Quench Protection Study
for
Curved Solenoids of Super-Omega

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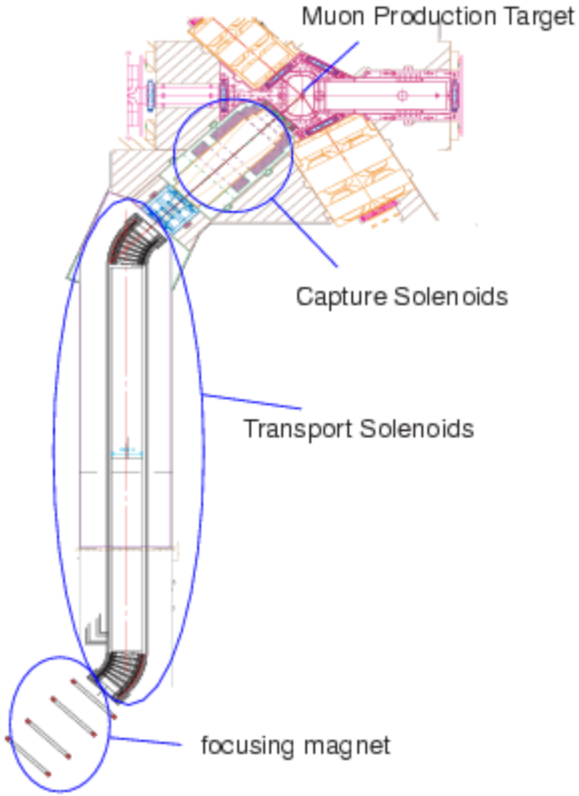
Curved Solenoids of the Super-Omega



Specifications of Transport Solenoids

Length	7m
Inner diameter	400mm
Central magnetic field	1.7T
Maximum magnetic field	4T
Stored Energy	1MJ
Temperature	4K～6K

Two designs

N-design

- Use thick wire and high current.
- Quench protection is easier.
- Heat load of current lead is larger.
- Designed by Nakahara

T-design

- Use thin wire and low current.
- Quench protection is more difficult.
- Heat load of current lead is smaller.
- Designed by Toshiba.

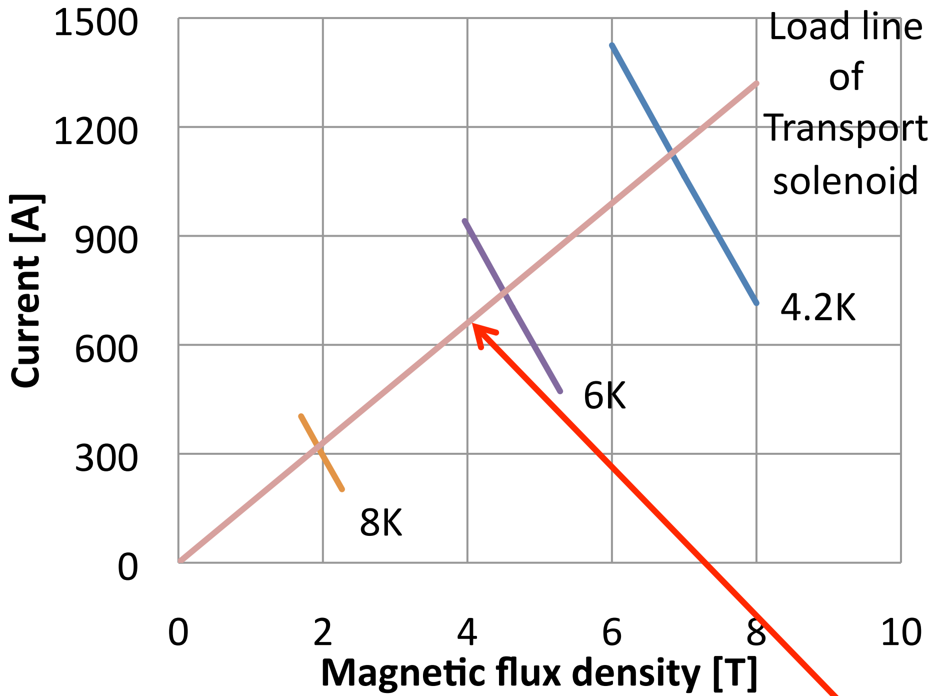
Superconducting Wire

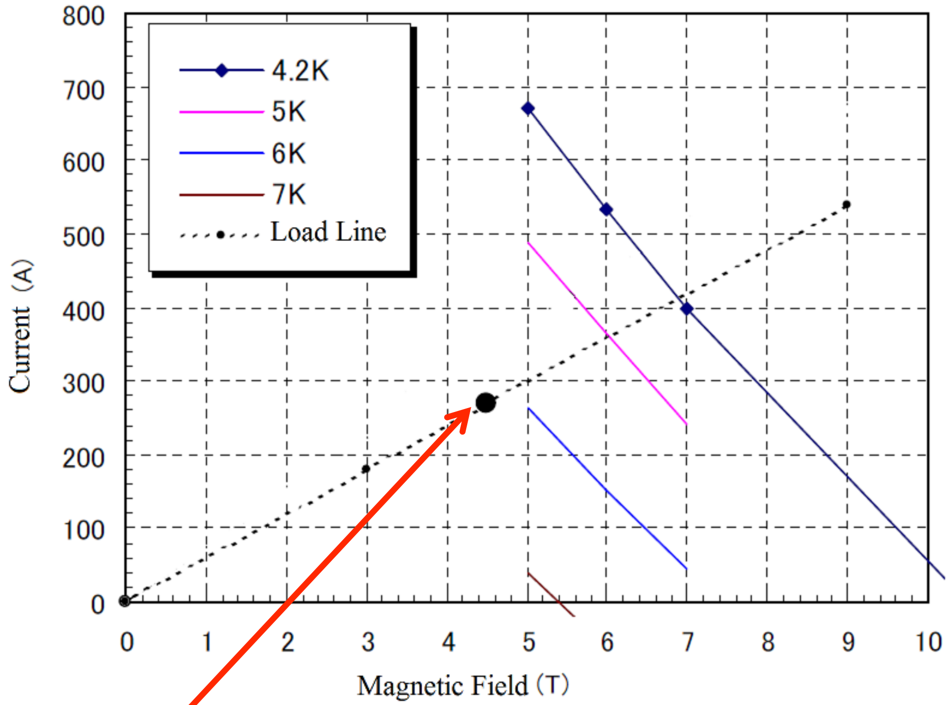
			N-design	T-design	ratio
Superconductor			NbTi	NbTi	
			Cu	Cu	
Shape			Rectangle	Round	
Size	Bare	mm	1.57x2.6	Φ1.2	
	Insulation	mm	1.67x2.7	Φ1.3	
Cross-section	Bare	mm	4.08	1.13	3.6
	Insulation	mm	4.51	1.33	3.4
Cu/NbTi Ratio			4.3	4	1.1
Ic @4.2K	@5T	A	--	610	
	@6T	A	1425	480	3.0
	@7T	A	1065	360	3.0
	@8T	A	715	--	

Coil Designs

		N-design	T-design	Ratio
Current	A	660	270	2.4
Inner diameter	mm	400	400	1.0
Length	m	7	7	1.0
Central magnetic field	T	1.7	1.7	1.0
Maximum magnetic field	T	4	4	1.0
Inductance	H	4.6	28	0.2
Total turns	turns	1.4×10^4	3.5×10^4	0.4
Stored energy	MJ	1	1	1.0

“Critical Current” and “Load Line”





N-design

T-design

Operation

MIITs

We can estimate maximum temperature at heat spot by using MIITs.

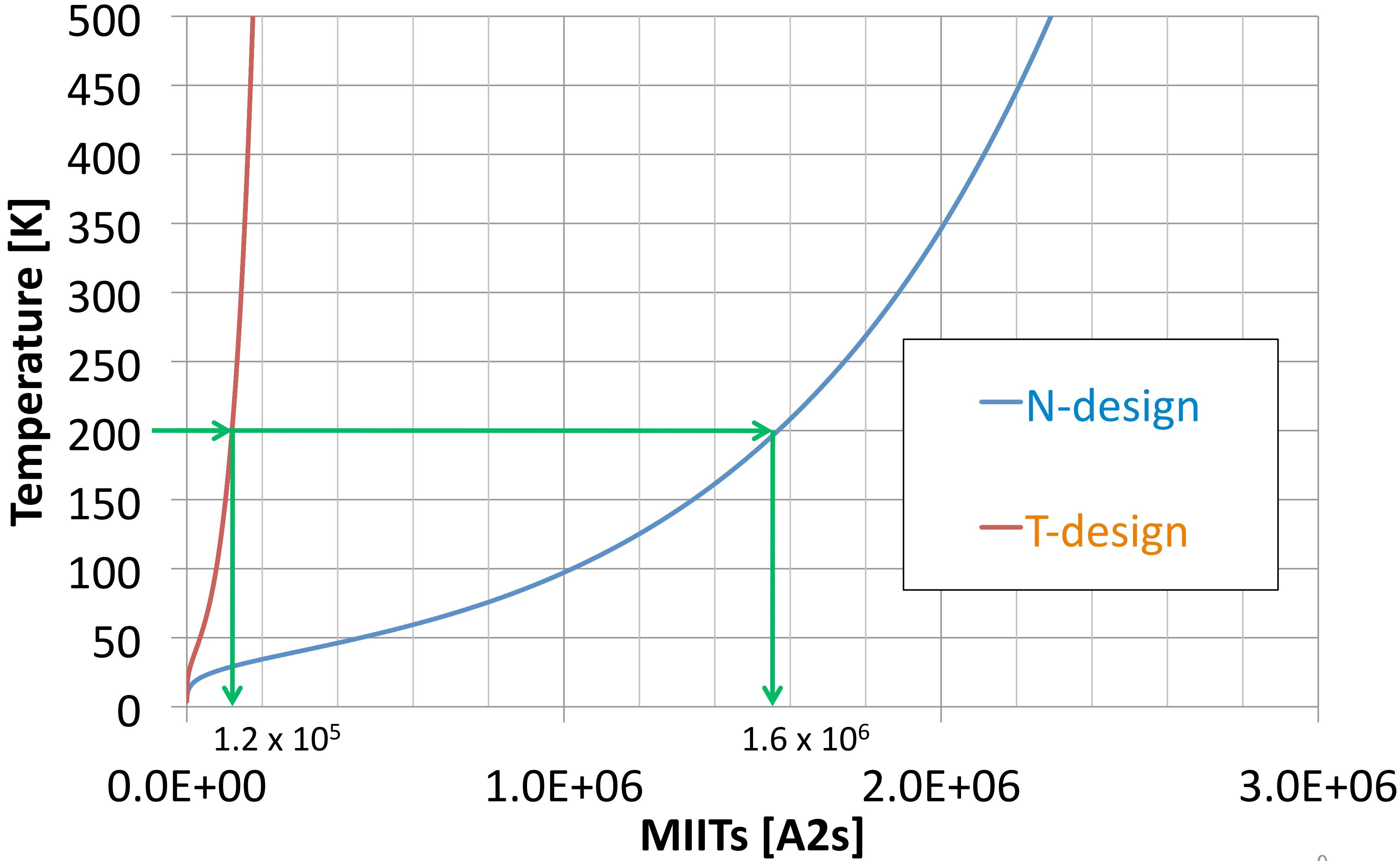
$$MIITs = \int_{T_0}^{T} \frac{C_{p\mathrm{Cu}} A_{\mathrm{Cu}} + C_{p\mathrm{SC}} A_{\mathrm{SC}}}{\rho_{\mathrm{Cu}} / A_{\mathrm{Cu}}} dT$$

Specific parameter of wire

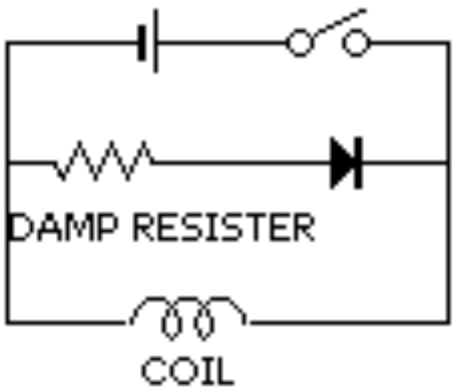
$$MIITs = \int_{t_0}^{t} I^2 dt$$

T : temperature
I : Current
t : time
C_p : heat capacity
A : cross-section
ρ : resistivity
Cu : Copper
SC : Superconductor

MIITs of Wires



MIITs of Damp circuits



$$L\frac{dI}{dt} + RI = 0$$

$$I = I_0 \exp\left(-\frac{R}{L}t\right)$$

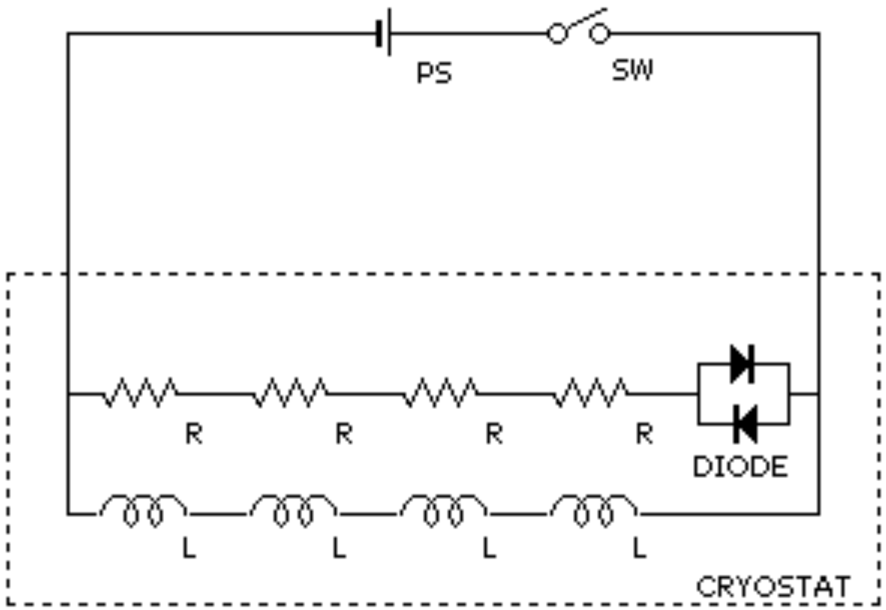
$$MIITs = \int_{t_0}^{t} I^2 dt$$

$$\text{MIITs} = \frac{L{I_0}^2}{2R}$$

		N-design	T-design	Ratio
Current	A	660	270	2.4
Inductance	H	4.6	28	0.2
Stored energy	MJ	1	1	1.0
Damp resister	Ω	0.75	1.85	0.4
Time constant	s	6	15	0.4
MIITs Damp	kA^2s	1.3	0.55	2.4
MIITs Wire 200K	kA^2s	1.6	0.12	13.3

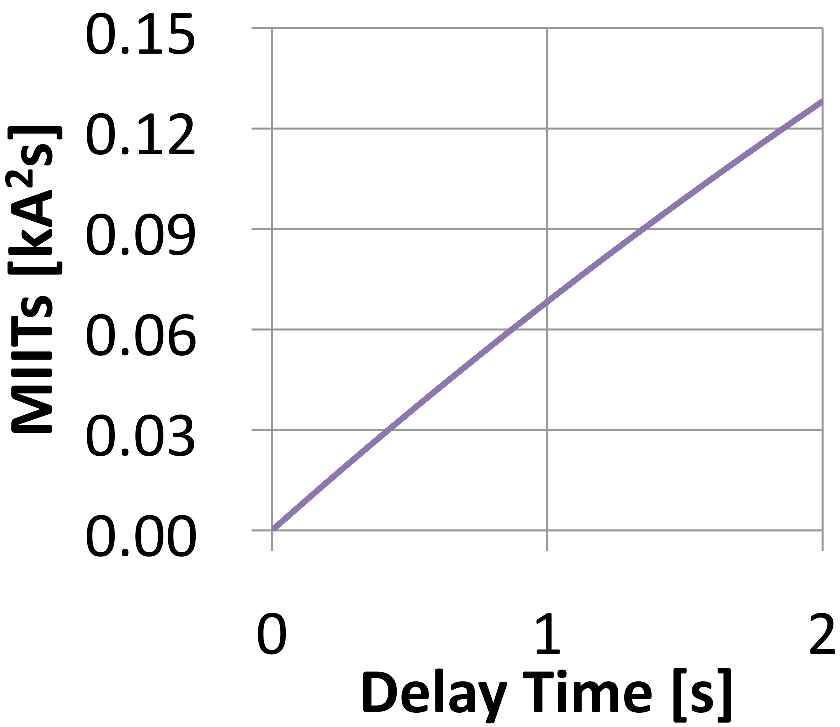
Quench-back

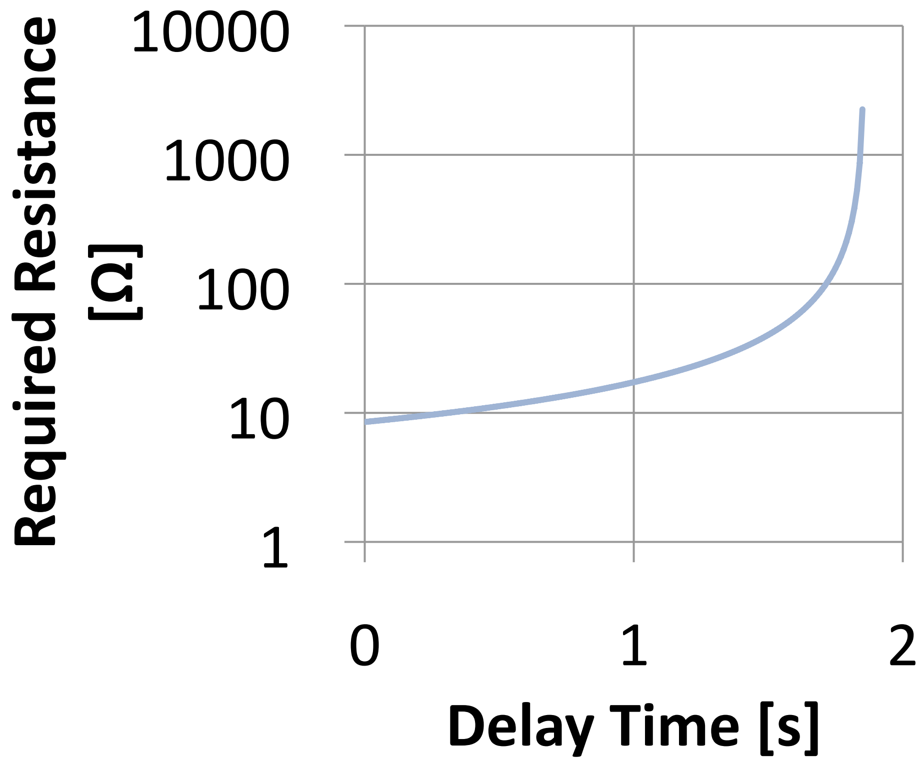
- When damp resister is Not enough.
- Use wire resistivity.
- Force wire quenched.
- Let quench propagate aggressively.



Required parameters for T-design

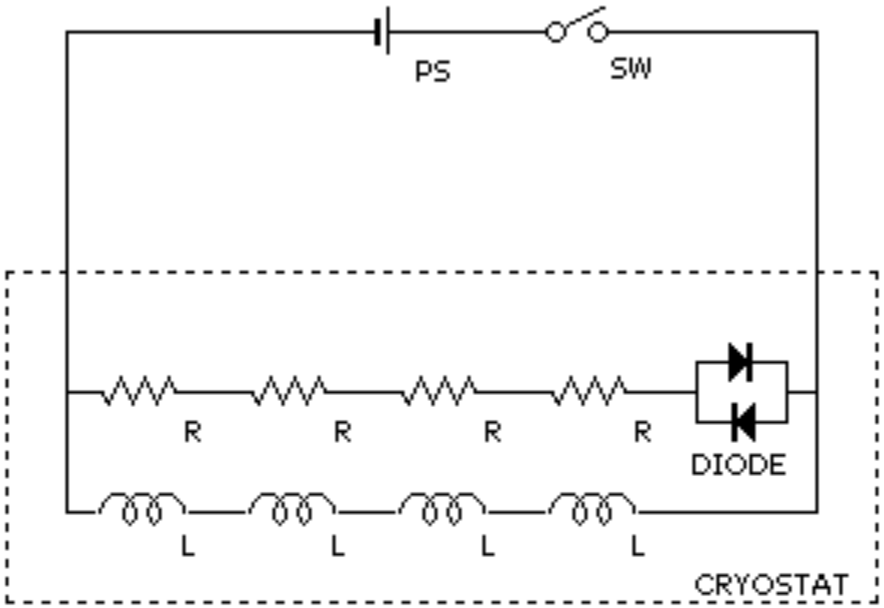
- MIITs = 1.2 kA^2s ⇒ Resistance > 8.5Ω
- Delay of quench-back requires more resistance.

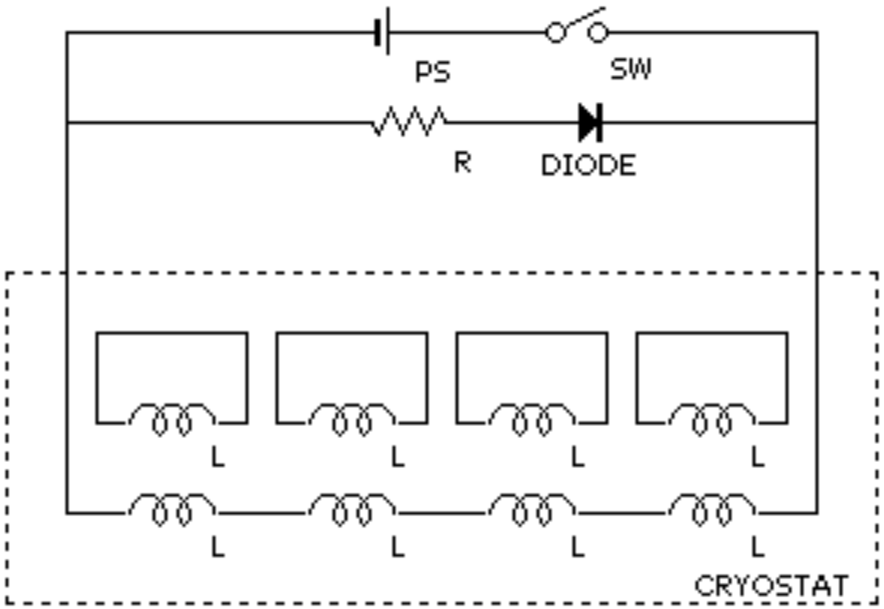




Resistance of wire ∼10Ω @10K ⇒ Delay < 0.3s

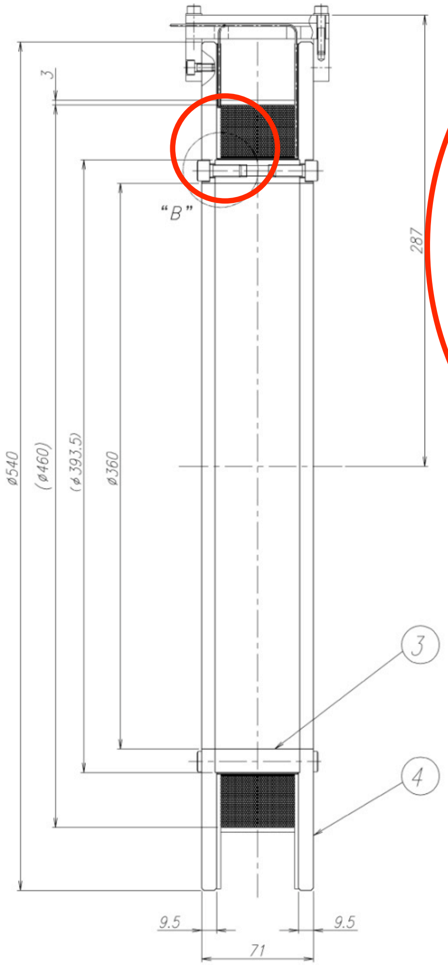
2 systems of quench-back



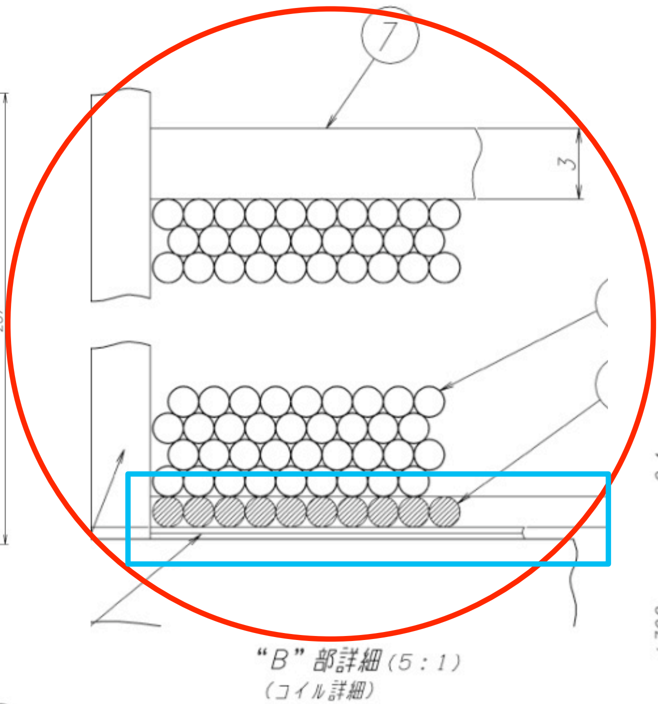


- Current is leaded to heaters.
- Damp of magnetic field cause current in heaters.

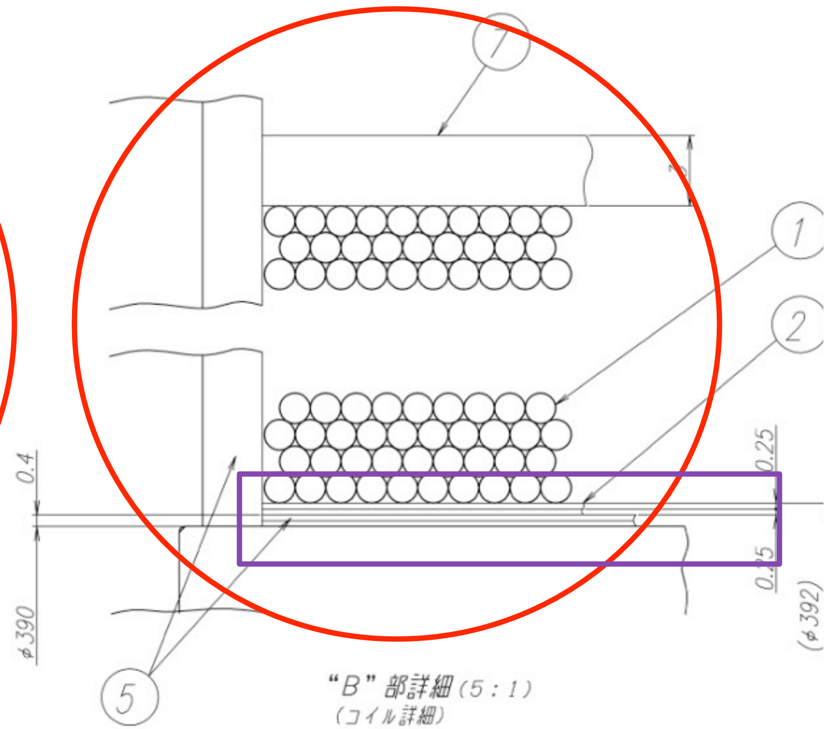
Structures of test coils



Cross-section of a coil



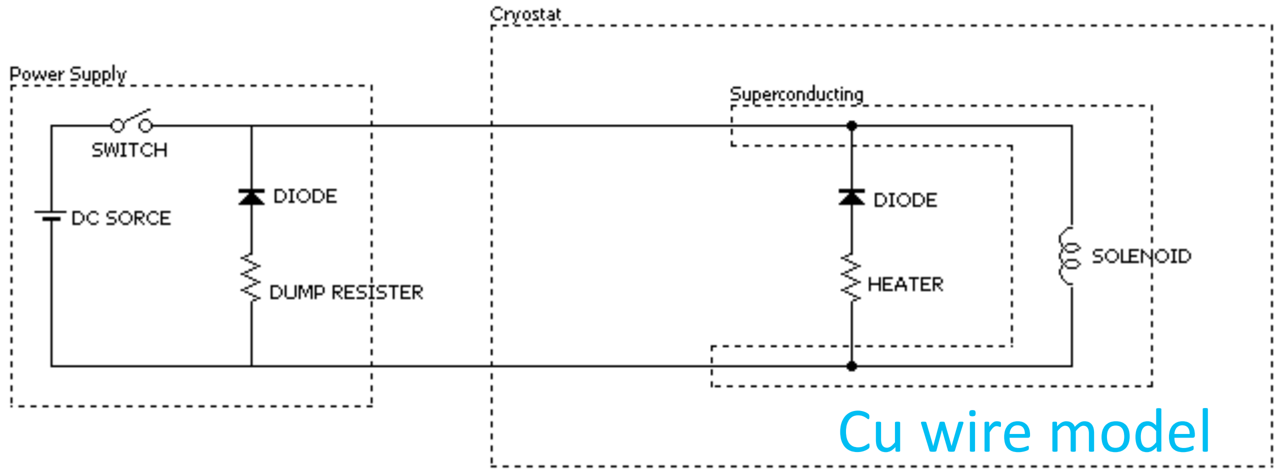
Cu wire inside the coil as a heater



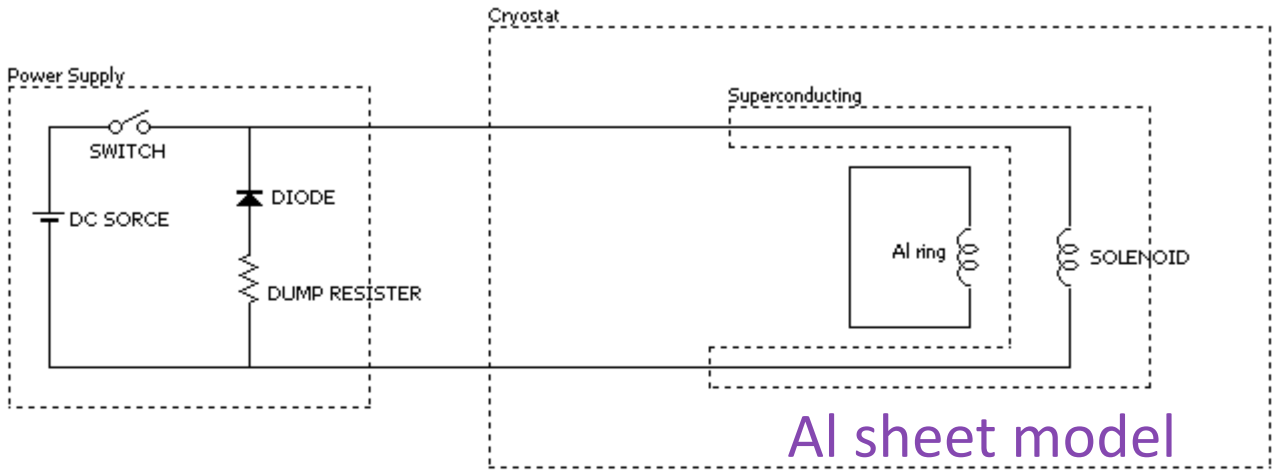
Pure Al sheets inside the coil as a heater

Test settings

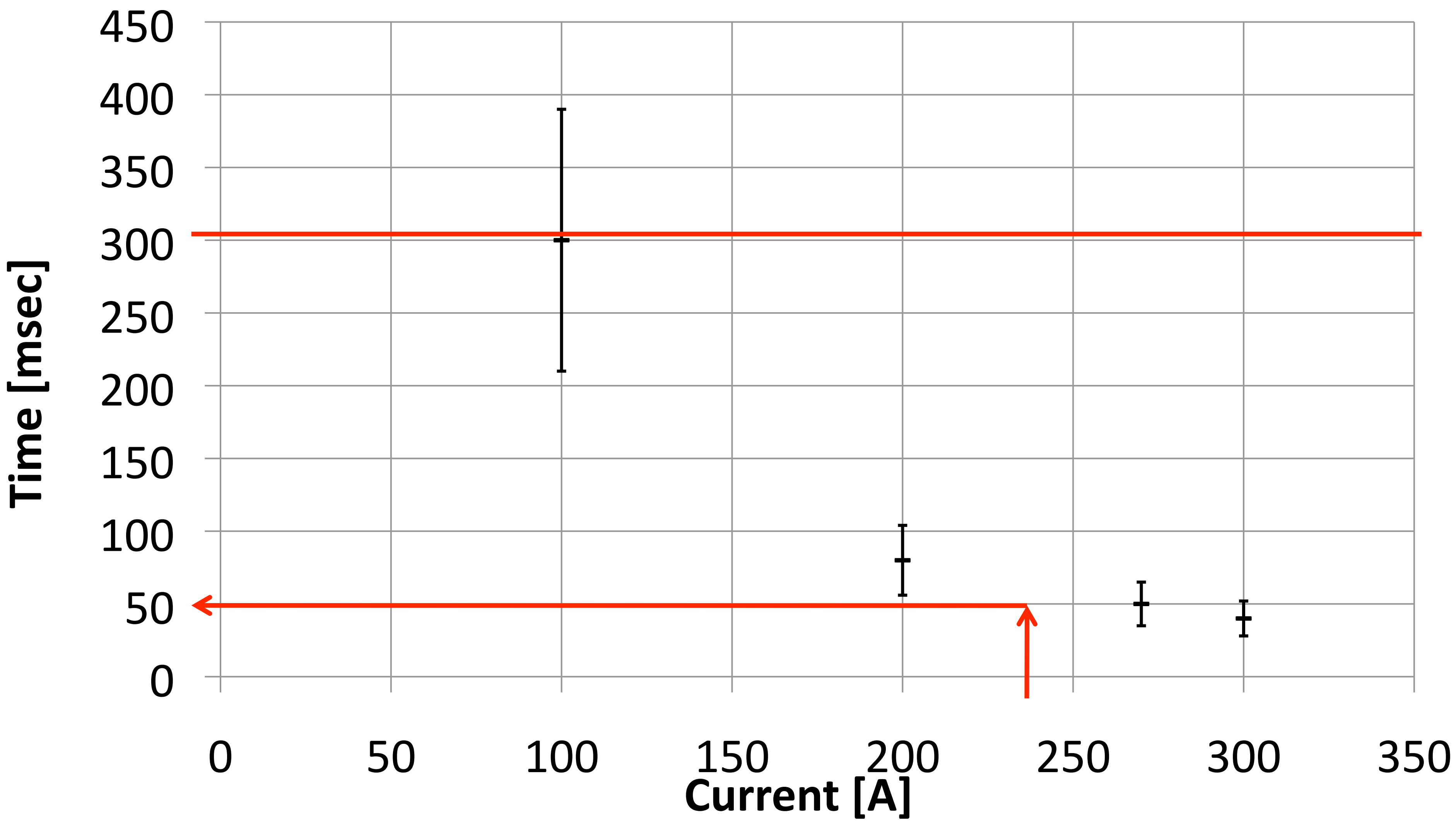
Coil Type	Solenoid
Wire	NbTi/Cu
Inner Diameter	400mm
Length	47mm
Turns	1015
Inductance	0.75H
Weight	～50kg



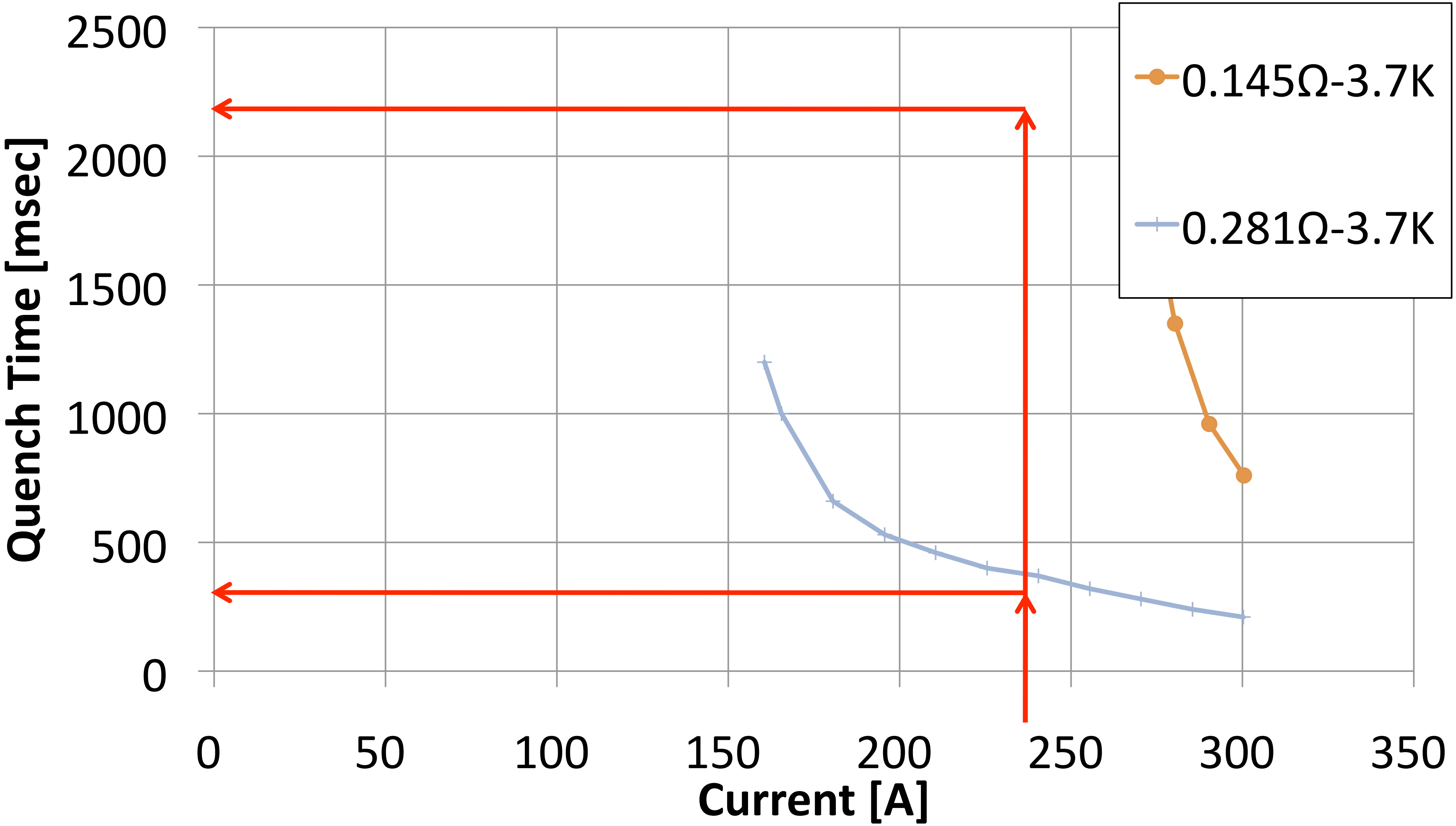
* Resistance of damp resister >> Resistance of heater



Test results (Cu wire model)



Test result (Al sheet model)



Discussion

- The Cu wire model is fast enough.

- Al sheet model requires fast damp.
  - It conflict with large inductance of the coil.
  - Detail is now under the consideration.

		T−design	Test1	Test2
Inductance	H	28	0.75	0.75
Damp resister	Ω	1.9	0.15	0.28
Time constant	s	15	5.2	2.7
Magnetic field	T	1.7	?	?
Delay time	s	0.3	2.1	0.28

Conclusion

- N-design is safe.
- T-design with Cu wire heater is safe.
- T-design with Al sheet is under the consideration.