Agenzia Nazionale per le Nuove Tecnologie,
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RICERCA DI SISTEMA ELETTRICO

TF System Quench analyses in operation condition

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contributors: L. Zani(F4E), B. Lacroix (CEA)

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TF SYSTEM QUENCH ANALYSES IN OPERATION CONDITION

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TF system quench analyses

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1- Introduction

2- Reference configuration

3- Parametric analyses

4- Conclusion & perspectives

1- Introduction

✓ Recent investigations on the impact of some design changes regarding components linked to the TF magnets system (TF strand, Power Supplies)

✓ Need of finalization for the protection system features

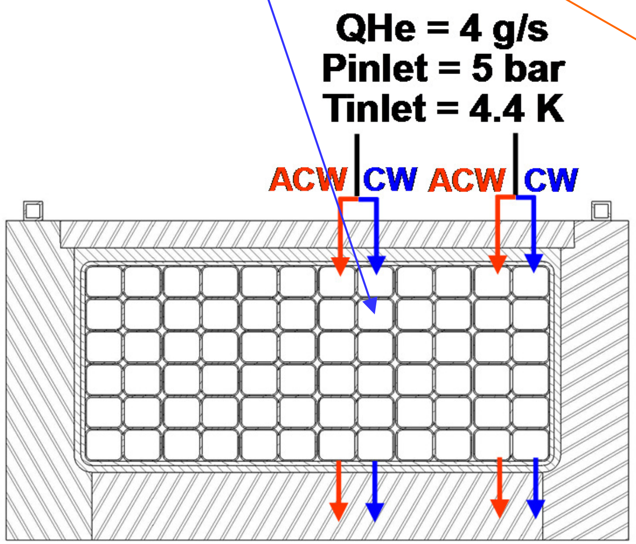
→ New modelisation works were launched both regarding thermohydraulics approach (Gandalf) or with more simple thermal approach (xls solver)

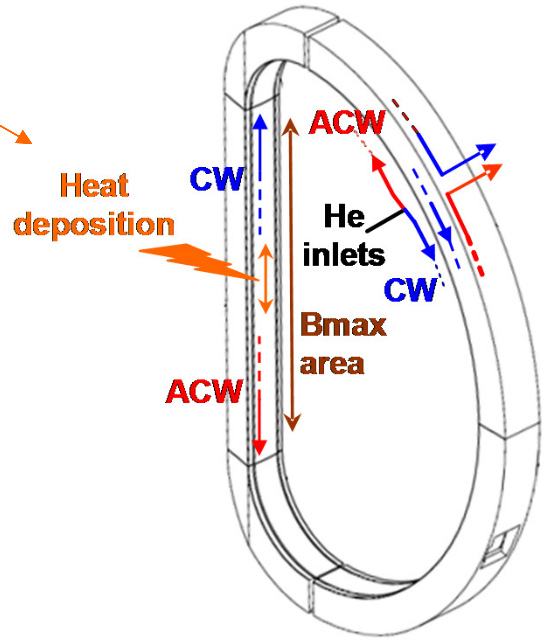
→ The results presented here aim at **setting the main parameters for protection circuit** and show their robustness in terms of reliability for magnet protection purpose

2- Reference configuration

Simulation of a quench with the GANDALF code:

- on the CW median conductor
- in operating conditions (Iop = 25 700 A)
- with the heat perturbation deposited in the middle of the Bmax zone (x = 12.5 m)



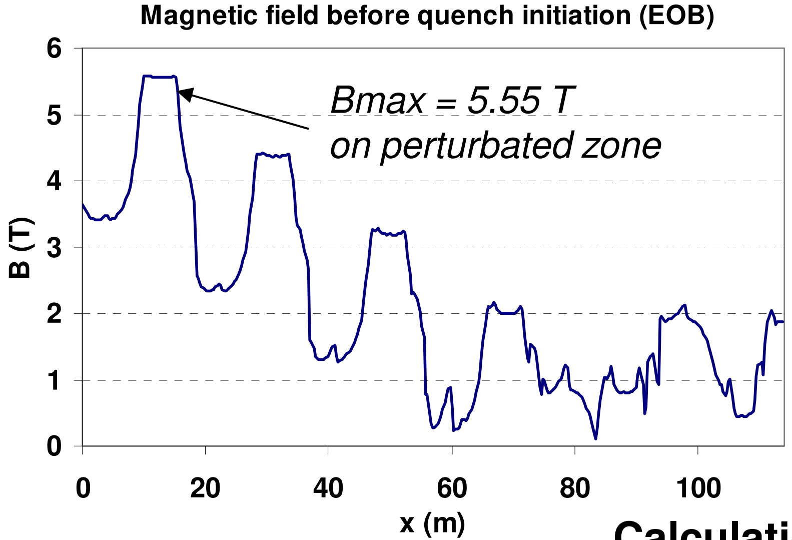


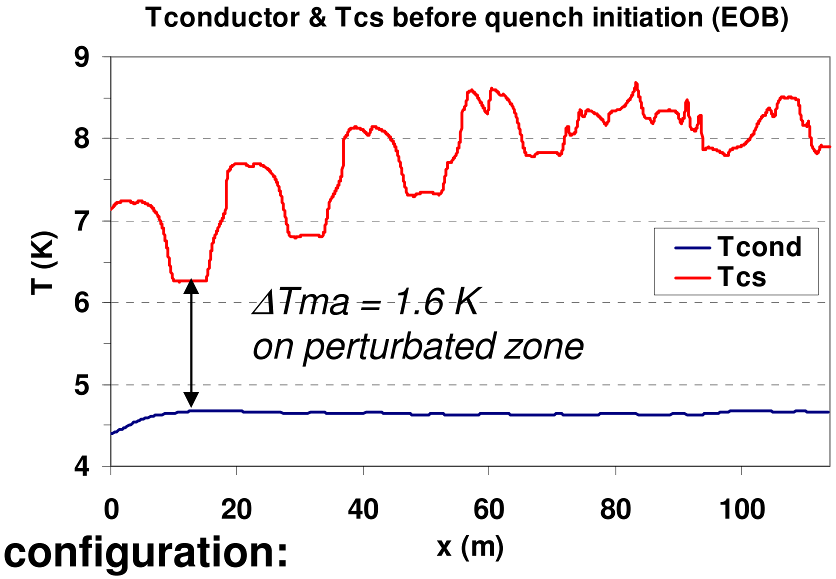
Main hypotheses:

- Model limited to the 114 m conductor (cryolines/feeders not represented)
- Updated friction factor correlation according to pressure drop measurements
- Updated strand design (A_{Cu} reduced of 5% >> CuNi barrier change), RRR=100

2- Reference configuration

Initial conditions (magnetic field & temperature distributions) correspond to the **End Of Burn for the 100 s burn scenario** with NY = 1.3 10^{17} n/s





Calculation baseline configuration:

- **1 m** heat deposition on equatorial plane (from 12 to 13 m) during **1 s**
- Reference MQE (RMQE) = 132 W ~ 791 mJ/cc → Quench triggered with **2*RMQE**

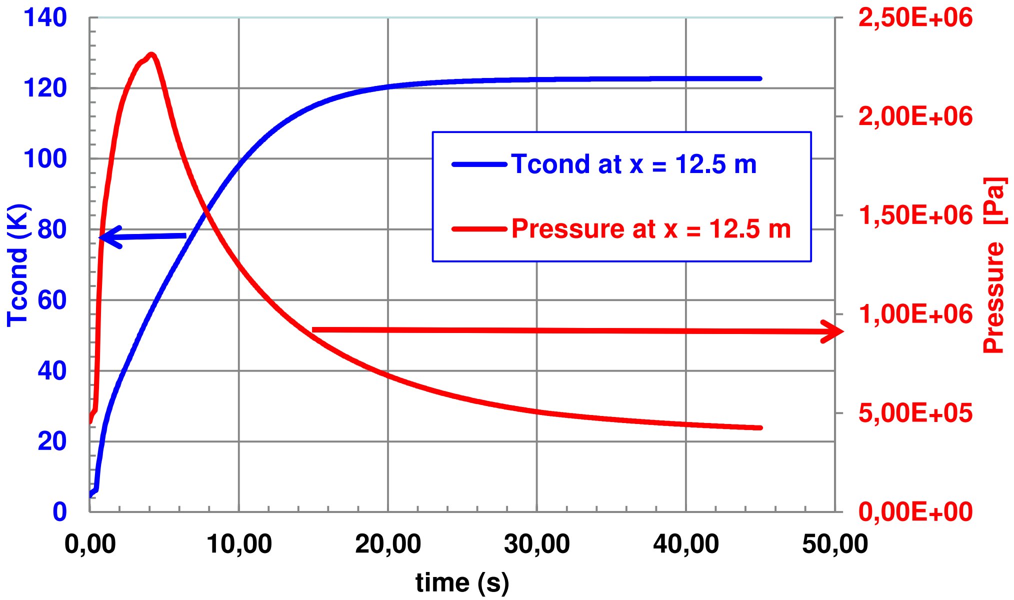
Reference features for protection circuit :

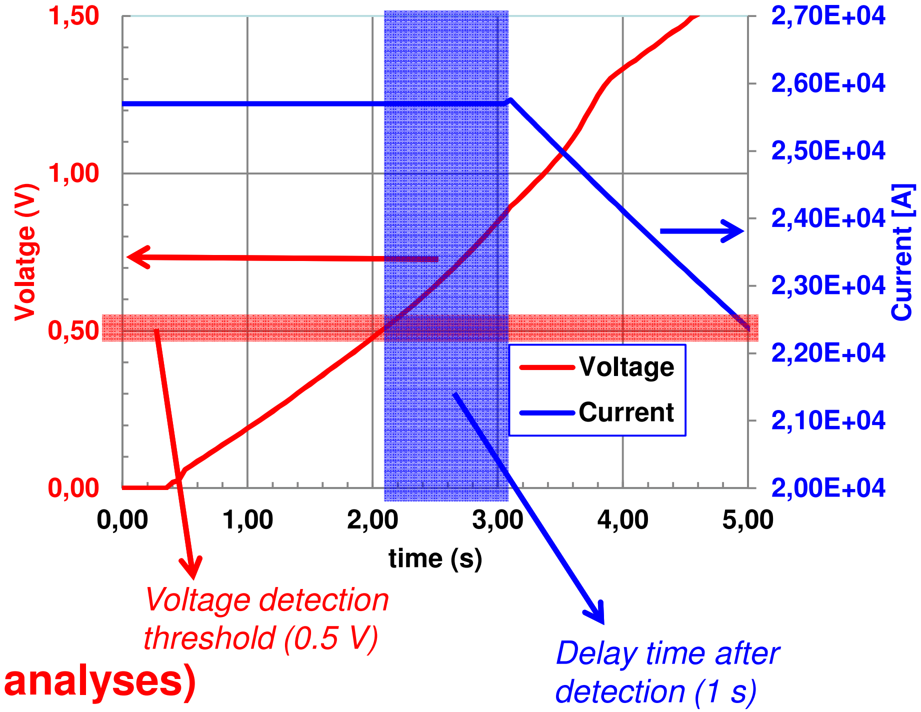
- **Voltage detection threshold = 0.5 V**
- **Tdelay (after detection) = 1 s**

  highly conservative approach with respect to PID conditions, but referring to real exploitation conditions (e.g. Tore Supra)

2- Reference configuration

	Case #	V_detect [V]	T_delay [s]	RRR	heated length [m]	Mdot [g/s]	T_duration [s]	P_perturb	MQE [W/m]	MQE [mJ/cm^3]
Ref.	0	0.5	1	100	1	4.0	1	2*MQE	2*132	2*791





Pressure < 25 bar (value considered for mechanical analyses)

➔ the conductor temperature < 130 K (upper classical limit ~150 K)

2- Reference configuration

	Case #	V_detect [V]	T_delay [s]	RRR	heated length [m]	Mdot [g/s]	T_duration [s]	P_perturb	MQE [W/m]	MQE [mJ/cm^3]
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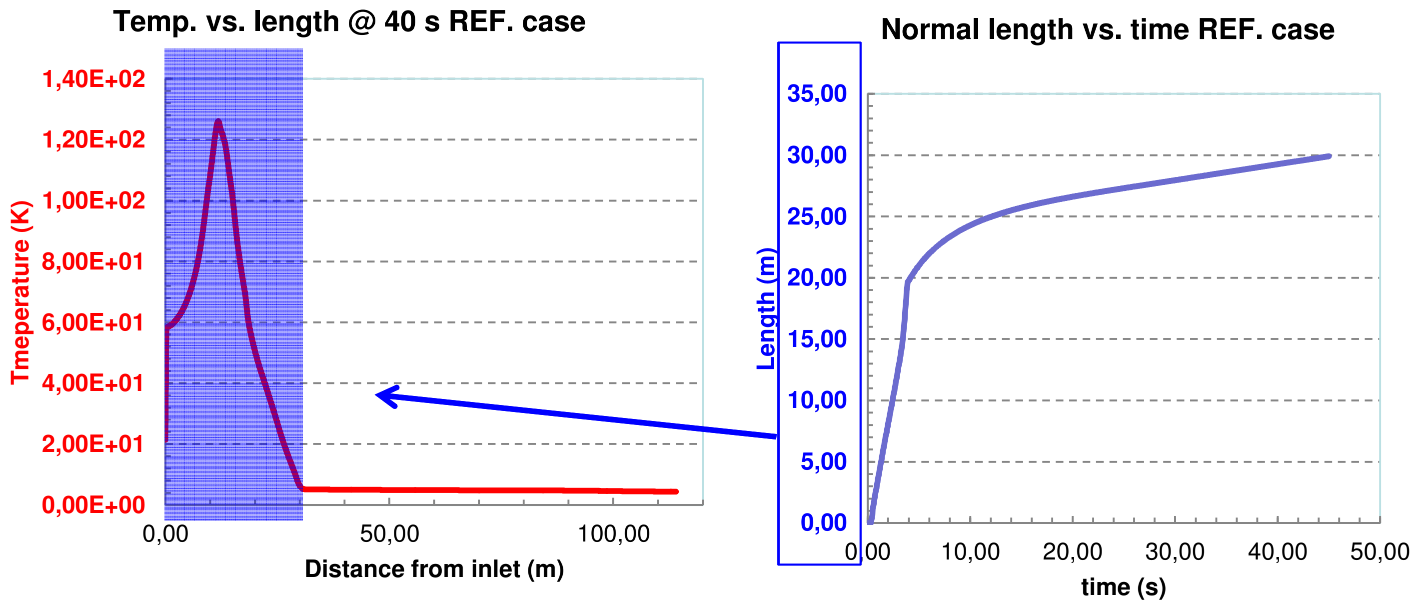
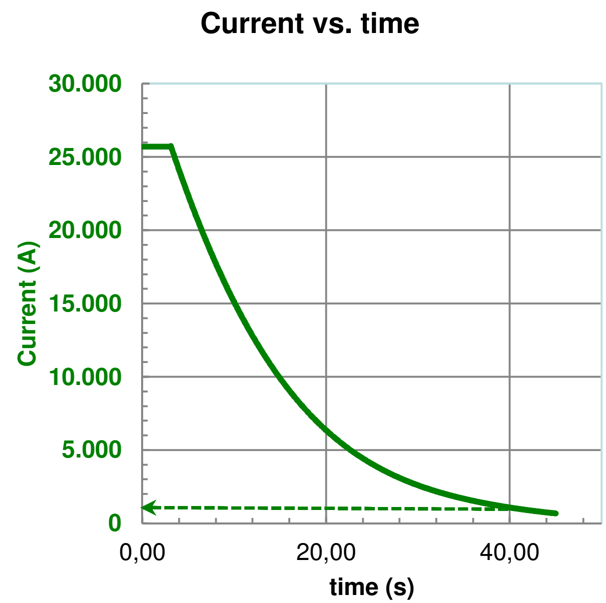




The extension of the normal length keeps below 40 m during the period considered for simulation

At 40 s I ~ 1000 A

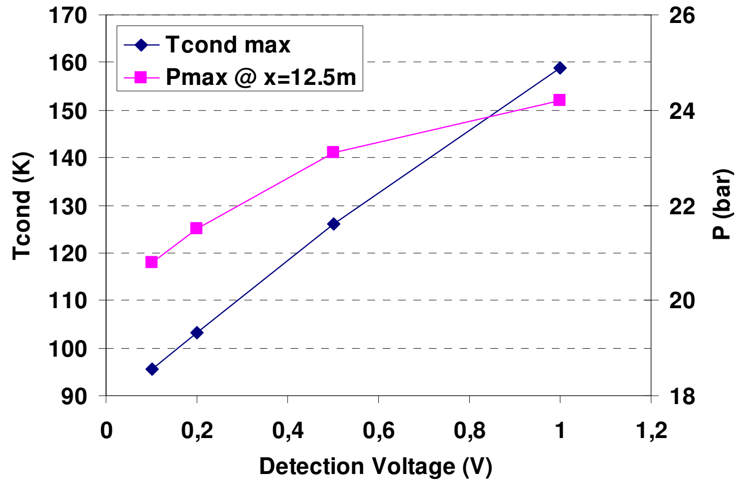
3- Parametric analysis: overview

Case	RRR	T_delay [s]	A_Cu [mm^2]	P_perturb [W/m]	Length [m]	V_detect [V]
Ref.	100	1	180	2*132	1	0.5
RRR	55 70 100 130 160	-	-	-	-	-
T_delay	-	0.5 1 1.5	-	-	-	-
A_Cu strand	-	-	170	-	-	-
MQE	-	-	-	10*132	-	
Length	-	-	-	-	0.05 0.2 1 5	-
V_detection	-	-	-	-	-	0.1 0.2 0.5 1

Sensitivity to **detection voltage**

Voltage (V)	Tmax (K)	Pmax (bar) at x = 12.5m
0.1	95.6	20.8
0.2	103.2	21.5
0.5	126	23.1
1	158.8	24.2

Reference → (0.5)

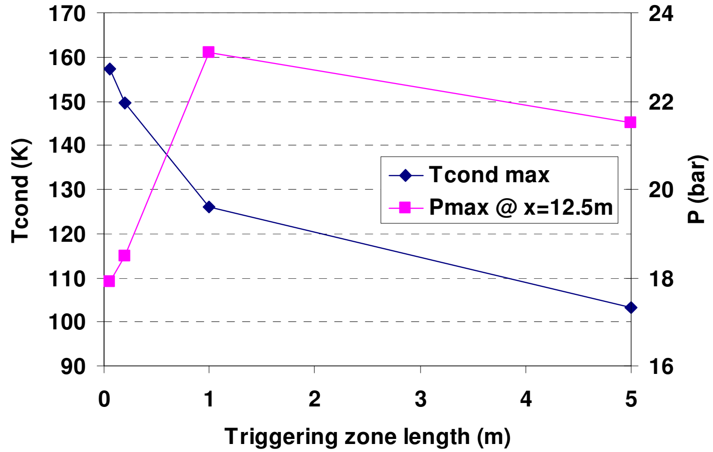


Strong impact of detection voltage on Temperature

Sensitivity to **perturbation length**

Perturbation length (m)	Tmax (K)	Pmax (bar) at x = 12.5m	Perturbation Power (W/m)
0,05	157,2	17,9	2*524
0,2	149,5	18,5	2*196
1	126	23,1	2*132
5	103,2	21,5	2*112

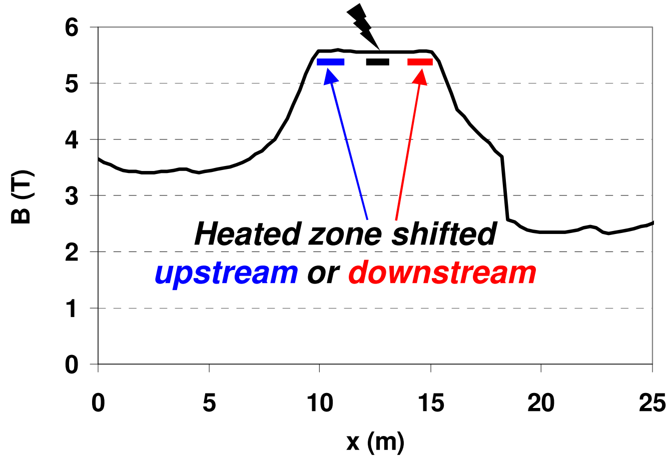
Reference → (1)



The lower heated length, the higher Tcond, but acceptable

3- Parametric analysis

Shifting the heated zone in the Bmax area
→ low impact

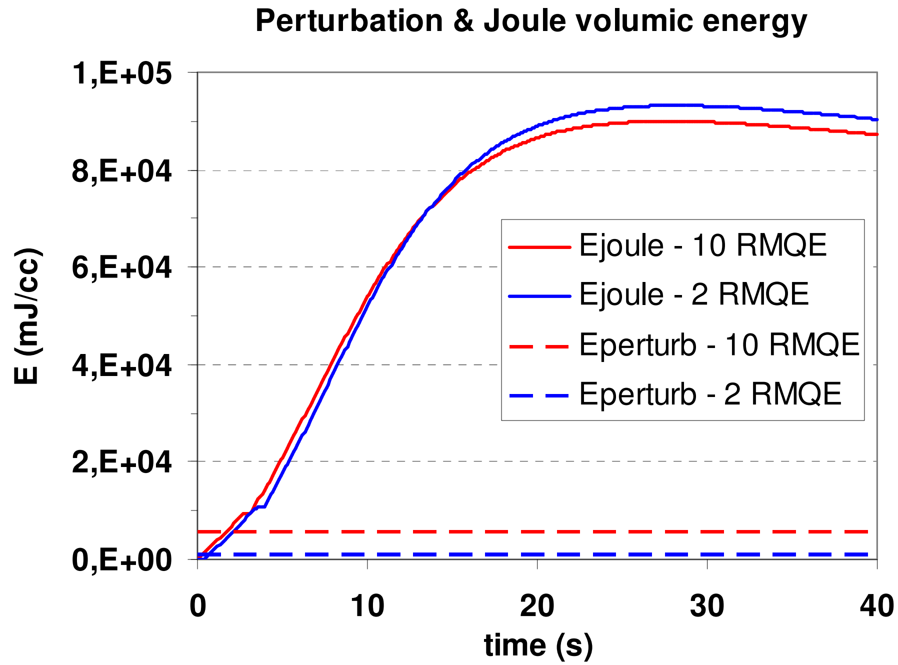


Heated zone position	Tmax (K)	Pmax (bar) at x = 12.5m
upstream	125.8	22.2
Center (ref.)	126	23.1
downstream	129	24.3

Influence of the perturbation energy

P_perturb	Tmax (K)	Pmax (bar) at x = 12.5m
2 MQE = 2 * 132 W/m	126	23.1
10 MQE = 10 * 132 W/m	138	24.9

Joule heating dominates
→ limited impact of perturbation energy

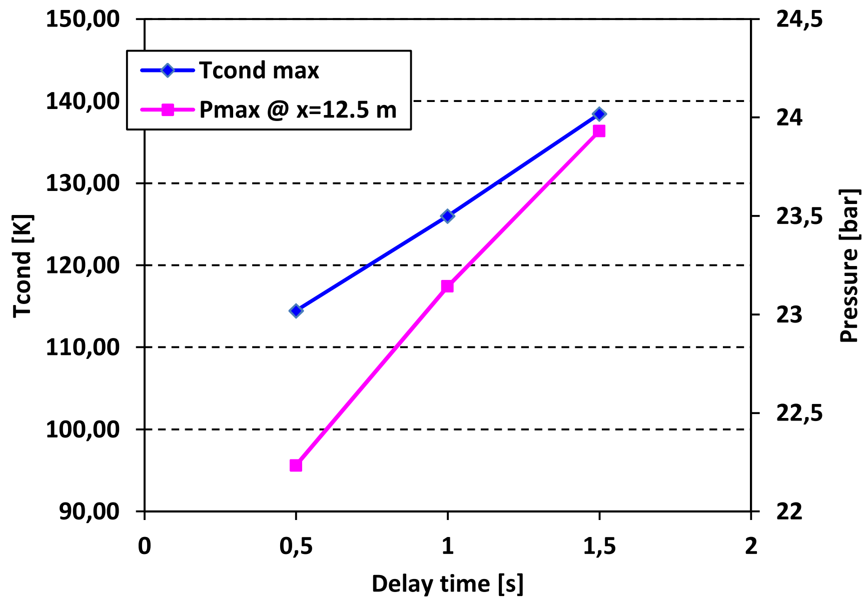


3- Parametric analysis

Sensitivity to **delay time after quench detection**

Delay time (s)	Tmax (K) at x = 12.5m	Pmax (bar) at x = 12.5m
0.5	114	22.2
1	126	23.1
1.5	138	23.9

Reference → 1

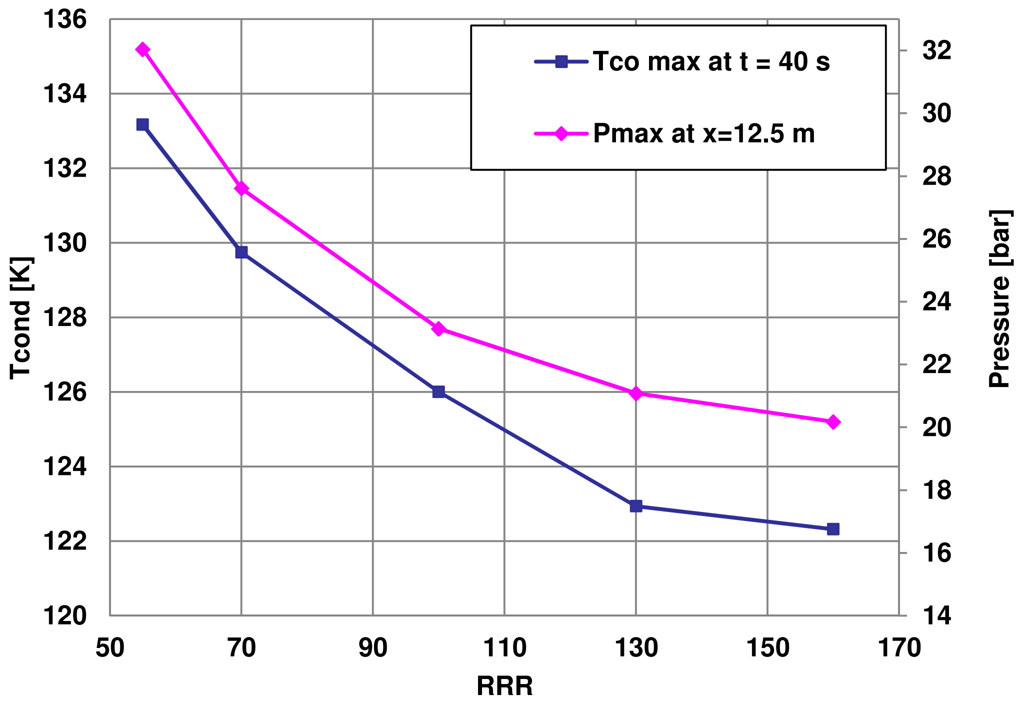


The longer delay time, the higher Tcond, but acceptable

3- Parametric analysis

Sensitivity to parameters relevant of manufacturing tolerances

RRR	Tmax (K)	Pmax (bar) at x = 12.5m
55	133	32.0
70	129	27.6
100	126	23.1
130	123	21.1
160	122	20.2



The lower the RRR time, the higher Tcond, but acceptable
Pressure also increases even if not dramatically critical

3- Parametric analysis

Conservative model cross-check used for design in a straightforward approach (see presentation **TCM12-02-09**).

Working hypotheses :

- reference scenario same as Gandalf, with reaching V_{detect} immediatly
- **RRR** taken as minimum in TF strand specifications → *value of 80*

⇨ $\mathbf{T_{MAX}}$ **~ 263 K**

⦿ Gandalf cross check

- in similar conditions (no He) ΔT_{MAX} ~ 25 K ⇨ good consistency, still under investigations

⦿ Mitigation : RRR is in average higher than specifications

- from Cu and NbTi production the minimum "effective RRR" ~ 100 ⇨ $\mathbf{T_{MAX}}$ **~ 250 K**
- in similar conditions (no He) in Gandalf T_{MAX} + 25 K ⇨ still under investigations but good consistency,

Remark : upper limit value commonly used is 250 K but the present situation is highly conservative (no Helium present in the cable) and this criterion is commonly considered for "dry magnets" , which is not the case for JT-60SA.

4- Conclusion & perspectives

A **reference configuration for TF magnet protection system** was defined with :

- a **voltage detection threshold of 0.5 V**
- a **delay after detection of 1 sec**

This configuration aims at enabling a good capacity to distinguish transient parasitic signals to real DC quench ones ("filter" by amplitude and frequency).

The present analyses led with Gandalf showed that **this reference configuration is robust**, demonstrated as :

- showing acceptable cable temperature (<130 K) and pressure (< 25 bar) increase for a quench scenario which is reasonably conservative.
- being in a domain where the variations of central parameters (RRR, detection V, delay time or length quenched) do not imply a critical change in the temperature rise.

Should this reference configuration features be agreed, it is then proposed that the PID is modified accordingly.

Some further investigations are under consideration to consolidate the results before switching to the TF cold tests configuration.

Sensitivity to parameters relevant of manufacturing tolerances