Thermal Analysis Of ITER Central Thermal Shield Joints

Objectives

The main objective of the presented analysis is to evaluate an impact of the joint design on the TS shielding insulation performance. For this purpose the parametric analysis has been performed to study impact of the emissivity of the joint area (bare or silver coated) and the pitch between bolts on:
the VVTS and CTS joints area temperature state;
the maximal and average heat influx on to TFC via joint area.

Initial data

Calculation cross section for VVTS/TTS, CTS and VVTS joints are shown in Fig. 4. 1 - 4. 3 respectively.

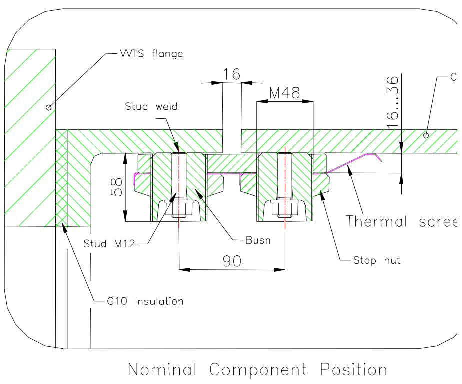

Fig. 4.1. VVTS/TTS joint

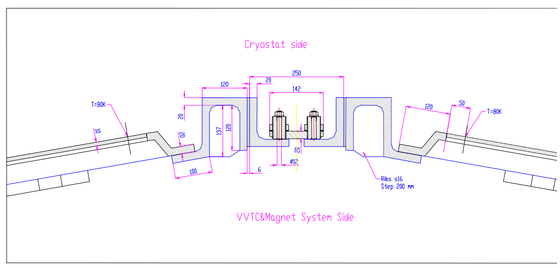

Fig. 4. 2. CTS joint

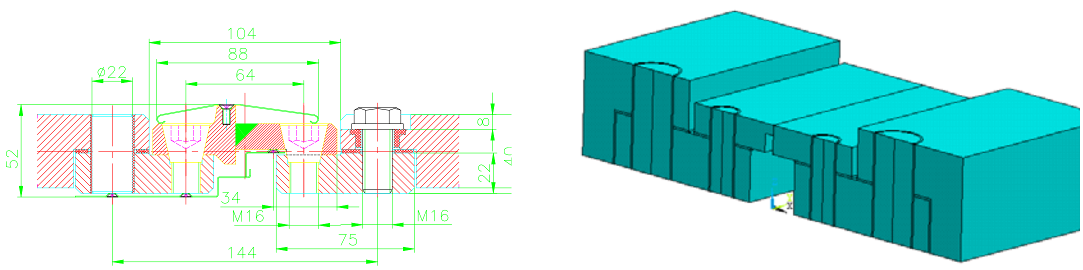

Fig. 4. 3. VVTS joint sketch and 3D model

The following data have been applied for the analyses:

- Pitch between bolts along flanges 400 mm (200 mm);
- Pitch between ribs (stiffeners) in CTS along flanges 200 mm;
- Heat transfer coefficient to GHe 1000 $W/(m^2 \cdot K)$;
- Heat exchange (TS plate -> TFC; TS plate -> VV or Cryostat) by radiation only.

Surface emissivities:

- Thermal shield plates (silver-coated) 0.05;
- Splice plates (silver-coated) 0.05;
- VV surface (no special treatment) 0.35;
- TFC surface (coated with ice monolayer) 1.0;
- Bolt with bush: bare 0.35;
  silver coated 0.05;
- Screen for welded zones* 0.05.

Boundary conditions (temperature)

Cryostat wall		20 °C;
Vacuum vessel wall	normal operation	120 °C;
	baking condition	200 °C;
TFC surface		4 K;
GHe-coolant		80 K.

Stainless steel thermal conductivity temperature dependence (Fig. 4.4) was taken into account for calculation model.

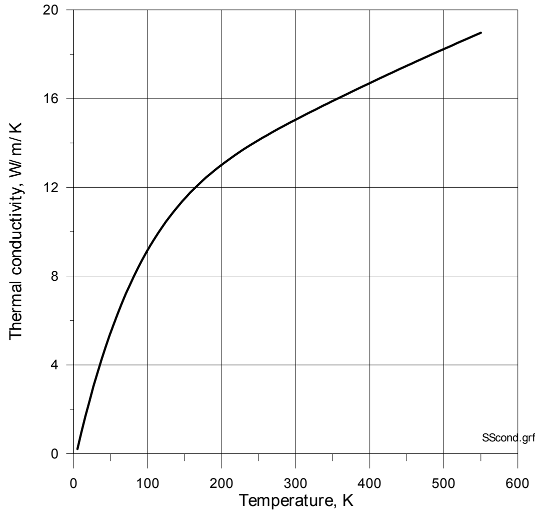

Fig. 4.4. Stainless steel thermal conductivity

- Insulation effect of the screens protected the welded zone has been taken into account by setting the effective emissivity of those zones to 0.025.

Results of analysis

Temperature state for different types of joints are shown in the following figures:

– for options of VVTS/TTS joint (Fig. 4.5 - Fig. 4.8);
– for options of CTS joint (Fig. 4.9 - Fig. 4.12);
– for options of VVTS joint (Fig. 4.13 - Fig. 4.14).

Maximal temperatures of joints, average and maximal local heat flux to TFC are summarized in Table 4.1.

VVTS/TTS joint

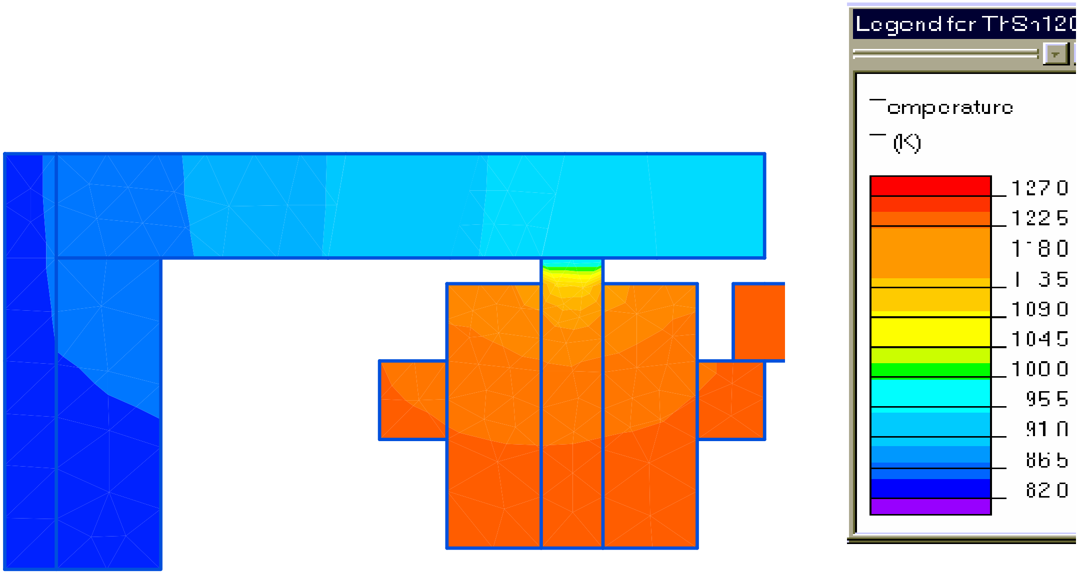

Fig. 4.5. VVTS/TTS joint. Temperature distribution. Normal operation.
(Bare bolt and bush emissivity factor - 0.35)

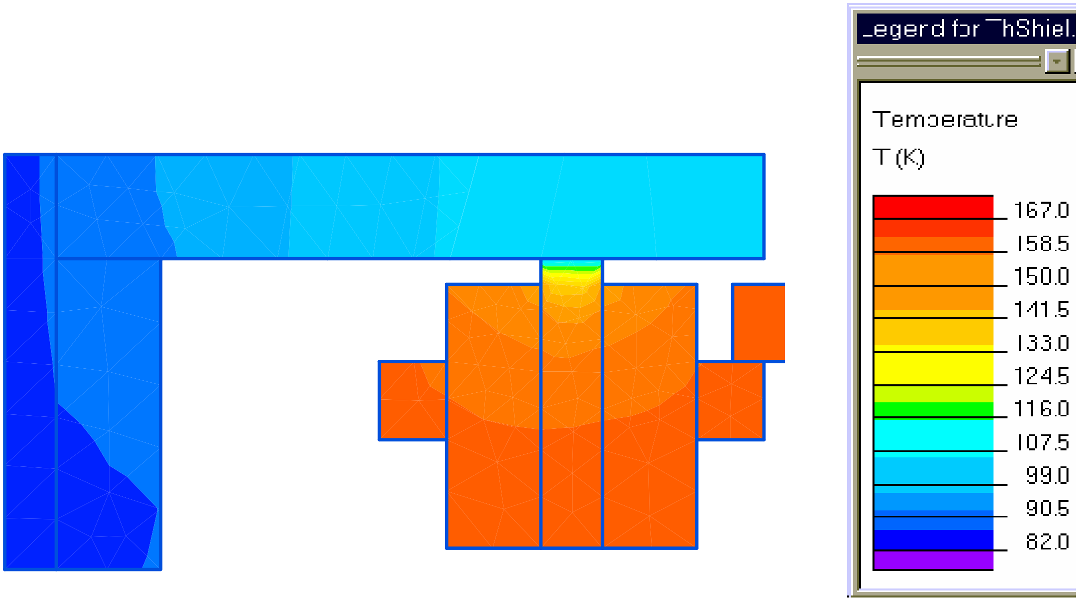

Fig. 4.6. VVTS/TTS joint. Temperature distribution. Baking condition.
(Bare bolt and bush emissivity factor - 0.35)

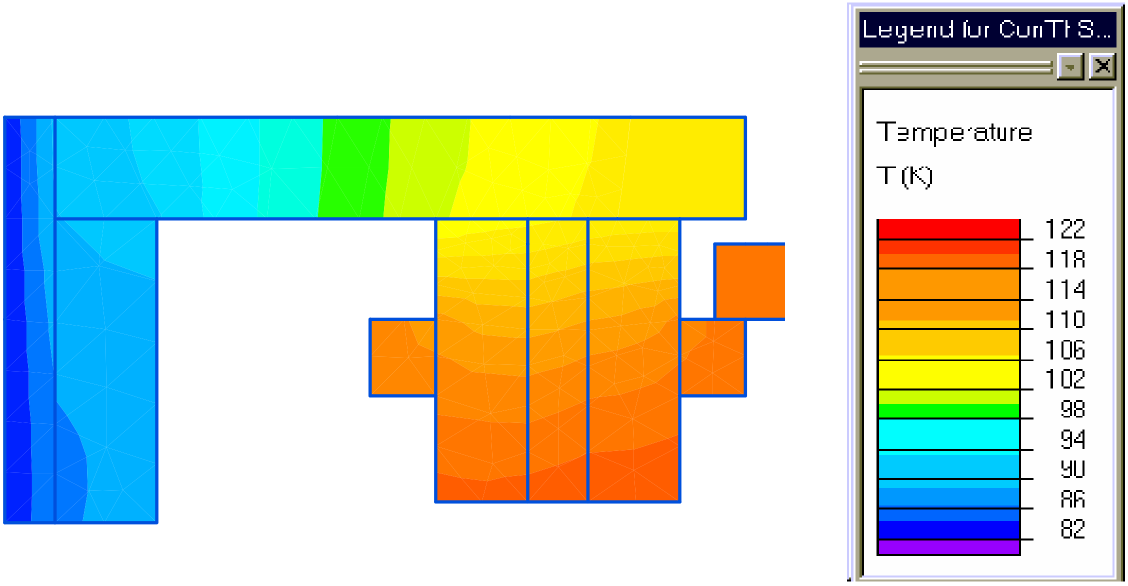

Fig. 4.7. VVTS/TTS joint. Temperature distribution. Baking condition.
(Bare bolt and bush emissivity factor - 0.35)
Perfect thermal contact between bush and plate

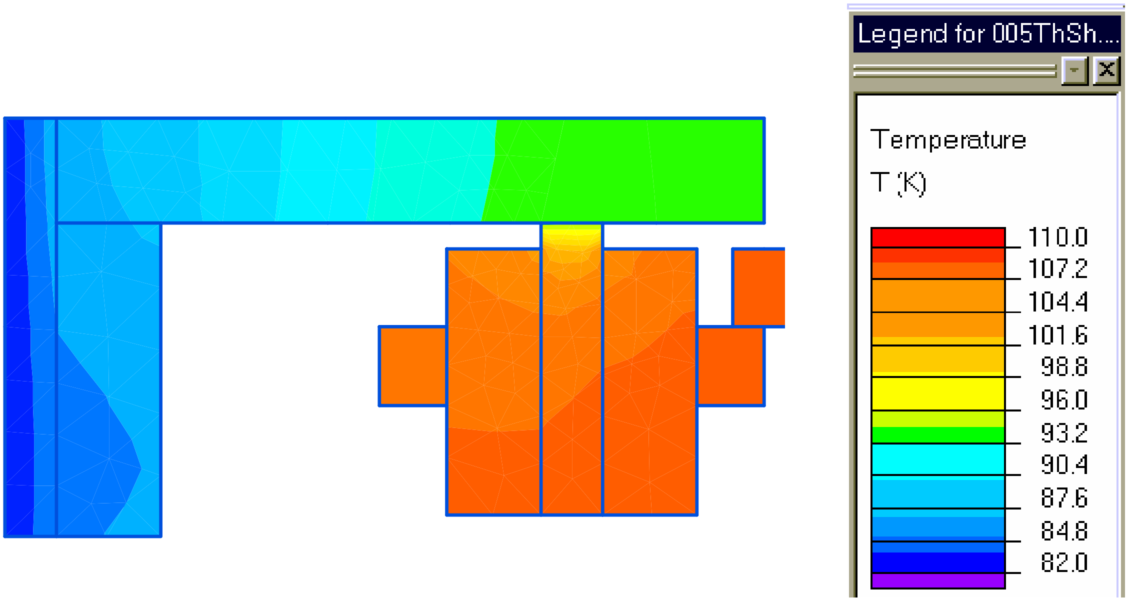

Fig. 4.8. VVTS/TTS joint. Temperature distribution. Baking condition.
(Coated bolt and bush emissivity factor - 0.05)

CTS joint

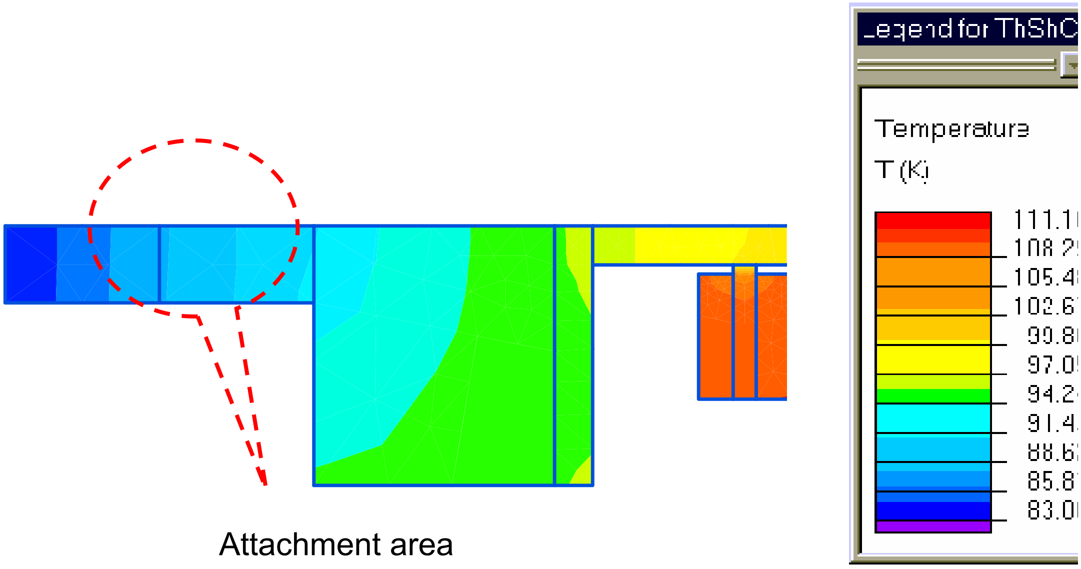

Fig. 4.9. CTS joint. Temperature distribution.
(Bare bolt and bush emissivity factor - 0.35)
In attachment area: No bolts.

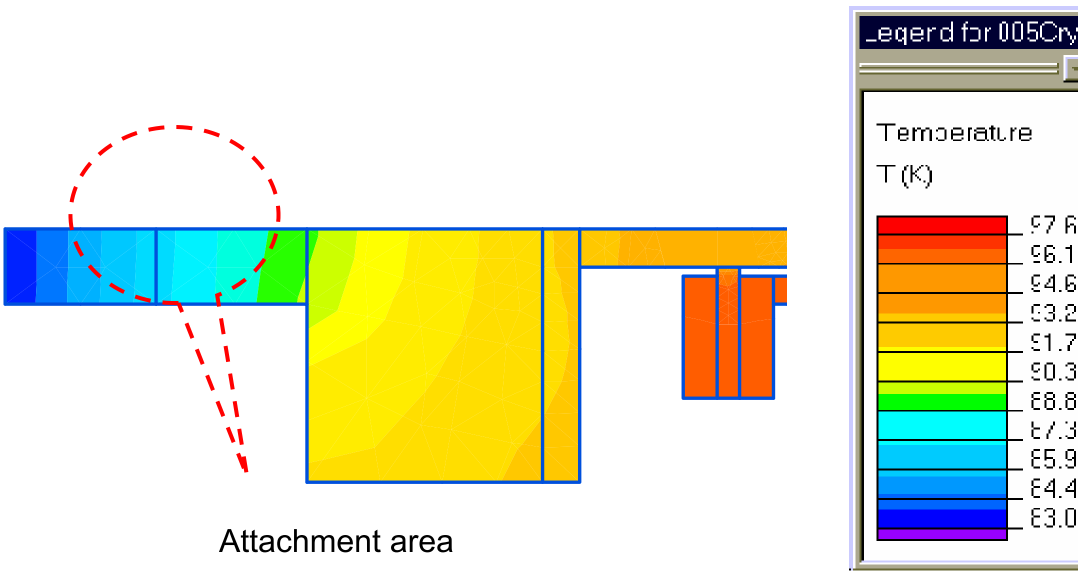

Fig. 4.10. CTS joint. Temperature distribution.
(Coated bolt and bush emissivity factor - 0.05)
In attachment area: No bolts.

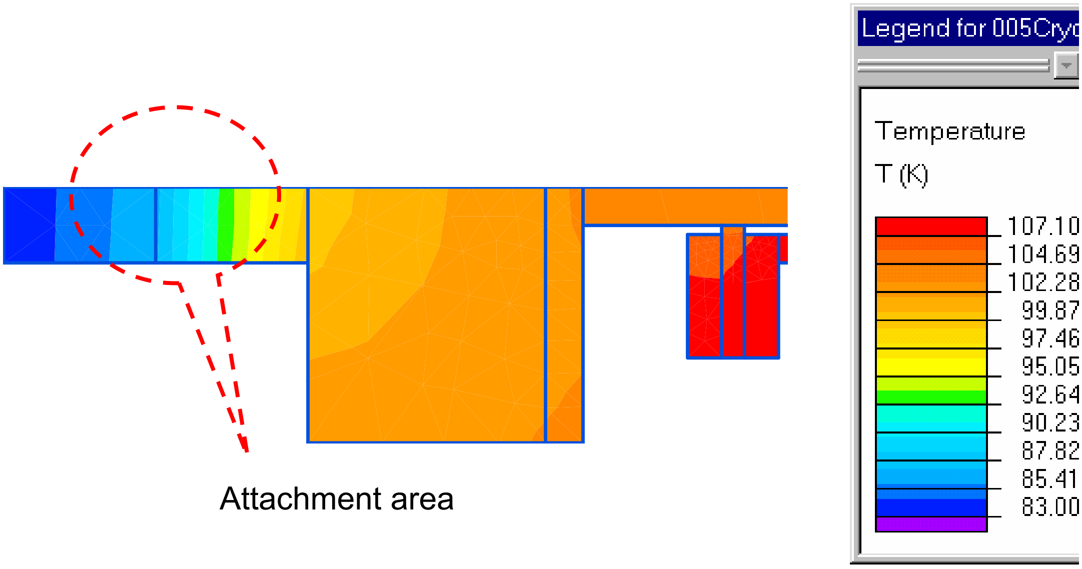

Fig. 4.11. CTS joint. Temperature distribution.
(Coated bolt and bush emissivity factor - 0.05)
In attachment area: Step between bolts - 200 mm.

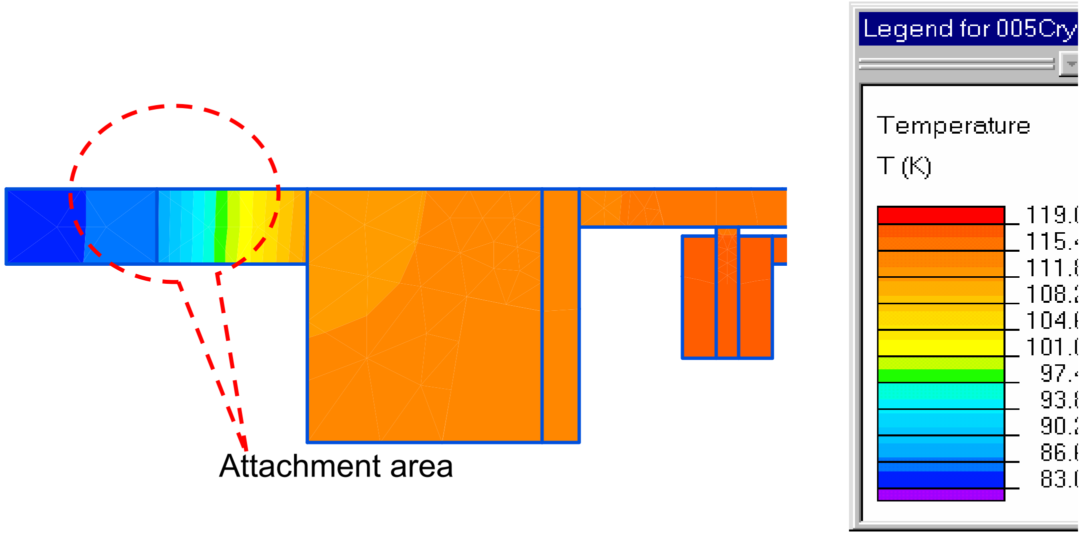

Fig. 4.12. CTS joint. Temperature distribution.
(Coated bolt and bush emissivity factor - 0.05)
In attachment area: Step between bolts - 400 mm.

VVTS butt weld joint

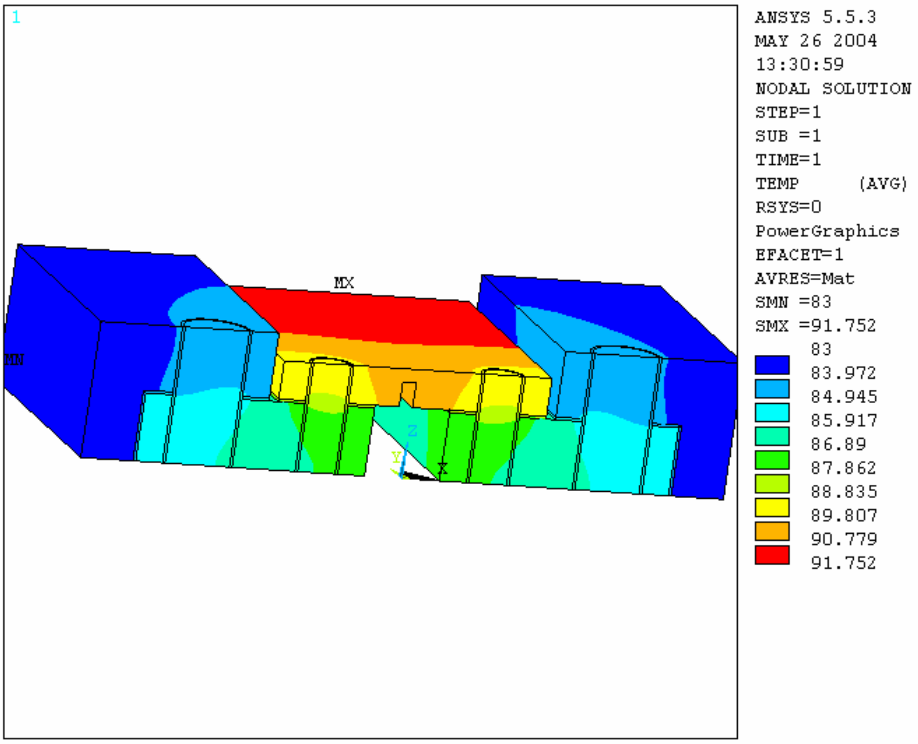

Fig. 4.13. VVTS joint. Temperature distribution. Normal condition.

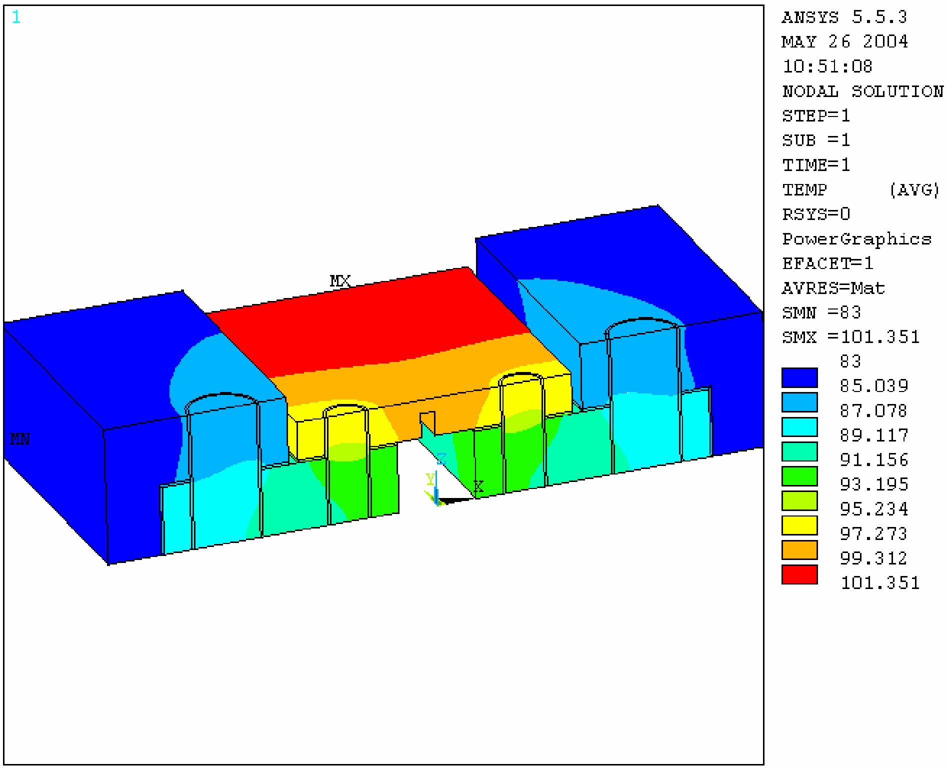

Fig. 4.14. VVTS joint. Temperature distribution. Baking condition.

Result summary

Table. 4.1.

Fig. N	Joint type	VV or Cryostat temperature	Bolt and bush emissivity	Max temperature	Heat flux		
					Max local	Average	Exceeding the base radiation
		°C		K	W/m²	W/m²	
Fig.4.5	VVTS	120	0.35	127	0.74	0.25	2.2
Fig.4.6	VVTS	200	0.35	167	2.24	0.41	3.5
Fig.4.7	VVTS*	200	0.35	122	0.63	0.32	2.8
Fig.4.8	VVTS	200	0.05	110	0.42	0.24	2.1
-	VVTS**	200	0.05	102	0.31	0.23	2.0

- perfect thermal contact between bush and plate;

** - reduced step between bolts – 200 mm.

Fig. 4.9	CTS	20	0.35	111	0.43	0.27	2.3
Fig. 4.10	CTS	20	0.05	97.6	0.26	0.23	2.0

Fig. 4.12	CTS, bolt step 200 mm	20	0.05	107	0.37	0.25	2.2
Fig. 4.11	CTS, bolt step 400 mm	20	0.05	119	0.51	0.32	2.8

Fig. 4.13	VVTS	120	0.05***	92	0.18 / 0.18	0.17 / 0.17	1.47 / 1.47
Fig.	VVT	200	0.05**	101	0.	0.	1.72 /

4.14	S		*		22 / 0.21	20 / 0.20	1.72

***- under screen;
above line – for line crossed bolts, under line – for line between bolts.

Conclusion

The parametric analysis performed to study impact of the joint area design features of VVTS/TTS and CTS on their thermal insulation performance revealed that:

- a decrease of the bolt emissivity from 0.35 to 0.05 would cause a reduction of the local heat influx by ~ 1.5 times. An average heat flux is expected to be less affected.
- a decrease of the bolt pitch from 400 mm to 200 mm leads to reduction of the local heat influx to TFC in 1.35 times (from 0.42 to 0.31 W/m^2) at the bolt emissivity of 0.05, in the same time an average heat flux to the TFC reduces negligibly.
- good thermal contact between the bush and the splice plate decreases drastically the temperature of the splice plate as well as a local influx to the TFC.
- local heat influxes to the TFC for all the studied options are below the stated limit of 40 W/m^2.
- an average heat load on the TFC near the joints is up to 3.5 times higher than the "background" level (thermal radiation to the TFC from the TS panel at 80 K). However, this is below 1 W/m^2 limit specified for all options.