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Study of the Hot-Spot Temperature during Quench in the Non-Planar Coils of W7-X

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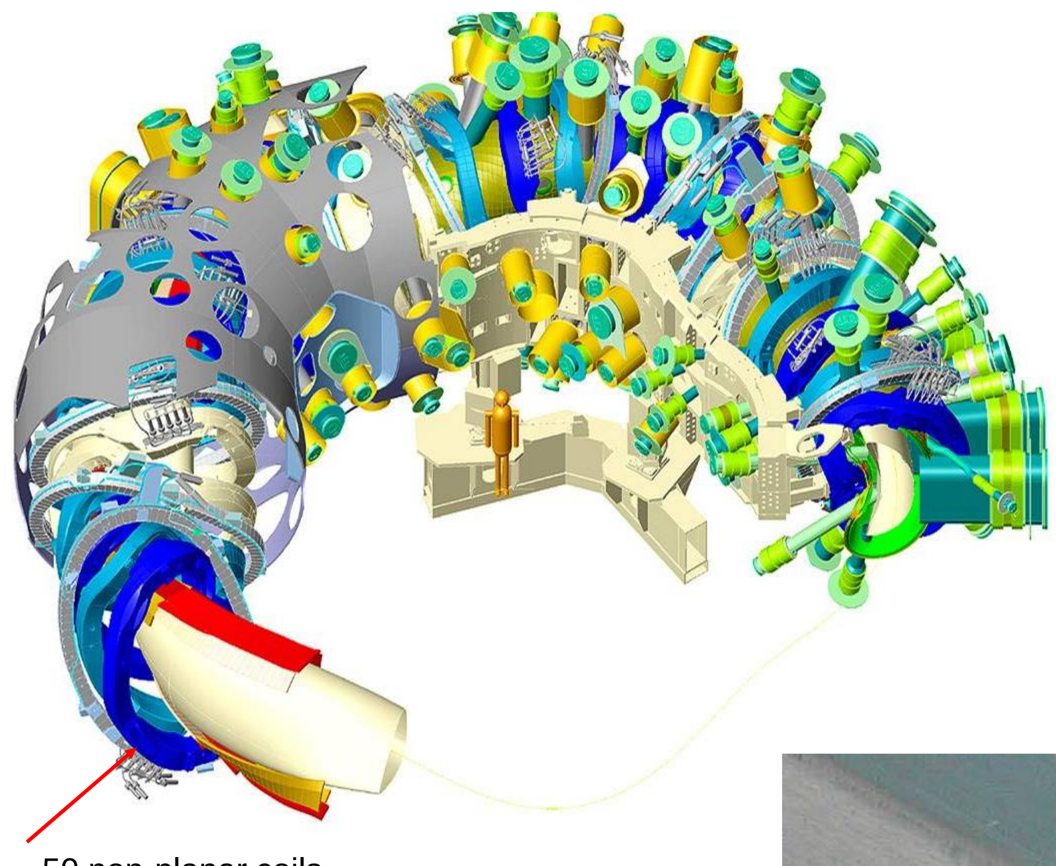
The quench protection system of the non-planar coils of the Wendelstein 7-X stellarator was laid out over fifteen years ago. At that time, the assessment of the hot-spot temperature by a basic adiabatic model was done using design values for material and operation parameters. After the operating experience in 2016, the hot-spot temperature is re-assessed with the thermal-hydraulic program THEA, using the actual values for delay and dump time. The electrical resistivity of the conduit alloy is measured over the whole range of temperature and in magnetic field on relevant samples of conductor, exposed to the hardening heat treatment after winding. The results are fed into Thea. Parametric variations are studied in the calculations, e.g. testing the effect of the quench initiation zone, delay time and dump resistor.

Wendelstein W7-X non-planar coil

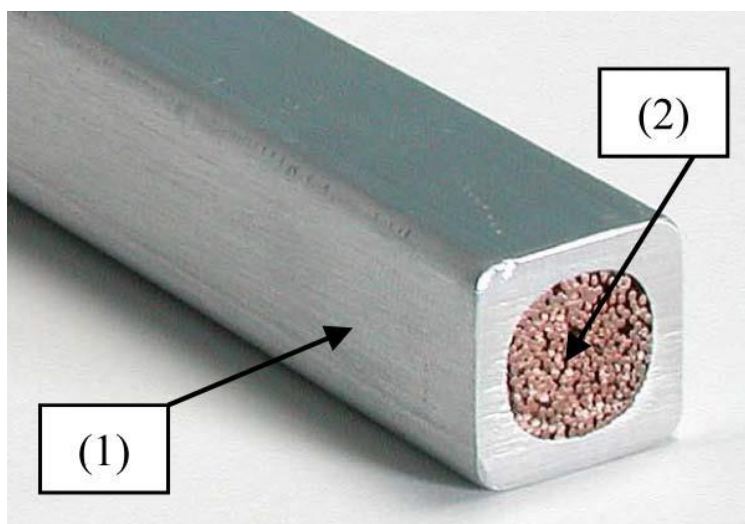


Wendelstein W7-X non-planar coil:

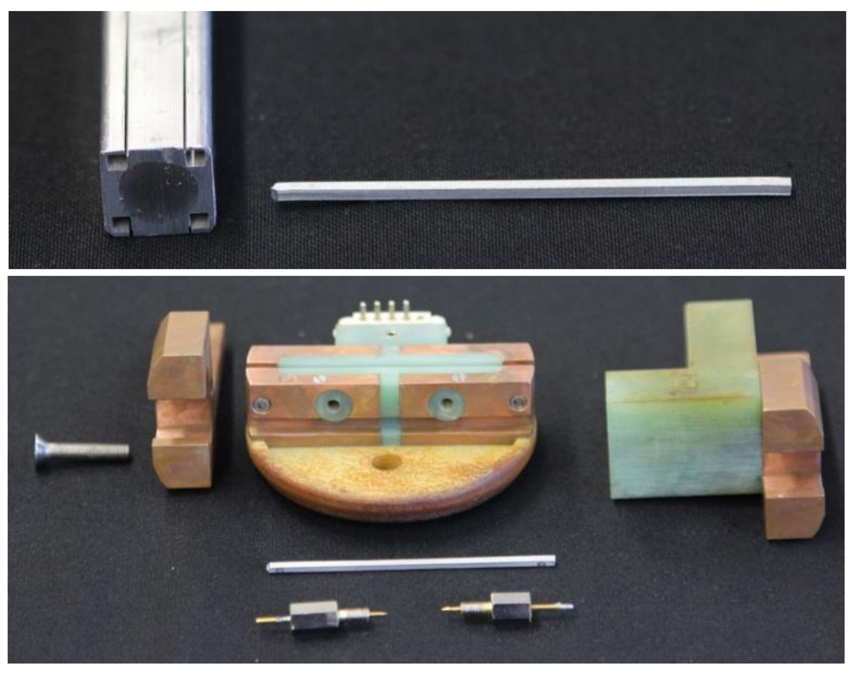
- Largest contribution to the magnetic field of W7-X.
- Consists of 108 turns divided into six double-pancakes.
- Hydraulically, the double pancakes are connected in parallel.
- Coil dimens.: 3.5 x 2.5 x 1.5 m.

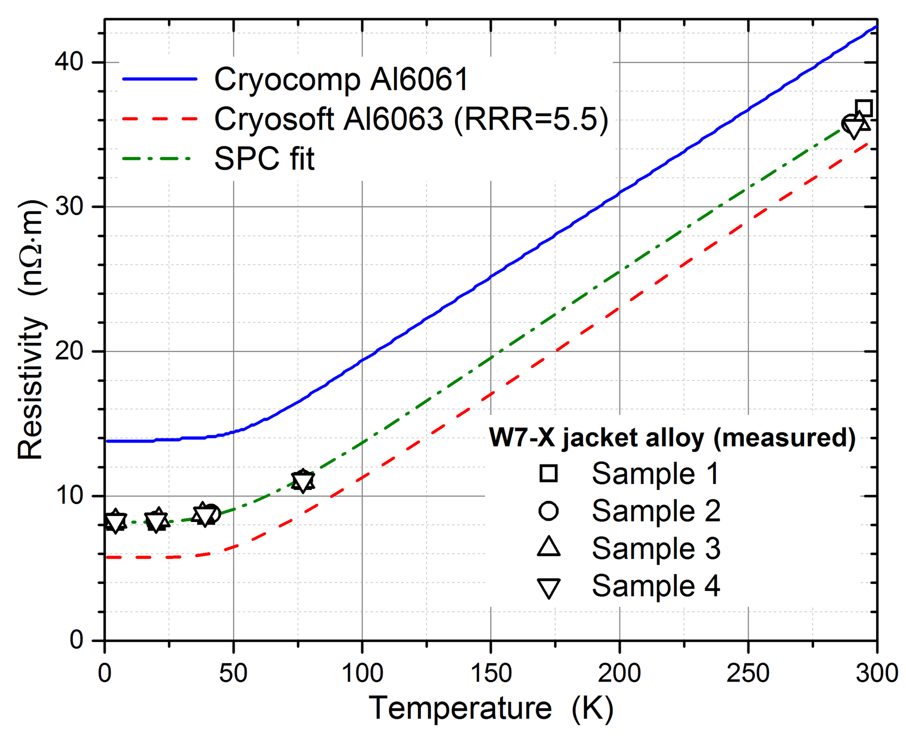
Conductor:

- NbTi superconductor.
- 243 strands.
- Aluminium-alloy jacket.



Resistivity Measurement of the Conduit Alloy





Jacket resistivity:

- Four samples (bars 2 x 2 x 100 mm) cut out (by wire erosion) of a conductor left-over piece.
- Resistivity measured at different temperatures at SPC.

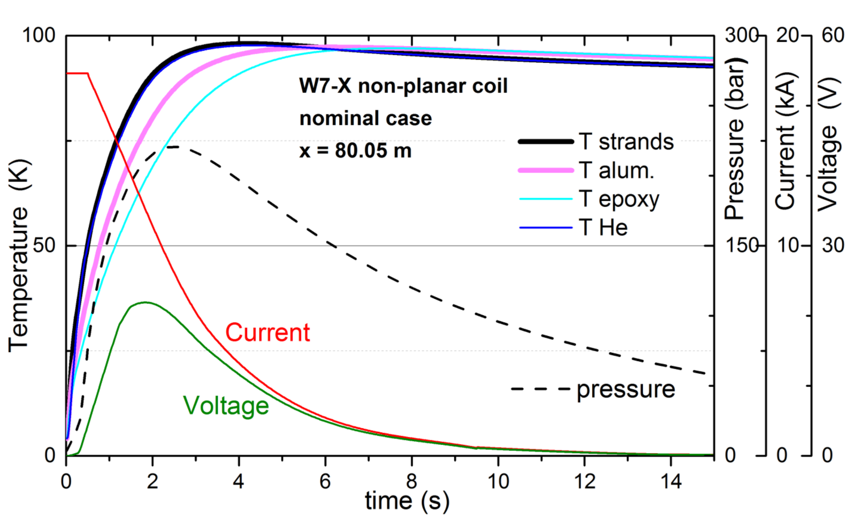
THEA Model

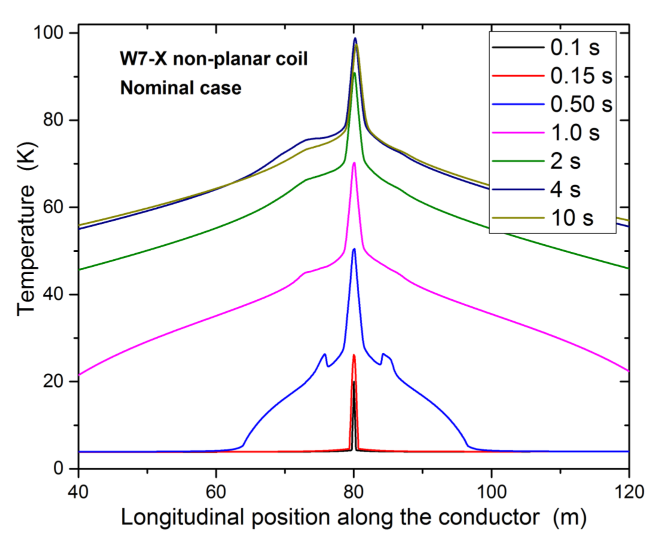
The Hot-Spot Temperature Assessment during Quench is done by Program THEA

- Three thermal elements: NbTi strands, jacket and glass-epoxy insulation wrap.
- One hydraulic element: Helium.
- Key features: Heat transfer between elements; Quench initiation by local heat deposition; Quench detection via voltage threshold.
- Four possible initial conditions (scenarios) employed.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Current, kA	18.2	18.2	18.2	15.32
B, T	6.7	6.7	6.7	5.64
T inlet, K	3.80	3.40	4.40	4.10
T outlet, K	3.99	3.64	4.51	4.14
p inlet, bar	4.45	4.45	4.45	3.62
p outlet, bar	3.14	3.14	3.14	3.26
Δp, bar	1.31	1.31	1.31	0.36
dm/dt of He, g/s	1.23	1.24	1.20	0.59

Coil Operation at 18.2 kA





Hot-Spot temperature for quench at 18.2 kA current: Tmax=99 K.

This is below the limit set internaly by IPP to 130 K ➔ some operating margin exists.

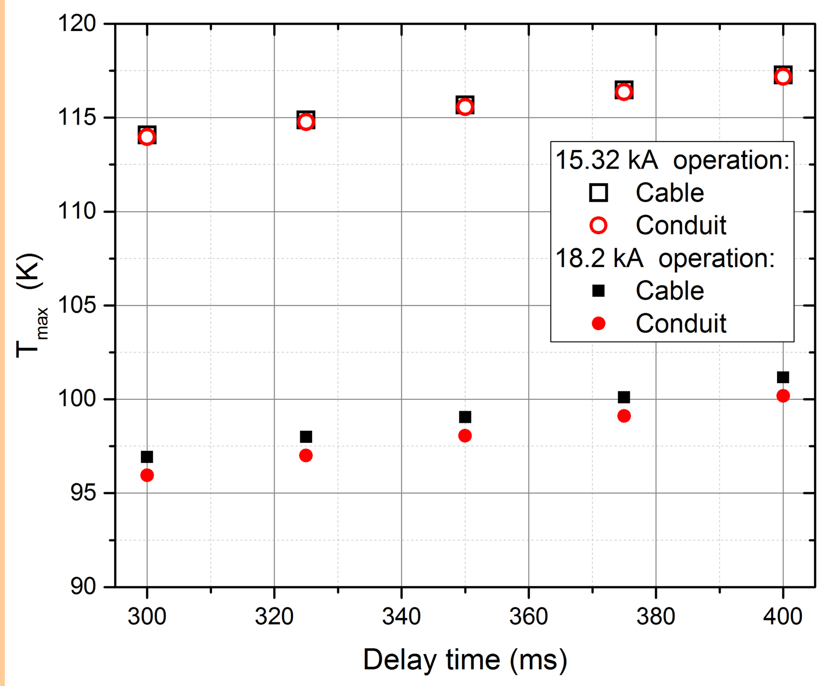
Coil Operation at 15.32 kA

- If the non-planar coil is operated at next lower possible current, i.e. at 15.32 kA, it might be possible to make the fast current switch off (e.g. after quench detection) slower.
- The advantage of slower switch off is reduced high voltage built up during the current discharge, which would be safer for the coil operation.

➔ This possibility was investigated using THEA. A slower current decay, corresponding to a modified dump resistor, was simulated by a dedicated program. Our assessment leads to the hot-stop temperature of 116 K, well below the limit of 130 K.

(The operation at 18.2 kA and slow current decay leads to the hot-spot temperature of 156 K.)

Parametric Studies

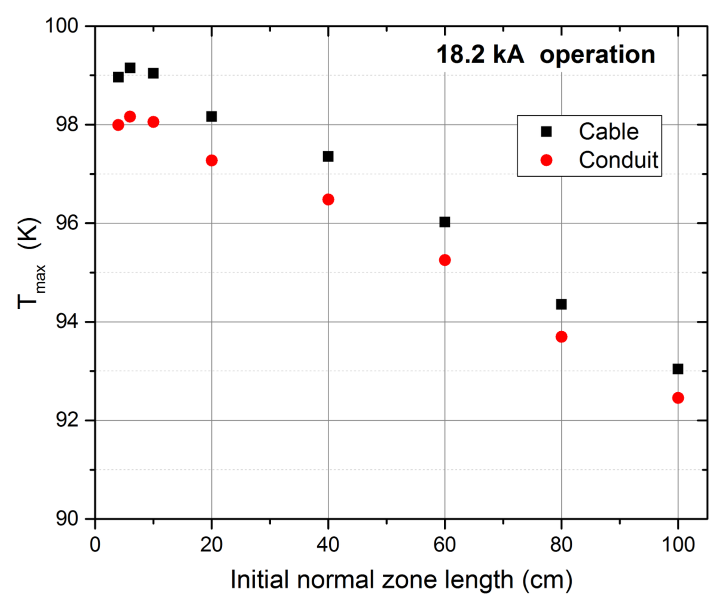


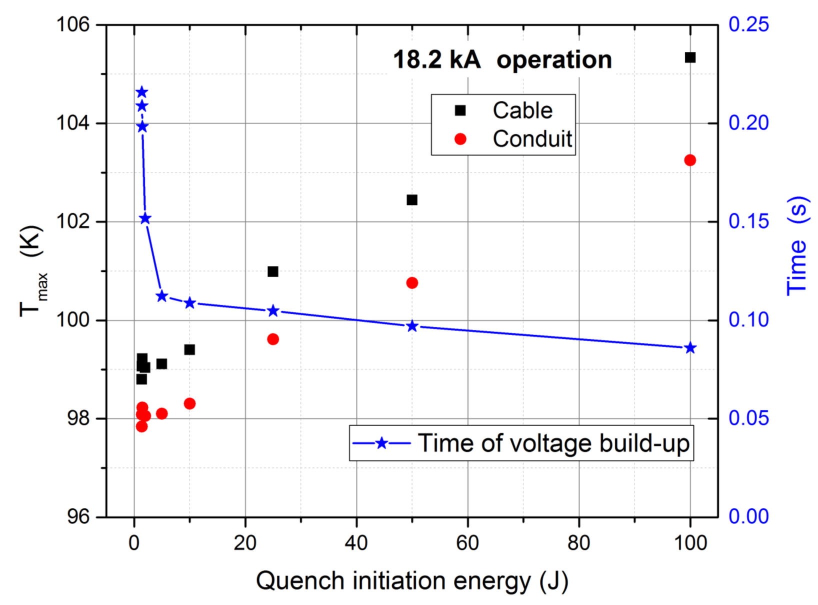
Delay time t_{delay} in quench protection:

- Nominal t_{delay} = 350 s (50 s for quench validation plus 300 s for breakers opening)
- Voltage threshold of quench detection = 150 mV.
- Hot-spot temperature depends only slightly on the delay time (within the reasonable experimental range of possible t_{delay}).

Initial normal zone length:

- Nominal quench init. zone = 10 cm.
- Quench init. energy (heat) = 20 J/m, deposited during 100 ms.
- The hot-spot temperature slightly decreases with the length of the initial normal zone.





Quench Initiation Energy:

- MQE (found with THEA) = 1.38 J.
- Small dependence on the quench initiation energy.

Conclusions

- The results indicate that the maximum temperature (hot-spot temperature) calculated by THEA is:

T_{max} = 99 K for the nominal case (B = 6.7 T, I_{op} = 18.2 kA, t_{delay} = 350 ms)

T_{max} = 116 K for the new dump resistor case (B = 5.64 T, I_{op} = 15.32 kA, t_{delay} = 350 ms, slower current decay)

- A big source of hot-spot temperature uncertainty, the temperature-dependent resistivity of the jacket alloy, has been eliminated by experimental measurement of the jacket material resistivity.
- The remaining uncertainties in the hot-spot temperature assessment are quite limited, within a few Kelvin.

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