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Conductor Design of the Madmax 9 T Large Dipole Magnet

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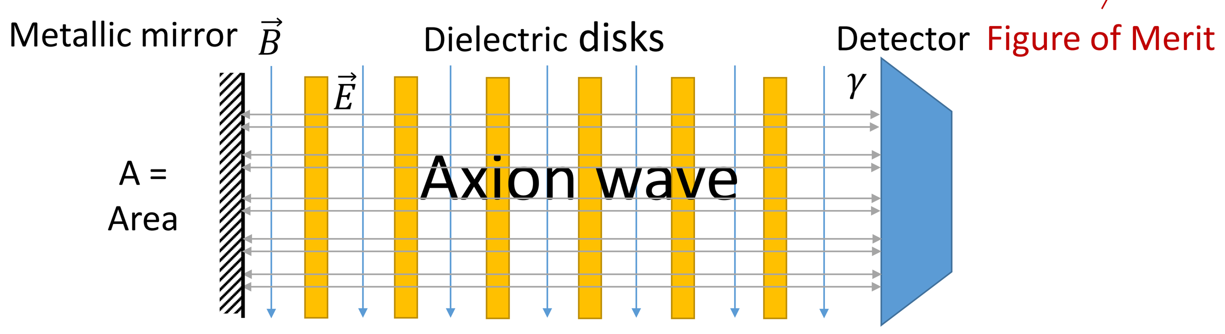
Abstract - The Madmax (MAgnetized Disc and Mirror AXion) project is an experiment dedicated to the discovery of the axion particle, the mass of which is expected to lie in the range of 100 µeV. To detect the axion, a dipole field with a square-field integral value of 100 T²m² is required. This field spread over 2 meters along the axis to install a booster that amplifies the signal. The conductor has been designed to minimize the global magnet cost. This will be the world largest dipole block type working at superfluid Helium temperature with a total weight of 200 tons, including 42 tons for the NbTi windings.

Magnet

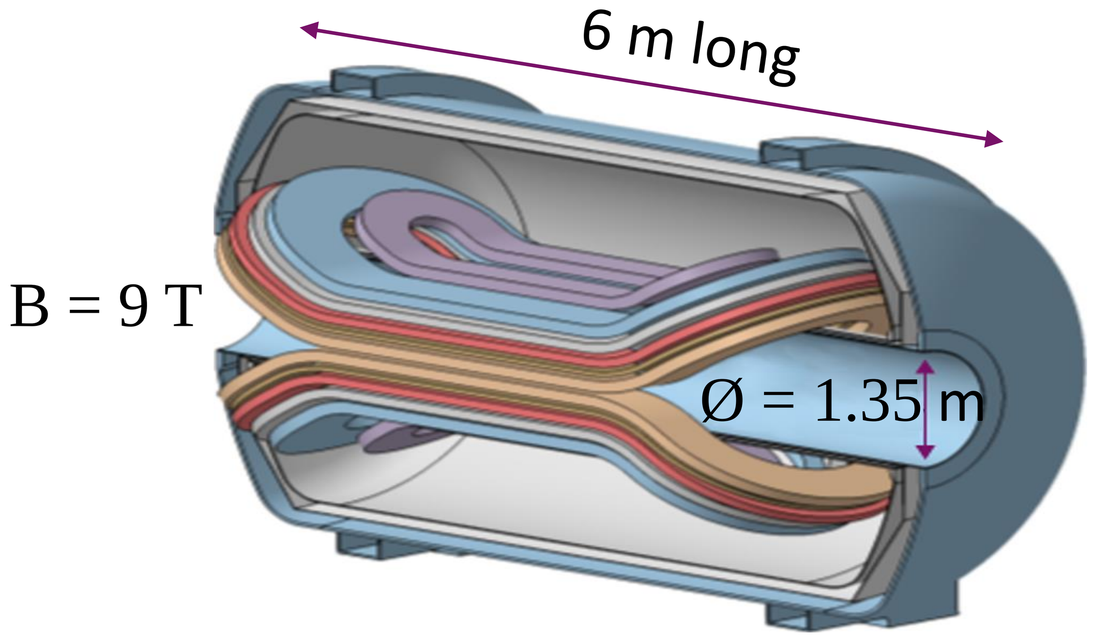
Axion measurement

$$P_{cavity} \propto 2 \cdot 10^{-28} \frac{W}{Tm^2} \cdot B^2 A$$

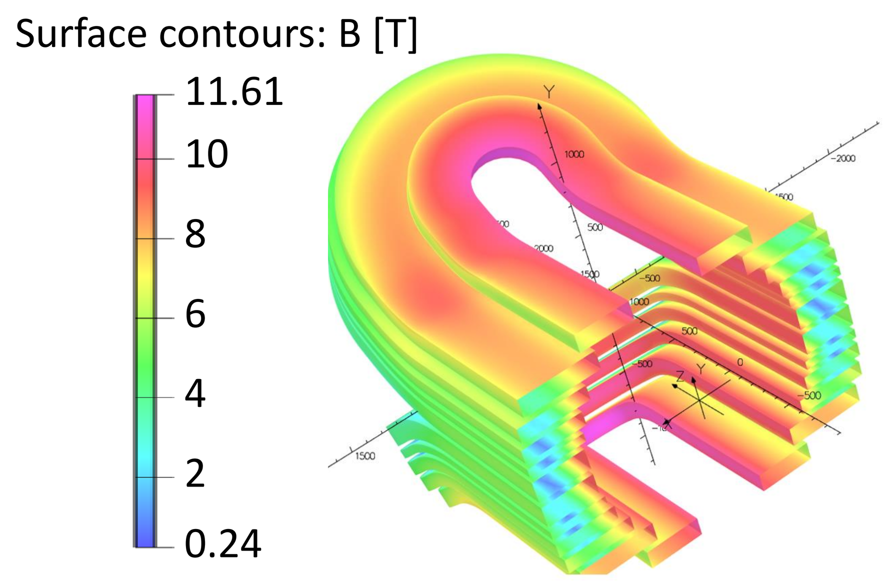


Magnet specifications

Parameter	Value	Units
Figure of Merit (z = 0 m; Ø < 1.25 m)	100	T²m²
Straight length	2	m
Figure of Merit (z = ± 1 m; Ø < 1.25 m)	> 90	T²m²
Warm bore	1.35	m
Field at the center	9	T
Homogeneity (z = cste)	± 5%	
Maximum overall length	6.9	m
Maximum overall weight	200	t



Overall dimension

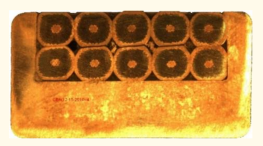


Magnetic field

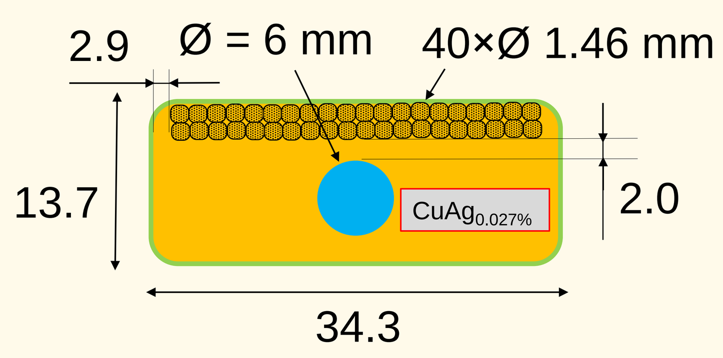
Conductor design

Conductor specifications

Madmax specifications	Block	Units
Engineering current density	50	A/mm²
Maximum magnet field (+ self-field)	10.1+0.2	T
Energy	667	MJ
Conductor volume	5.7	m³
Conductor aspect ratio	≤ 2.5	
Minimum bending radius (easy way)	0.137	m
Conductor insulation thickness	0.5	mm
Working temperature	1.8	K
Load line margin	10%	
Maximal hot spot temperature	100	K
Maximal allowed stress	190	MPa
Voltage during the discharge	± 1	kV
Quench detection duration	1	s



Iseult main conductor IRM 11.7 T, 9.2*4.9 mm²



Design conductor geometry for 23.5 kA

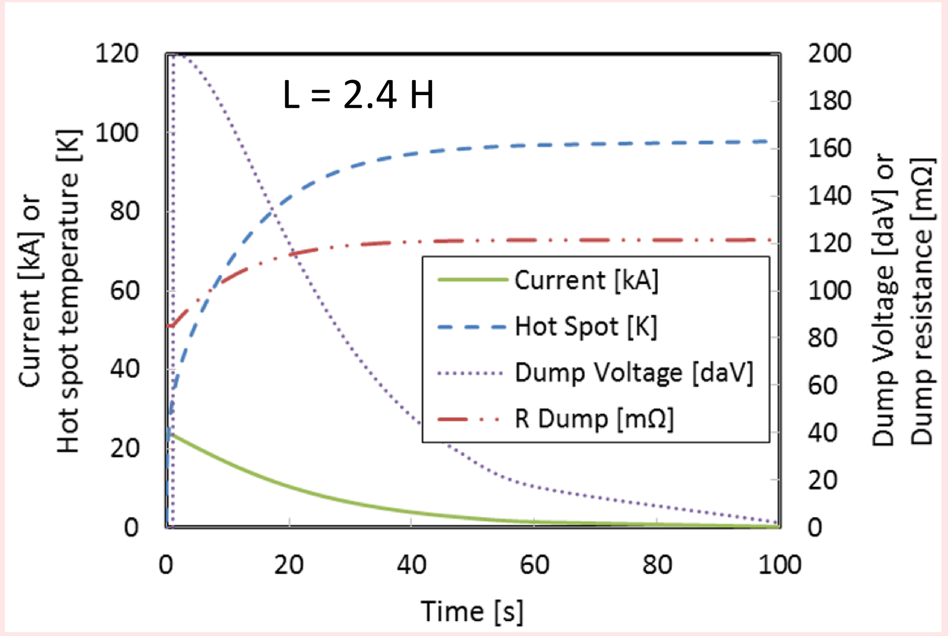
Hybrid LNCMI solenoid 9 T 18*13 mm²

Hot spot formula

$$\int_{T_0}^{T_{max}} \frac{C}{\rho}\, dT = j_0^2 \times \frac{\tau}{2} = j_0^2 \times \frac{E_m}{U_0 . I_0}$$

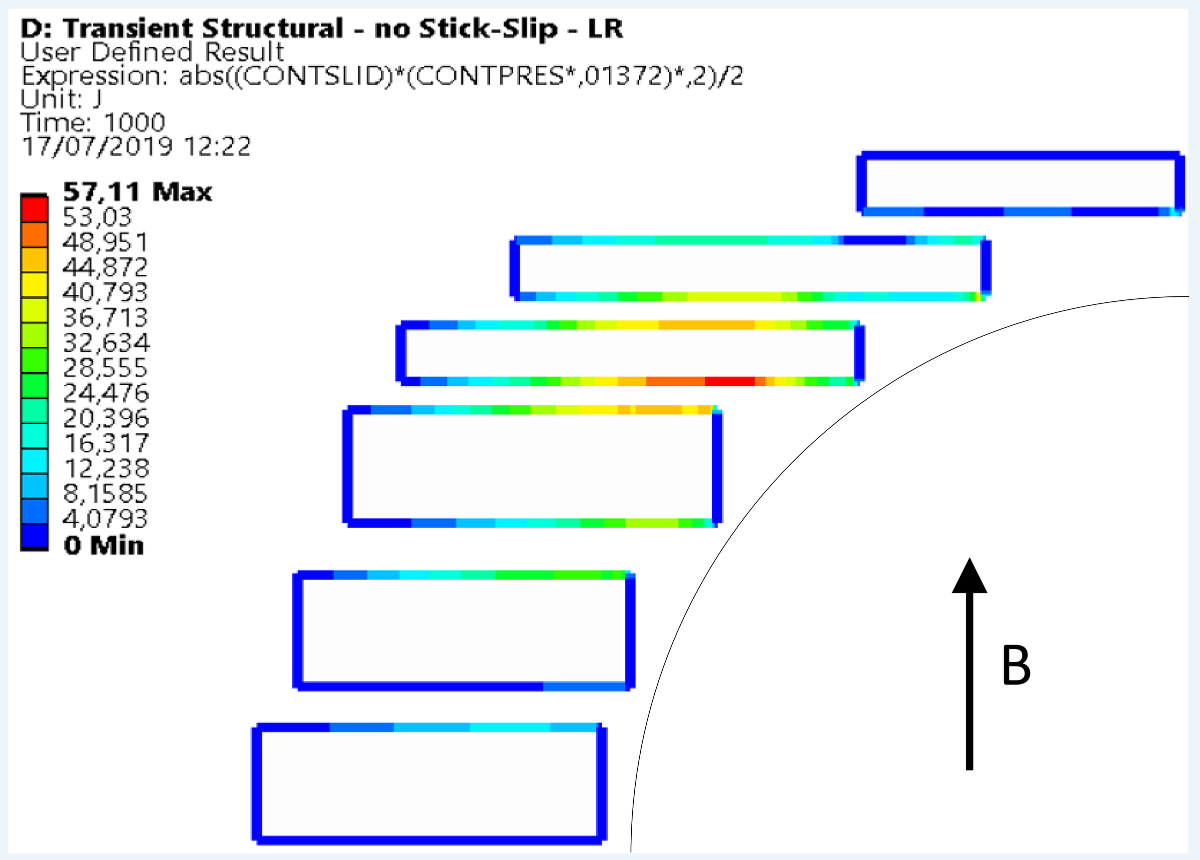
With

- T_0 Initial temperature (1.8 K);
- T_{max} Final temperature (of the Hotspot = 100 K);
- C Heat capacitance (sum on the conductor section);
- ρ Resistivity (with a magnetoresistance coefficient of $0.45 \times 10^{-10}\ \Omega . m/T$);
- j_0 Initial current density (50 A/mm²);
- τ Current decay time constant;
- E_m Magnetic energy (667 MJ);
- U_0 Dump voltage (2 kV);
- I_0 Initial current (nominal).



Discharge curves after a quench

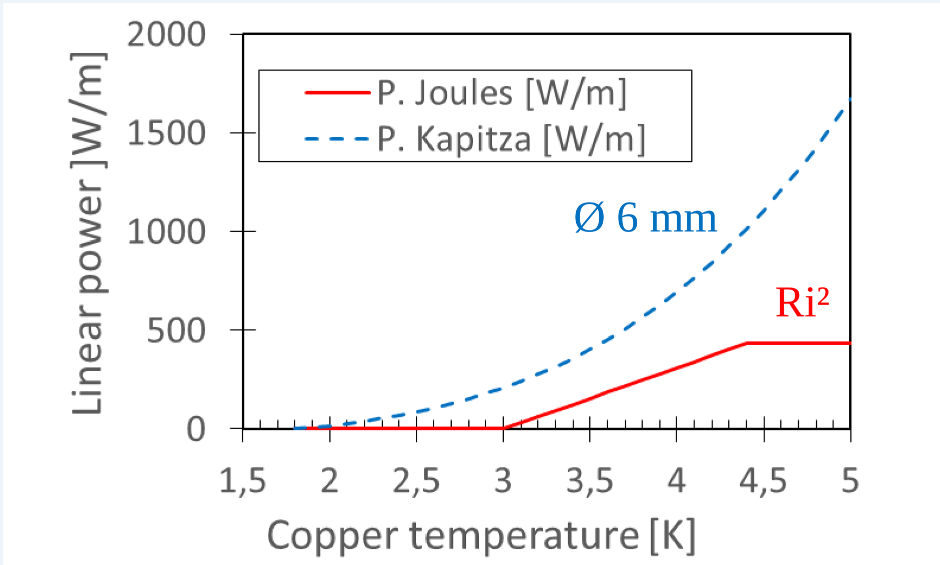
Cryostability



Total energy deposition per 1 m long conductor

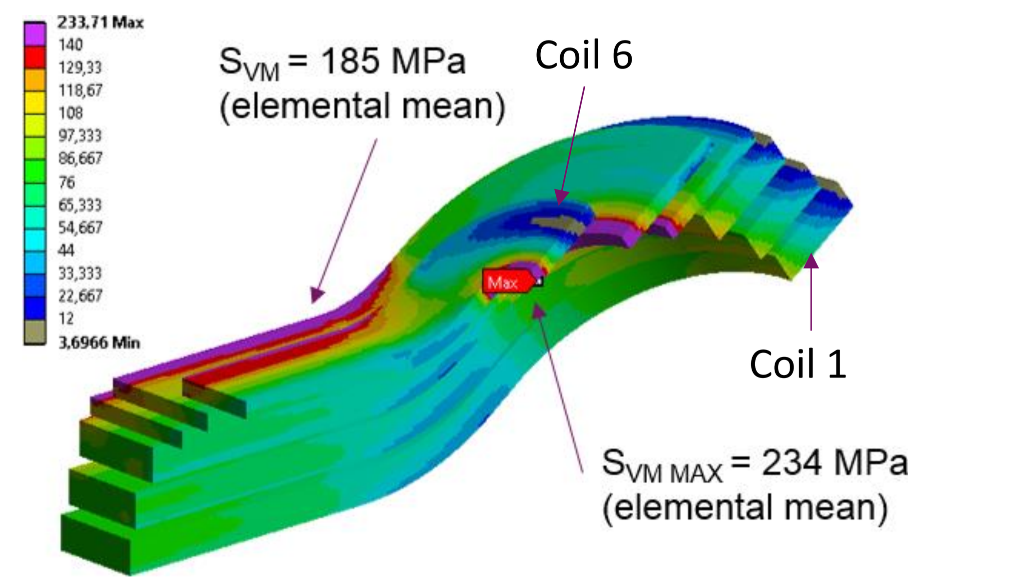
Heating - cooling balance

Heating power	Values
Friction after stick and slip	< 11 J/m
NbTi hysteresis (50 µm)	12 J/m
Helium enthalpy up to Tλ	14 J/m
Helium enthalpy up to T_{CS}	21 J/m

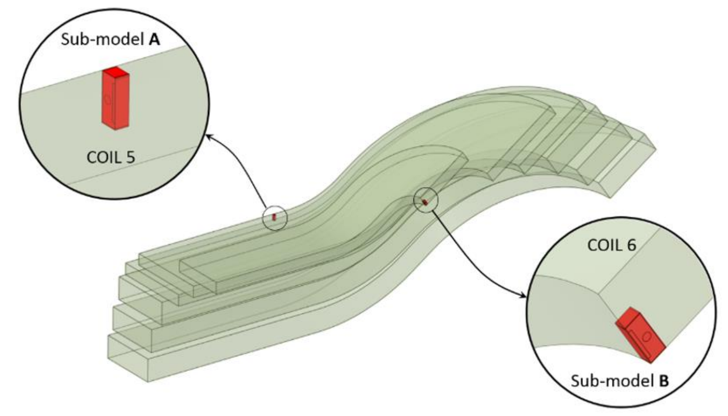


Steckly criteria

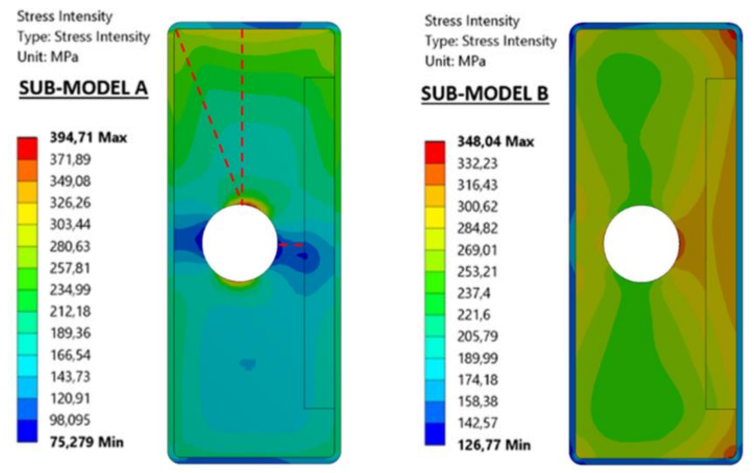
Mechanical computations



Von Mises stress due to thermal cold down and magnetic forces of the homogenous winding model.



Conductor embedded in the homogenous winding model



Von Mises stress due to thermal cold down and magnetic forces of the sub model with the homogenous winding model

Conclusion

This preliminary analysis demonstrated that it is possible to realize a large dipole (9 T, $Ø_{warm}$ = 1.35 m & length ~ 6 m) with a cryostable winding but the level of stress are very high.

In more, the present design give a level of cost over the available budget at Max Plank Institute (Germany). A reduction strategy is underway with the mockup suppression and the optimization of the detector performance corresponding to a reduction of about 20% of magnet magnetic energy.

See also:
- Mon-Af-Or5-04 *Madmax: design of a very large dipole for dark matter experiment.*
- Tue-Mo-Po2.03-02[10] *2D and 3D Conceptual Magnetic Design of the MADMAX Dipole.*