Optimizing single-turn coils for scientific applications beyond 100T

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High-field magnets for science

Currently, STC are the only available choice for measurements
a) above 100 T and
b) w/o sample destruction.

Coil destruction and μs-timescales cannot be avoided.
How STCs work:

Connect a simple disposable coil to a capacitor bank.

Electrical parameters determine the rise time of the field: impedance and capacitance.

Mechanical parameters determine the coil’s disintegration: coil mass and magnetic force.

The circuit impedance can be adjusted to make the field rise faster than the coil disintegrates.

Good to know:

The outward acceleration of conductor fragments protects equipment in the bore (... at least up to 150 T).
Why do we need a better understanding of the discharge dynamics of SC?

**Problem 1:** STC typically feature a bore ratio of $d/h=1$, but the value has never been systematically tested.*

![Diagram showing bore ratio](image)

* unlike the conductor thickness, which represents a compromise between peak field, destructive effects and practical issues.

**Problem 2:** Existing installations can produce 200 T in 10 mm. However, applications are mostly limited to 150 T to avoid destructive effects at higher fields.

![Cu deposit after a 210 T shot with heavy destruction.](image)

![Impact traces of fragments formed in a 150 T shot.](image)
Established experimental techniques for measurements with STC
(at cryogenic temperatures)

**VIS-NIR spectroscopy:**
Fibre-based magneto-transmission measurements with monochromatic sources.

**MIR spectroscopy:**
Free-beam optics with high-power MIR-lasers (CO, CO$_2$) and fast MCT detectors.

**Magnetization:**
dM/dt with compensated pick-up coils and background elimination by averaging alternate measurements.

**Problem 3:** homogeneity requirements of magnetization measurements
Electrical coupling of filaments (matrix equation)

\[ I(t + dt) = I(t) + dt M^{-1}(t) \left[ V(t) - \left( \dot{M}(t) + R(t) \right) I(t) \right] \]

Local heating (1 simple equation per filament)

\[ T(t + dt) = T(t) + dt \frac{j^2(t) \rho(t)}{D(t) C(t)} \]

Displacement (1 simple equation per filament disc)

\[ r(t + 2dt) = r(t + dt) + dt v(t) + dt^2 \frac{\Delta F}{\Delta m} \]

STC discharge simulations based on Nakao’s filamentary approach
Field & current on the up-sweep and at $B_{\text{max}}$

Negligible coil expansion up to peak field; the current distribution reflects the effect of magnetic diffusion.
Field & current on the down-sweep and at $B_{\text{max}}$

Homogeneity in 10mm coils is surprisingly good: less than 1% deviation in a 1.5mm sphere.
Field & current at $B_{\text{max}}$ in coils with 7 and 10 mm width

Flat coils may give several % more field with tolerable effect on homogeneity.
Temperature & pressure at $B_{\text{max}}$ for 30 and 40 kV

Overheating gives rise to explosive sublimation when magnetic pressure is released > destruction in the bore.
**Future projects**
(towards a 200 T standard for scientific applications)

**Project 1:** Faraday rotation imaging of field homogeneity

**Project 2:** improve simulations (structured coils, material properties, mechanics ...)

**Project 3:** Quasi-3d feed-gap simulation using polygonal filaments

\[
A(r) = \frac{\mu_0 I}{4\pi} \sum_{n=1}^{N} e_{n,n+1} \ln \left[ \frac{|r - r_n| + |r - r_{n+1}| + |r_{n+1} - r_n|}{|r - r_n| + |r - r_{n+1}| - |r_{n+1} - r_n|} \right]
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