As the pressure drop of the divertor coils is higher than the pressure drop of the other PFCs, the cooling of these coils is ensured by an independent water loop with a new centrifugal pump. This paper presents the design and thermo-mechanical analysis of this system including piping stress and supports analysis according to CODETI standards.

Keywords: WEST, B30, Cooling Water System, CODETI, Piping analysis, supports analysis.

1 Introduction: TORE SUPRA - WEST

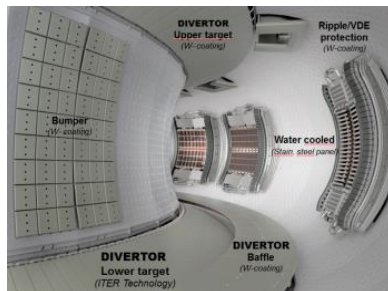
The WEST project aims at transforming Tore Supra into an X-point divertor tokamak in order to adapt it to a unique relevant facility as test bed for ITER offering the key capability of testing the ITER technology of high flux components in real plasma environment.



Tore Supra (CIEL configuration with Carbon limiter) is able to reach the ITER pulse length (400 s) therefore WEST will allow testing for the first time a tungsten divertor in a long pulse tokamak.

The main objective of the WEST project is to provide a relevant platform to qualify industrial components for ITER which require relevant steady state plasma conditions such as plasma facing components, heating systems or diagnostics with a particular focus on ITER divertor target components.

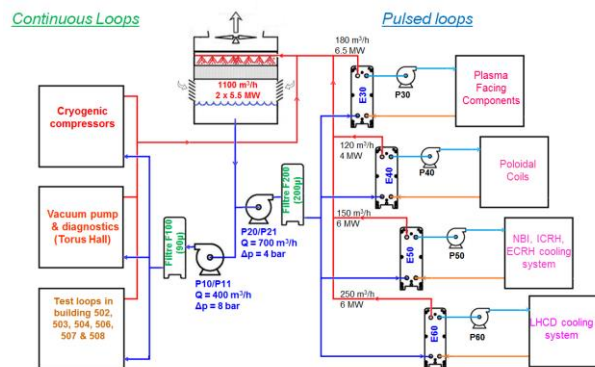
PFCs consist of upper and lower divertor, baffle, high and low magnetic field side Vacuum Vessel protections, bumper ant ripple protection.



2 TORE SUPRA Cooling Water System

PFCs are connected to a closed loop of deionised and deoxygenated water called B30. Demineralised water is used, from a water treatment system, to minimize leakage current and deoxygenated water at around Ph = 9 (at 25 °C) for corrosion control of carbon steel pipes. In presence of dissolved oxygen or under near neutral pH conditions, the electrochemical corrosion rate of iron at 200 °C is important.

So, it is necessary to maintain the oxygen rate less than about 5 parts per billion and the Ph value comprised between 8.8 and 9.2.



Primary loops: The B30 is the plasma facing components cooling loop. It has several operating modes.

The pulsed loops are used to cool the poloidal coils (B40), the NBI, ICRH and ECRH heating generators and auxiliaries (B50) and the LHCD heating system (B60).

Secondary loop: The Heat Rejection System (HRS) is the secondary loop that cools the primary loops fluid through several heat exchangers (E30, E40, E50 and

E60). Two contiguous cooling towers are used. This forces the B30 loop to be completely shut down for regulations-mandated inspections once a year (and thus the whole installation is not plasma-capable during this time).

The continuous loops are used for the cryogenics compressors cooling, the vacuum pumps cooling, the B70 loop (demineralized water) and for air conditioning.

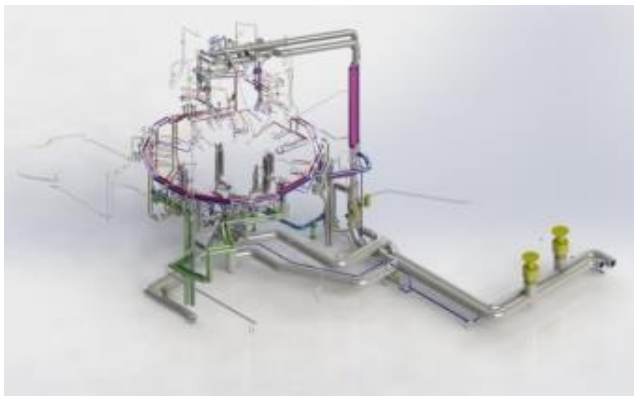
In order to allow the baking and plasma conditions necessary for Tore Supra operation, the cooling system must perform several functions:

- Heating (outgassing PFC prior to plasma operation)
- Cooling (regulate loop T° by evacuating the heat collected by PFC through heat exchanger)
- Water circulation (Regulate water flow by P30, P31 and P33 pumps)
- Pressure and level control (maintain the water in the loop in a liquid state)
- Refiling (in order to be able to cool down the loop anytime)
- Draining (purge the loop when shutting down the system, or when heating to compensate the thermal dilatation)
- Filtration (to prevent the obstruction of the cooling channels)

3 WEST Cooling Water System: B30 update

All equipment of the existing cooling loop B30 cannot ensure the cooling of the W divertor elements under ITER nominal conditions (12 m/s).

New W Plasma Facing Components (upper and lower divertor, baffle, bumpers & VDE protections), Vacuum Vessel Protection Panels (high and low magnetic field side) and divertor copper coils are connected to a closed loop of around 50m³, divided in 3 parts (Upper, Medium and lower).



4 B30 System Description

Distribution of the divertor coils and actively cooled PFCs in Torus Hall is divided in 3 parts:

	Flow Distribution (m ³ /h)				Total
	Lower part	Medium part	Upper part	Exchanger	
WEST	1008	260	95	340	1703
CIEL	595		435	80	1110

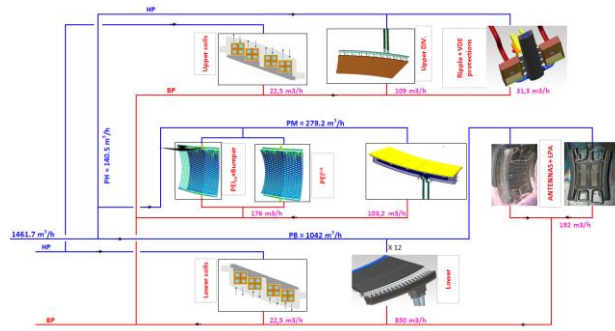
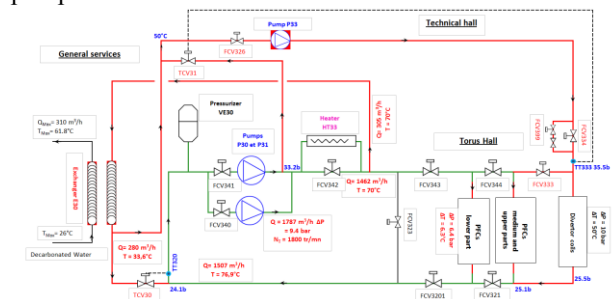


Table below indicates the hydraulic characteristics of new components:

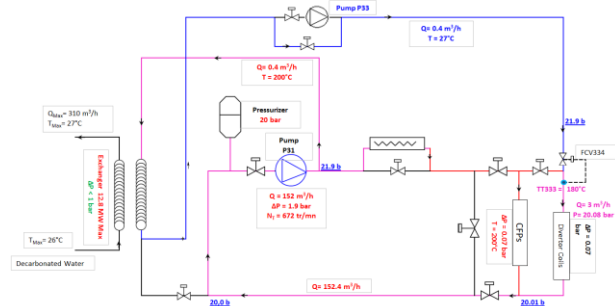
New components	Number	Place	Flow (m ³ /h)	DN	Total flow (m ³ /h)	ΔP (bar)
Lower Divertor	12	Lower part	70.8	2"1/2	850	5.7
Upper Divertor	12	Upper part	9.1	1"	109.2	2.4
Baffle	12	Medium part	8.6	1"	103.2	5
VDE Ripple protections	12	Upper part	1.5	1/4"	18.4	< 4.2
PJ Ripple protections	6	Upper part	1.5	1/4"	9.2	< 4.2
PEI int + bumper	6	Medium part	5.3	3/4"	32.0	5.0
PEI ext	18	Medium part	8.0	3/4"	144.0	5
Endoscope	7	Upper part	0.5	1/4"	3.5	4.2
Casemates	3	Upper part	0.5	1/4"	1.5	< 4.2
PEI baffle	6	Medium part	1.5	1/2"	9.0	< 5

5 B30 Loading conditions

Plasma operation: water inlet temperature is 70 °C (P30, P31) and 50 °C (P33), and pressure at the inlet of the pump is 2.4 MPa:



Baking is performed at 200 °C and 2 MPa, to achieve the outgassing of components installed into the vacuum vessel during a maximum time of 5 days:



6 Materials

Pipes are made of P265GH steel or 316L stainless steel.
Coils are made of copper R240 ½ Dur
Supports are made of S235 steel or 316L stainless steel.

Data are considered according to [4], [5], [6] and [7].

7 Piping analysis design criteria

According to CODETI [1], under permanent loads, piping stresses must verify this equation:

$$(Eq1) \quad \sigma_1 = \frac{PD}{4t} + \frac{0,75 i MA}{Z} \leq f_{200^\circ C}$$

Under thermal expansion loads, piping stresses must verify this equation:

$$(Eq2) \quad \sigma_2 = \frac{i MC}{Z} \leq f_{a T^\circ C} = U * (1,25 f_{20^\circ C} + 0,25 f_{T^\circ C}) \cdot \frac{E_{T^\circ C}}{E_{20^\circ C}}$$

If Eq2 criteria is not verified, an alternative equation combining permanent loads and thermal expansion can be verified:

$$(Eq3) \quad \sigma_3 = \frac{PD}{4t} + \frac{0,75 i MA}{Z} + \frac{i MC}{Z} \leq f_{T^\circ C} + f_{a T^\circ C}$$

With:

- P : Internal pressure
- D : Outside diameter
- t : Thickness
- i : Stress Intensification Factor
- Z : Section Modulus
- MA : Moment resulting from permanent loads
- MC : Moment resulting from thermal expansion
- U : fatigue correction factor*
- $f_{T^\circ C} = R_{p1,0}/1.5$ for Stainless Steel, $R_{p0,2}/1.5$ for steel and $R_m/4$ for Copper : Allowable reference Stress

*During each plasma campaign of 120 days with a frequency of twice a year, 5 cycles at 200°C, 20bars (baking and Glow discharge) are foreseen and a reaching at operating conditions of 100°C, 33bars. Pressure cycles are more numerous since pressure reaches 8 bars every night. Considering 20 years of lifetime for B30 network, cycles number is about 2500 (125x20), giving a factor U of 1 according to CODETI C3.2.4.3.

	$f_{20^\circ C}$ MPa	$f_{100^\circ C}$ MPa	$f_{200^\circ C}$ MPa	$f_{a 100^\circ C}$ MPa	$f_{a 200^\circ C}$ MPa	f_E MPa
Inox 316L	150	133	110	204	199	214
P265GH	177	151	128	251	246	252
Copper R240	60	54	46	82	80	152

Note: since Tore Supra is considered as an ICPE (facility classified for environmental protection) and not INB (Basic Nuclear Facility), seismic impact is not taken into account for the studies.

8 Support analysis design criteria

Allowable limits are specified in CODETI [1].For linear supports:

- Axial stress : $f = \min\left(\frac{Rp_{0,2}}{1,5} ; \frac{Rm}{2,4}\right)$
- Shear stress : 0.66 f
- Combined stresses : f

For Plate or shell type supports:

- Membrane stress : $f = \min\left(\frac{Rp_{0,2}}{1,5} ; \frac{Rm}{2,4}\right)$
- Shear stress : 0,5 f
- Bending stress : 1.5 f
- Membrane + Bending stress : 1.5 f

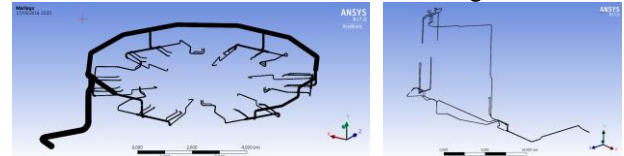
For bolting elements, CODETI follow applicable norms. Eurocode 3 criteria specify rules for mettalic structure. Allowable limits are the following:

- Shear : $F_T < F_{v,Rd} = \frac{\alpha f_{ub} A_s}{\gamma_{M2}}$
- Traction : $F_N < F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$

With: $\alpha = 0,6$ and $f_{ub} = 800$ MPa for A4.80 bolts equivalent to class 8.8, and $k_2=0,9$ for non-countersunk bolts. However, a 1.5 coefficient for variable loads has to be taken into account according to Eurocode 3.

9 Results

Piping and support analysis have be done with ANSYS V17 finite elements software using piping elements to mesh the neutral fiber model with according sections.



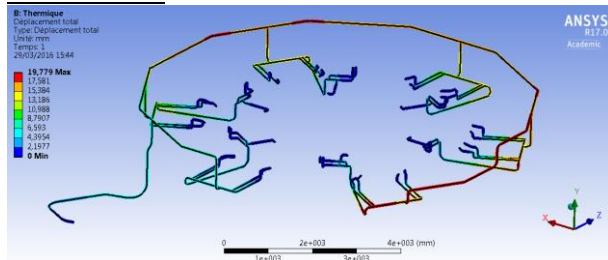
Note: since stress indice factor are not directly implemented, analytical post processing has been realized in order to verify codes equations.

	Situation	Margin Eq1 : W+P	Margin Eq2 : Th	Margin Eq3 : W+P+Th
HP upper	Envelop case	41.8%	28.1%	36.0%
BP upper	Envelop case	41.8%	15.1%	33.4%
HP med	Plasma operation	38.3%	27.9%	42.7%
	Baking	46.8%	-20.9	11.9%
	Test	44.7%	-	-
	Handling	16.5%	-	-
BP Med	Plasma operation	50.8%	33.9%	54.1%
	Baking	42.7%	-45.7%	2.6%
	Test	57.2%	-	-
	Handling	66.8%	-	-
HP-BP low	Envelop case	73.4%	-19.2%	14.2%
Divertor supply Inox	Plasma operation	31.4%	61.4%	54.4%
	Baking	28.1%	-14.8%	16.8%
	Test	50.2%	-	-
Divertor Supply Copper	Plasma operation	34.9%	39%	37.4%
	Baking	81 %	-45.1 %	0.9 %
	Test	59.1%	-	-
General services	Plasma operation	61.6%	72.1%	69.3%
	Baking	61.3%	34.9%	47.4%

Upper part :

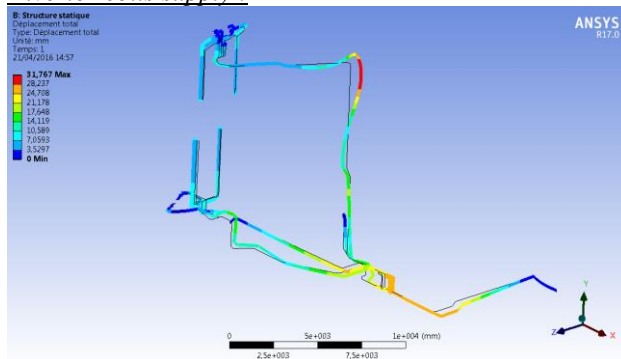
Weld-on supports for fix points in each of 6 modulus.

Medium Part :



20 mm radial thermal expansion at 200°C => use of slide bearing plates for supports in each of the 6 modulus
For handling situation temporary supports on modulus n°6 has to be forsaken.

Divertor coils supply :



Thermal expansion lyre added for copper coils conductors with low mechanical resistance.
Supports optimization to deal with 32mm thermal expansion at 200°C.

General services :

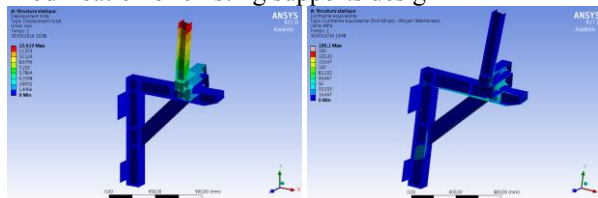
Lateral Expansion Joints added on pipe between existing loop and E30 exchanger in order to reduce loads on anchor flanges.
Reinforcement of piping openings: 5mm plate on DN200/DN250 and 10mm on DN200/DN350 branches.

Lower part:

Metal hoses added in order to reduce bending moments on divertor collector and allow disassembly because of limited place.

Supports:

Modification of existing supports design



Add of linear supports and buckling analysis according to CODETI standards.

10 Conclusion: Status of Installation



Upper part

Upper part



Medium part

P33 General Services



E30 heat exchanger - General Services

11 References

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- [3] CODETI 2006
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- [5] NF EN 10216-2 : Tubes sans soudure en acier pour service sous pression
- [6] EN 10025-2 : Produits laminés à chaud en aciers de construction
- [7] NF EN 13605 : Cuivre et alliages de cuivre