Updates on TDIS design overview
Thermo-mechanical simulations results

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WP14 Coordination meeting 865/1-D17 2017/04/25

Updates on TDIS design overview
Thermo-mechanical simulations results

Agenda

- Introduction
- Jaws design update – Simulations summary:
  - Back stiffener
  - Cooling pipes
  - Absorbing blocks
- Conclusions / Next steps
- Annex

Updates on TDIS design overview
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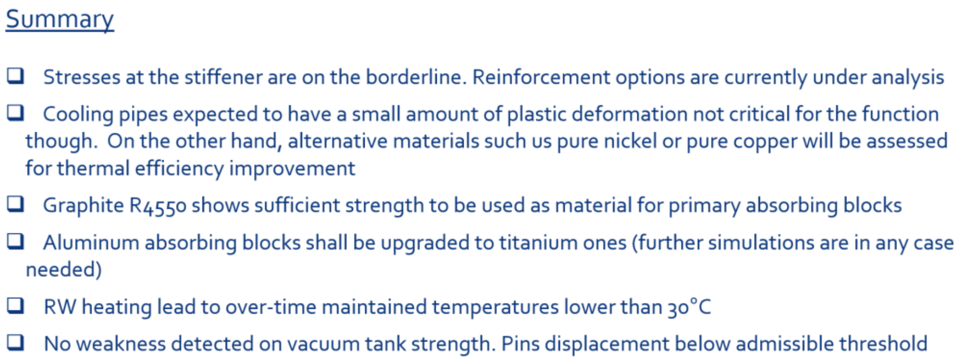
Introduction

- This presentation is an update on the one presented during the Dec’16 TDIS internal review meeting ([link]()). The conclusions were as shown hereunder:



Summary

☐ Stresses at the stiffener are on the borderline. Reinforcement options are currently under analysis

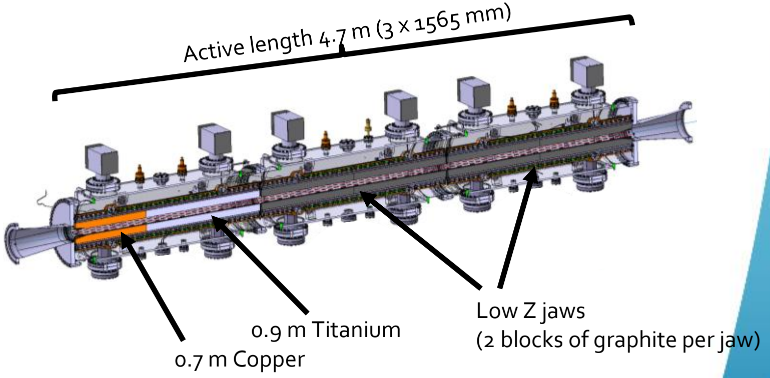
☐ Cooling pipes expected to have a small amount of plastic deformation not critical for the function though. On the other hand, alternative materials such us pure nickel or pure copper will be assessed for thermal efficiency improvement

☐ Graphite R4550 shows sufficient strength to be used as material for primary absorbing blocks

☐ Aluminum absorbing blocks shall be upgraded to titanium ones (further simulations are in any case needed)

☐ RW heating lead to over-time maintained temperatures lower than 30°C

☐ No weakness detected on vacuum tank strength. Pins displacement below admissible threshold



Updates on TDIS design overview
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Introduction

- Several loops of simulations and design updates conducted since then focused on the TDIS jaws
- Main affected components: back stiffener, cooling pipes and absorbing blocks
- Result: higher robustness against beam impact events

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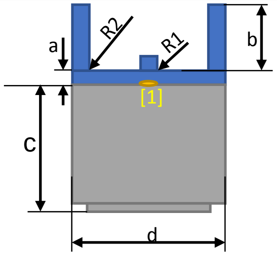
Jaws design update – Simulations summary

Back stiffener (1/4)

Case	Fluka sim.	Simulation Input									Simulation output (Stiffener)				Remarks
		Material	Tensile Yield strength [MPa]*	Geometry											
				a [mm]	b [mm]	c [mm]	d [mm]	R1 [mm]	R2 [mm]	Rib	Peak temperature [°C]	Peak VM stress [MPa]	Peak stresses zones	Safety factor	
#1	TDISv3	Alu 5083	145	8	37.1	54	80	0	0	Y	128	> 145	R1	< 1	Original design, high stresses at R1 zone. Plastic deformation expected.
#2								1		Y		> 145	R1	< 1	R1 corner rounded. Low reduction of stresses.
#3								-		N		> 145	[1] and R2	< 1	Rib removed. Peak stresses shifted to areas [1] and R2.
#4								-	3	N		> 145	[1] and R2	< 1	R2 corner rounded. Low reduction of stresses.
#5				5					0			> 145	[1] and R2	< 1	Thinner stiffener base. Moderate reduction of stresses.
#6	TDISv4			5		62					76	> 145	[1] and R2	< 1	Stiffener shifted 8mm away from the beam. (absorbing blocks height increased in 8mm). Noticeable reduction of stresses but still far beyond the yield strength.



Jaw cross-section sketch

Stiffener + Absorbing block

🟨	Modification wrt previous case
*	Estimated value @peak temperature

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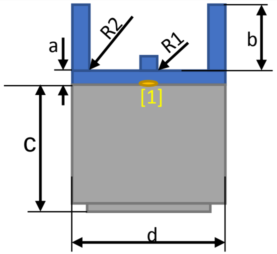
Jaws design update – Simulations summary

Back stiffener (2/4)

		Simulation Input									Simulation output (Stiffener)				
				Geometry											
Case	Fluka sim.	Material	Tensile Yield strength [MPa]*	a [mm]	b [mm]	c [mm]	d [mm]	R1 [mm]	R2 [mm]	Rib	Peak temperature [°C]	Peak VM stress [MPa]	Peak stresses zones	Safety factor	Remarks
#7	TDISv6	Molybdenum	480		37.1		80	-	0	N	260	> 480	R2	< 1	Material change. High temperature increase due to the high density of molybdenum. Safety factor slightly below 1
#8	TDISv7	Beryllium	240								45	212	R2	1.13	Material change. Strong reduction of temperature thanks to the very low density of beryllium. Peak stresses below yield strength.
#9	TDISv8	CuCrZr	280	8		67					145	> 280	[1] and R2	< 1	Material change. Stiffener shifted additional 5mm away from the beam. Thicker stiffener base.



Jaw cross-section sketch
Stiffener + Absorbing block

🟨	Modification wrt previous case
*	Estimated value @peak temperature

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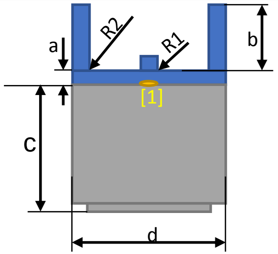
Jaws design update – Simulations summary

Back stiffener (3/4)

Case	Fluka sim.	Simulation Input									Simulation output (Stiffener)				Remarks
		Material	Tensile Yield strength [MPa]*	Geometry							Peak temperature [°C]	Peak VM stress [MPa]	Peak stresses zones	Safety factor	
				a [mm]	b [mm]	c [mm]	d [mm]	R1 [mm]	R2 [mm]	Rib					
#10	TDISv9	Mo alloy - MHC	615	8	37.1	67	80	-	0	N	226	452	[1]	1.36	Material change. Peak stresses below yield strength.
#11	TDISv10	Alu 2219	200								71	156	[1]	1.28	Material change. Higher strength aluminum grade used. Peak stresses below yield strength.
#12	TDISv11	Mo alloy - TZM	615		33.5		62				Modification done to decrease the cross-area of the stiffener for material and weight saving. - Results not available yet -				

🟨	Modification wrt previous case
*	Estimated value @peak temperature



Jaw cross-section sketch

Stiffener + Absorbing block

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- Jaws design update – Simulations summary
  - Back stiffener (4/4)

- More expensive TZM offers superior performance compared to other material alternatives (including better shower attenuation)
- Besides the cost, the other drawbacks are lower ductility and higher weight (+13kg vs Al. solution)
- Aluminium 2219 stiffener prototypes will be tested in parallel in 2017

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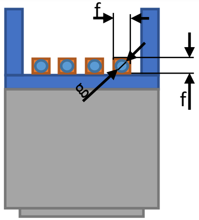
Jaws design update – Simulations summary

Cooling pipes (1/3)

Case	Fluka sim.	Simulation Input					Simulation output (Cooling pipes)		Remarks
		Stiffener Material	Cooling Pipes Material	Max. Elongation [%]	Geometry features		Peak temperature [°C]	Max. VM Strain [%]	
					f [mm]	g [mm]			
#1	TDISv3	Alu 5083	Copper C706	40	9	6	147	< 0.25	Original design, high temperature at the pipes. Minor plastic deformation expected.
#6	TDISv4						122		Stiffener shifted 8mm away from the beam. (absorbing blocks height increased in 8mm). Noticeable reduction of temperature.
#7	TDISv6	Molybdenum					85		Stiffener material change. Important decrease of temperature thanks to the higher density of molybdenum.
#8	TDISv7	Beryllium					128		Stiffener material change. Temperature increase due to low beryllium's density.



Jaw cross-section sketch

New Stiffener + Absorbing block + Cooling pipes

🟨	Modification wrt previous case
*	Estimated value @peak temperature

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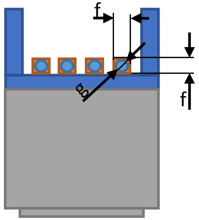
Jaws design update – Simulations summary

Cooling pipes (2/3)

Case	Fluka sim.	Simulation Input					Simulation output (Cooling pipes)		Remarks
		Stiffener Material	Cooling Pipes Material	Max. Elongation [%]	Geometry features		Peak temperature [°C]	Max. VM Strain [%]	
					f [mm]	g [mm]			
#9	TDISv8	CuCrZr	Copper C706	40	9	6	67	< 0.25	Stiffener material change. Additional 5mm shift away from the beam. High decrease of temperature thanks to the higher density of CuCrZr.
#10	TDISv9	Mo alloy					61		Stiffener material change. Inner surface peak stresses slightly above yield strength. Minor plastic deformation (not detrimental for the function) expected.
#11	TDISv10	Alu 2219					96		Stiffener material change. Higher strength aluminum grade used.
#12	TDISv11	Mo alloy	Copper C102	40	8	4	Results not available yet		



Jaw cross-section sketch

New Stiffener + Absorbing block + Cooling pipes

🟨	Modification wrt previous case
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- Jaws design update – Simulations summary
  - Cooling pipes (3/3)

- Cooling pipes cross-section decreased (8x8 – Ø4 mm instead of 9x9 – Ø6 mm) to allow for jaw height reduction.
- Minor plastic deformation (not detrimental for the function) expected at inner bore. Additional stresses due to water expansion have been taken into account in the analysis.
- Smaller pipes still provide sufficient cooling capacity even w/ low water flow (speed < 1m/s to avoid erosion corrosion in the long run). On the other hand, C102 alloy provides higher thermal conductivity.
- Cooling circuit configuration (serial vs parallel) under discussion.

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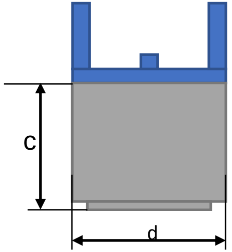
- Jaws design update – Simulations summary
  - Absorbing blocks (1/3)

Case	Fluka sim.	Simulation Input					Simulation output (Stiffener)			Remarks
		Material	Tensile Yield strength [MPa]*	Geometry						
				c [mm]	d [mm]	e [mm]	Peak temperature [°C]	Peak VM stress [MPa]	Safety factor	
#1	TDISv3	Graphite R4550	40	62	80	1565	1354	-	1.32	Christensen failure theory applied. See Annex.
		Al Alloy 5083	145			965	143	> 145	< 1	Original design, high stresses in case of grazing impact. Plastic deformation expected.
		CuCr1Zr	270			600	119	162	1.67	
#14	TDISv5	Graphite R4550	40			1565	1354	-	1.32	
		Ti6Al4V	830			782.5	365	273	3.04	Material change and shortened length. High safety factor thanks to high yield strength of Ti6Al4V.
		CuCr1Zr	270			782.5	250	> 270	< 1	Increased length. High temperatures and stresses at upstream end.

🟨	Modification wrt previous case
*	Estimated value @peak temperature



Jaw cross-section sketch

Stiffener + Absorbing block

Jaw length

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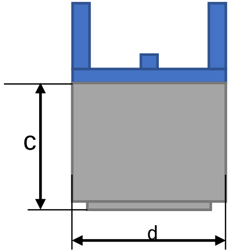
Jaws design update – Simulations summary

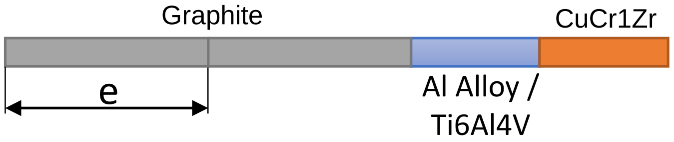
Absorbing blocks (2/3)

🟨 Modification wrt previous case
* Estimated value @peak temperature

Case	Fluka sim.	Simulation Input					Simulation output (Stiffener)			Remarks
		Material	Tensile Yield strength [MPa]*	Geometry						
				c [mm]	d [mm]	e [mm]	Peak temperature [°C]	Peak VM stress [MPa]	Safety factor	
#15	TDISv5b	Graphite R4550	40	62	80	1565	1354	-	1.32	
		Ti6Al4V	830			965	365	273	3.04	Block length increased for a better shielding of the CuCr1Zr absorbing block.
		CuCr1Zr	270			600	122	163	1.66	Block length shortened. High temperatures and stresses at the upstream end are thus avoided.
#13	TDISv11	Graphite R4550	40	67	62	62	Results not available yet			
		Ti6Al4V	830							
		CuCr1Zr	270							



Jaw cross-section sketch
Stiffener + Absorbing block



Jaw length

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Conclusions / Next steps (1/3)

- TZM is the baseline material for the jaw back stiffener. Fall-back solution: Aluminium alloy 2219.
- 2 addl’ stiffener prototypes will be ordered to be tested at Hi-RadMat facilities to validate TZM based solution.
- Although high, associated cost falls within the budget.
- Aluminium stiffener prototypes will be tested in parallel.

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Conclusions / Next steps (2/3)

- Cooling pipes material updated to pure copper for a better thermal conductivity.
- Size decreased to allow for jaw height reduction giving way to more space for jaws insertion inside the tank during assembly.
- Minor plastic deformation is expected at pipes inner surface in case of beam impact, not detrimental for the function though.
- Bending tests planned for CW18 w/ samples of the new geometry and material.

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Conclusions / Next steps (3/3)

- Absorbing blocks baseline shows sufficient strength against beam impact.
- Replacing Al-5083 by Ti6Al4V as high-Z absorbing material results in an admissible transverse impedance increase (8%) acc. to calculations.
- On the other hand, a reduction in the absorbing blocks width (from 80 to 62mm) is expected to have a positive effect on the impedance .

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Thanks for your attention

Content Input from from **Antonio Perillo Marcone, Inigo Lamas, Matthias Immanuel, Luca Gentini, Nicolò Biancacci**

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- Annex

To assess the graphite mechanical strength vs beam impact, Von Mises criteria is not suitable due to its high brittleness. Instead, a widely accepted failure theory for such kind of materials is the Christensen criterion :

$$\left(\frac{1}{T}-\frac{1}{C}\right)\sigma_{ii}+\frac{1}{2TC}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]\leq 1$$

Variable	Notation	[MPa]	Remark
Tensile strength	T	40	Min value for R4550 graphite
Compression strength	C	130	Min value for R4550 graphite
Principal stress 1	σ1	31	OK (values lower than tensile strength)
Principal stress 3	σ3	98	OK (values lower than compression strength)
Christensen parameter	$\left(\frac{1}{T}-\frac{1}{C}\right)\sigma_{ii}+\frac{1}{2TC}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]$	0.78	OK (value lower than 1)