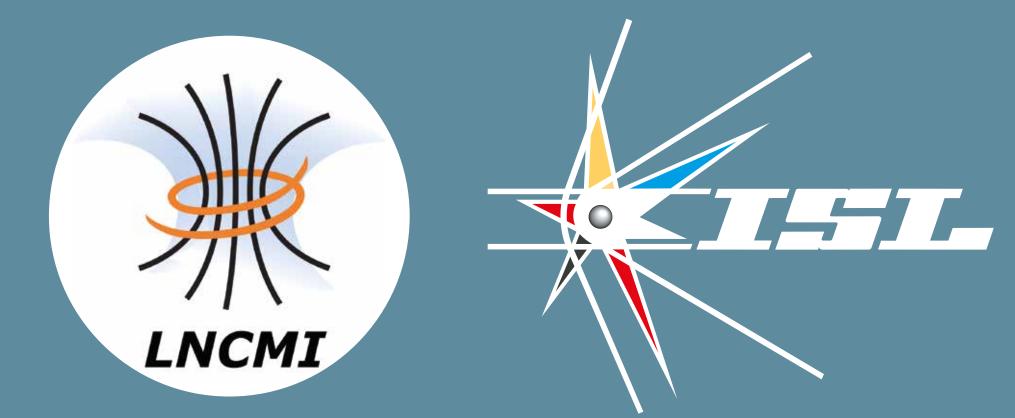
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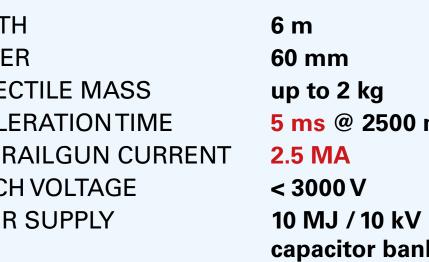
www.isl.eu

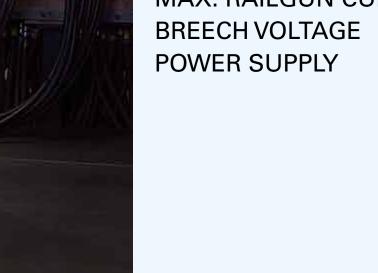
Application

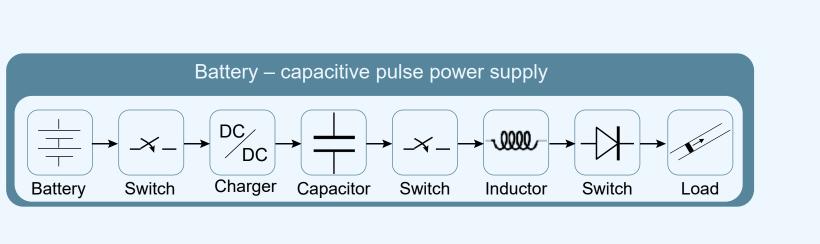
Ragone plot*



	LENGTH
#	CALIBER
8	PROJECTILE MASS
, as	ACCELERATIONTIME
Ø	MAX. RAILGUN CURRENT
	BREECH VOLTAGE
l,	POWER SUPPLY
4)	



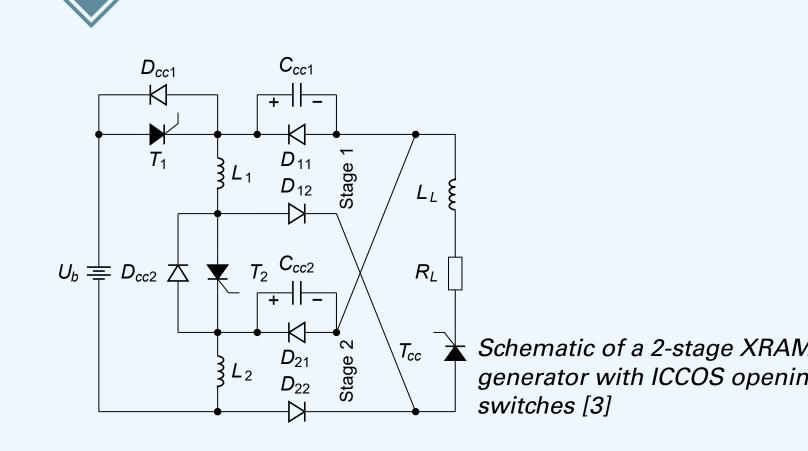




	Battery – inductive pulse power supply
Battery	Switch Inductor Switch Load

higher energy density of inductive storage.

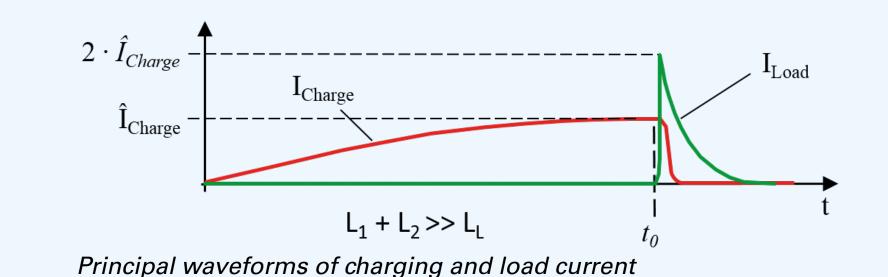
XRAM generator as inductive pulsed power supply for a railgun



Operation principle [2]

Step 1: U_b charges L_1 and L_2 via T_1 and T_2 in series Step 2: T_{cc} initiates discharge of pre-charged C_{cc}s

Step 3: T, and T, switch-OFF due to neg. voltage Step 4: L₁ and L₂ are discharged in parallel



A demonstrator of a 1 MJ XRAM generator

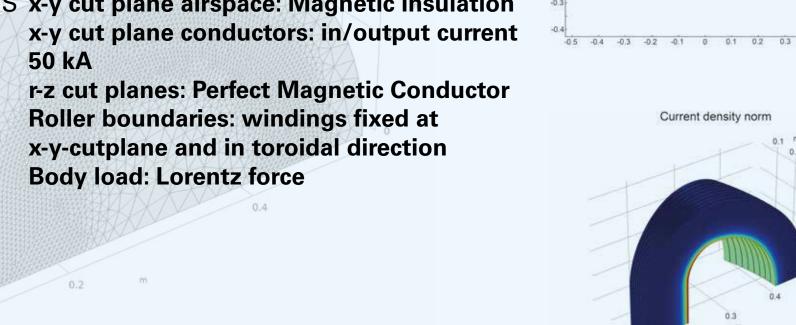
Required: A modular inductive storage with 20 stages, R < 10 m Ω and 1 MJ (i.e. L = 1 mH, I = 45 kA)

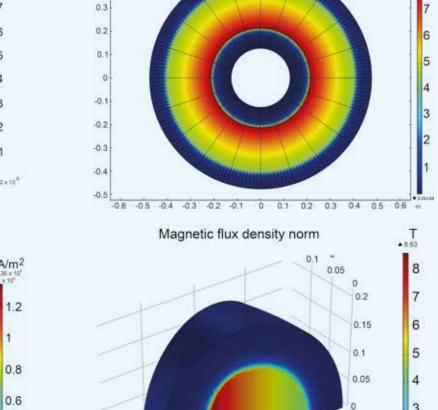
FEM simulation

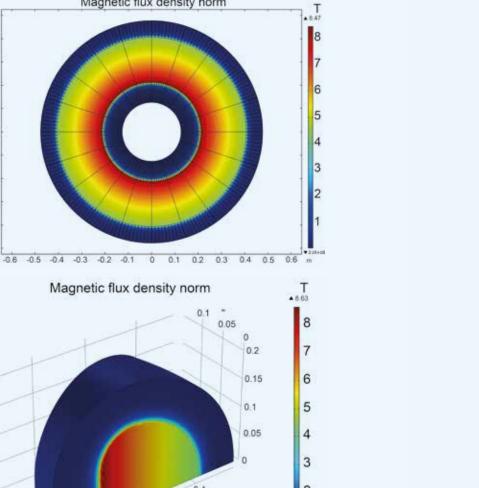
AC/DC: Magnetic Fields

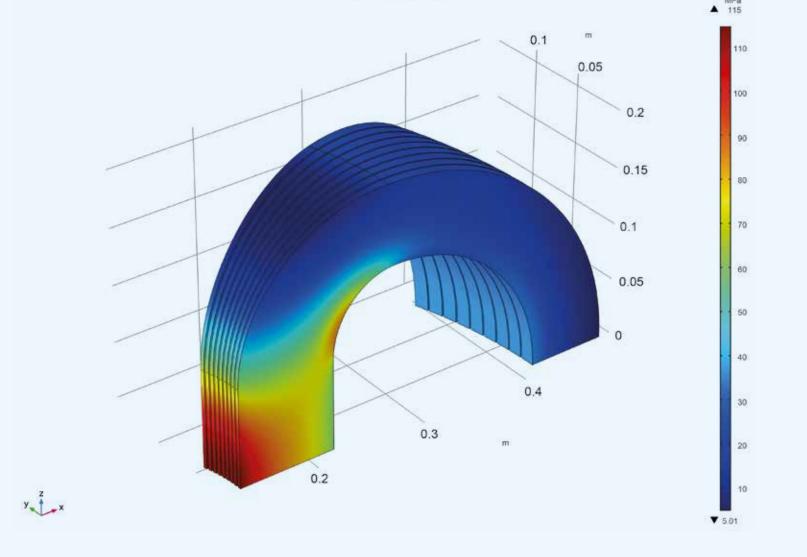
Inductance @ 62.5 Hz: 1 mH

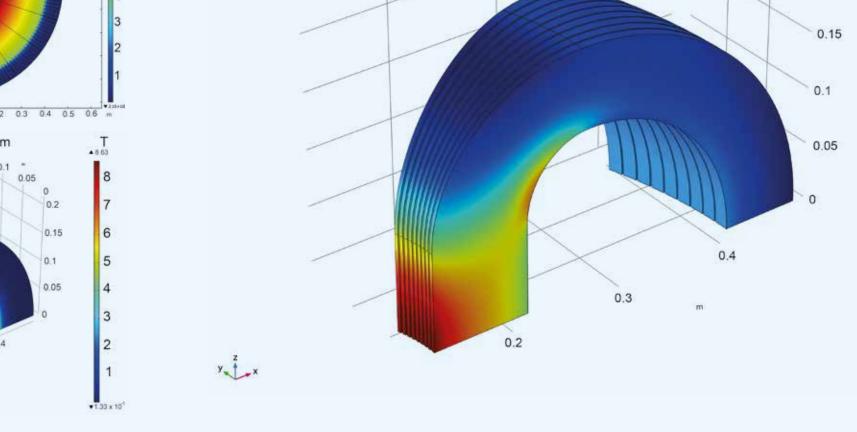
Resistance @ 62.5 Hz: 33 m Ω

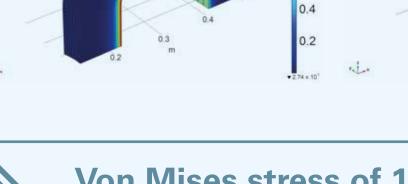






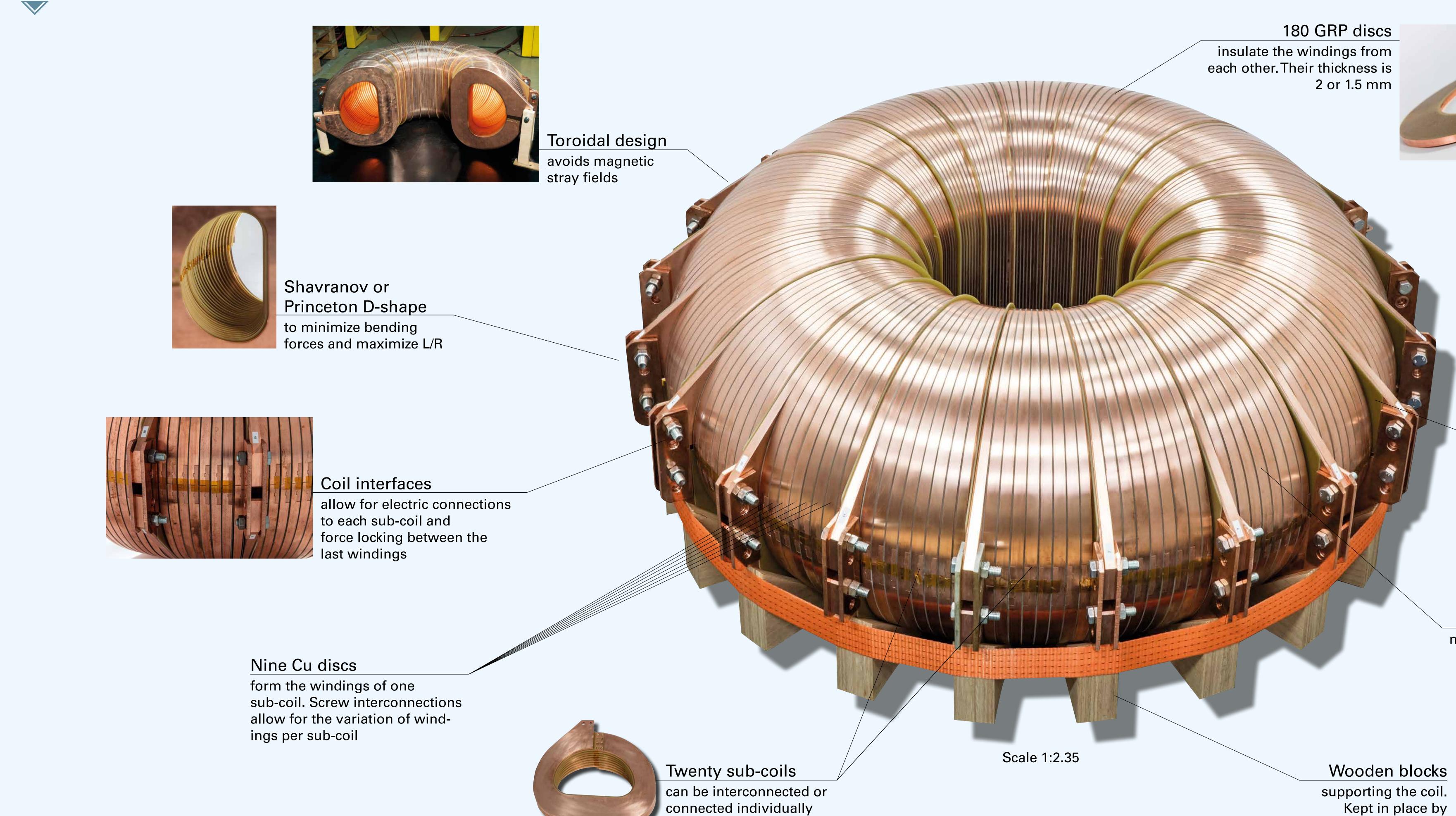




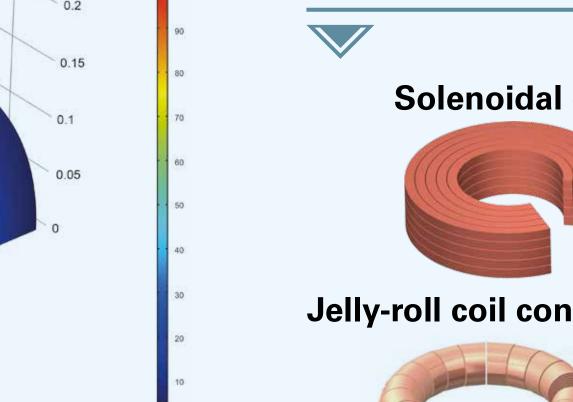


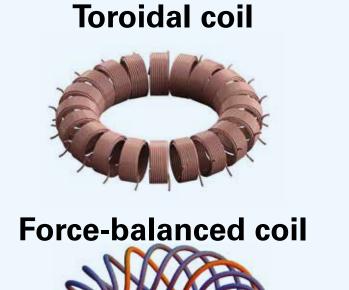


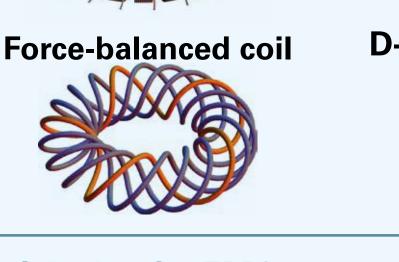
Design and construction of the short time 1 MJ magnetic energy storage

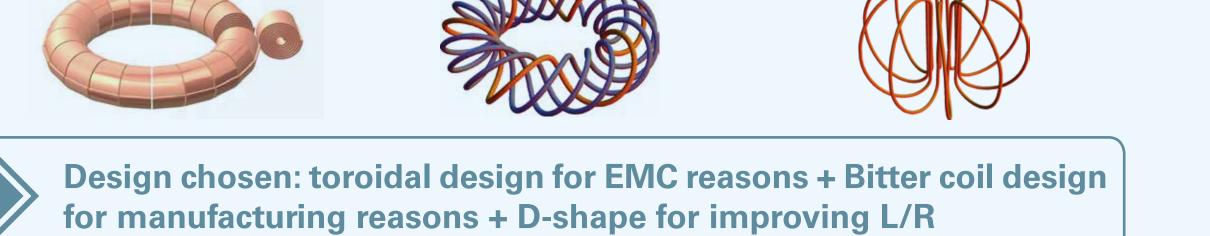


Considered coil designs [4]



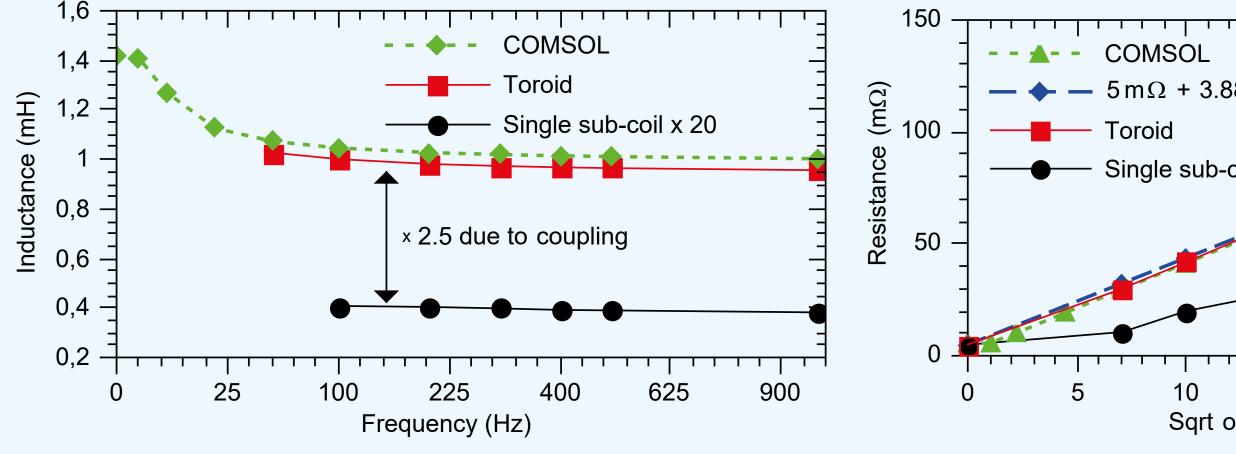


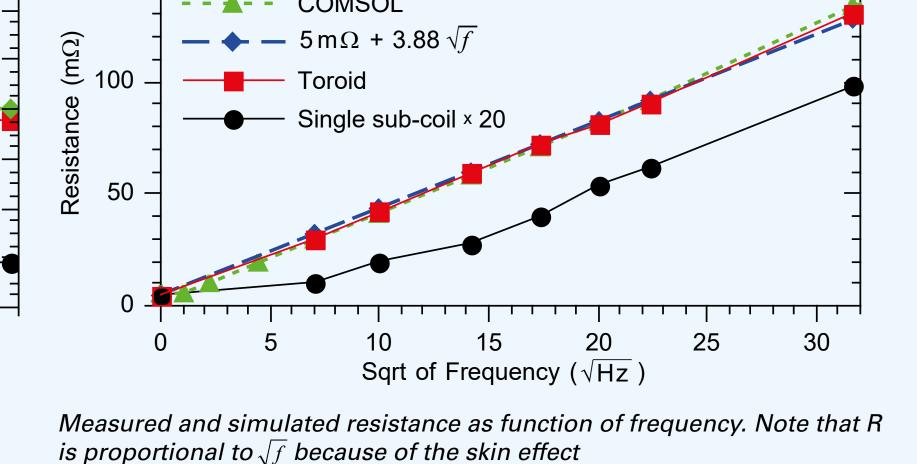




RCL-meter measurement

Measured and simulated inductance as function of frequency





Frequency Rise time Coil resistance t_{300 K → 400 K} $5 \text{ m}\Omega$ 3.3 s 1 Hz 250 ms 8.5 m Ω 3.8 s 10 Hz 25 ms 16 m Ω 2 s 50 Hz 5 ms $30~\text{m}\Omega$ 1 s

a tension belt

Approximation of coil restistance and heating time $t_{300\,K\to\,400\,K}$ in relation to pulse risetime (linear charging current with a maximum of 45 kA assumed).

1 kHz $250\,\mu\mathrm{m}$ 117 m Ω 0.3 s

Pulsed power testing



Coil specifications

NO. OF SEGMENTS

OUTER DIAMETER

VOLUME

WEIGHT

180 Cu discs

References

pp. 3327-3330, July 2019

1] S. Hundertmark, G. Vincent, F. Schubert, J. Urban

Plasma Science, vol. 45, no. 7, pp. 1108-1114, July 2017

[2] O. Liebfried, V. Brommer, S. Scharnholz

[5] E. Spahn, M. Lichtenberger, F. Hatterer

The NGL-60 Railgun, in IEEE Transactions on Plasma Science, vol. 47, no. 7,

Development of XRAM generators as inductive power sources for very high current pulses, 19th IEEE Pulsed Power Conference (PPC), San Francisco, CA, 2013, pp. 1-6,

[3] P. Dedie, V. Brommer, S. Scharnholz ICCOS Countercurrent-Thyristor High-Power Opening Switch for Currents Up to

28 kA, in IEEETransactions on Magnetics, vol. 45, no. 1, pp. 536-539, Jan. 2009

Review of Inductive Pulsed Power Generators for Railguns, in IEEE Transactions or

Pulse forming network for the 10 MJ-railgun PEGASUS, in Proceedings 5th European

Symposium of Electromagnetic Launch Technologie, Toulouse, FR, Apr. 10-13 1995

milled from copper plates

with a wedge-shape to

be arranged in a torus

MAX. VOLTAGE

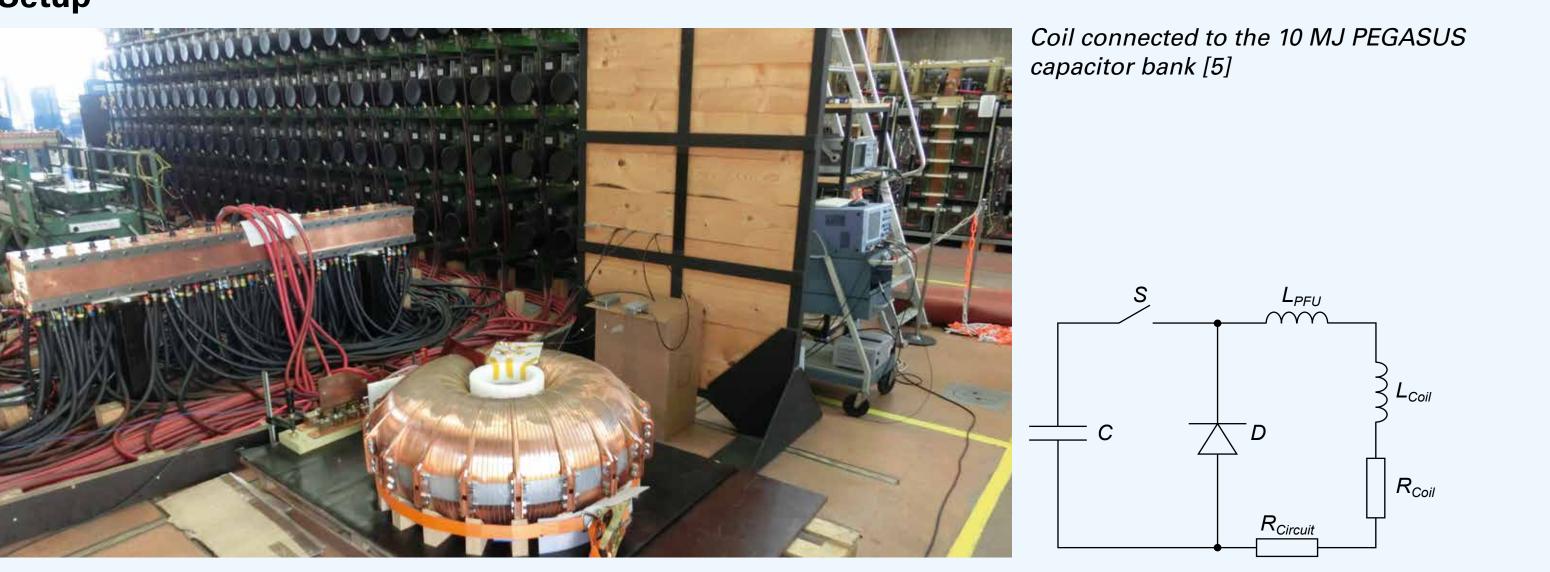
DC RESISTANCE

INDUCTANCE @ 50 Hz

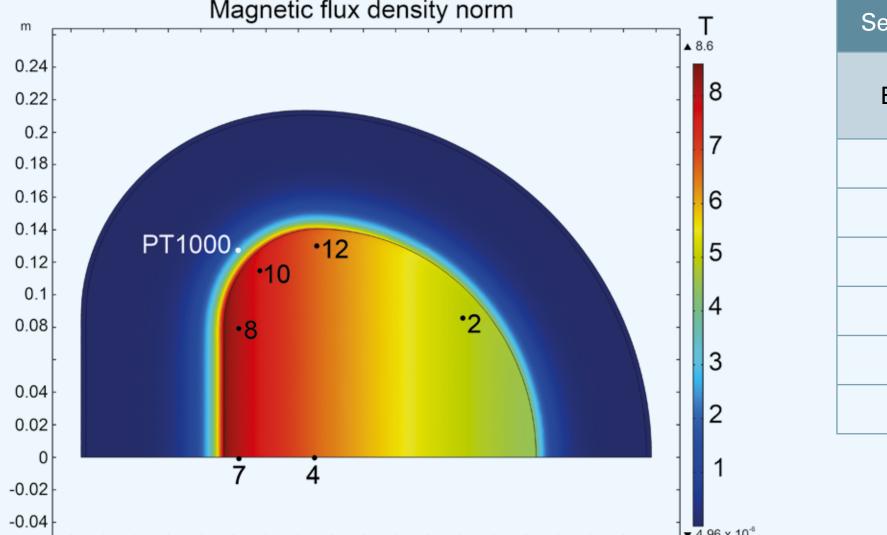
ENERGY DENSITY @ 50 kA 5.7 MJ/m³

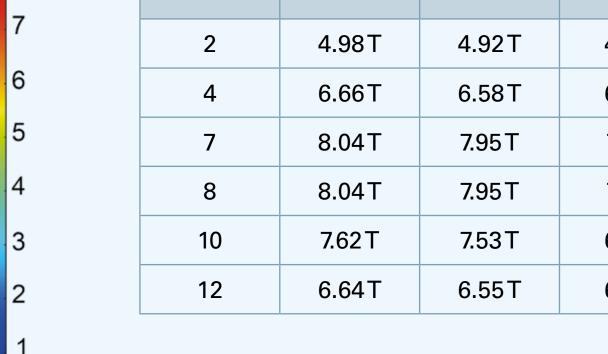
SPECIFIC ENERGY @ 50 kA 1.2 kJ/kg

WITH CONNECTORS

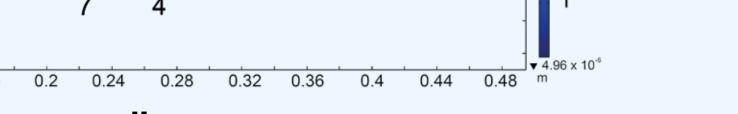




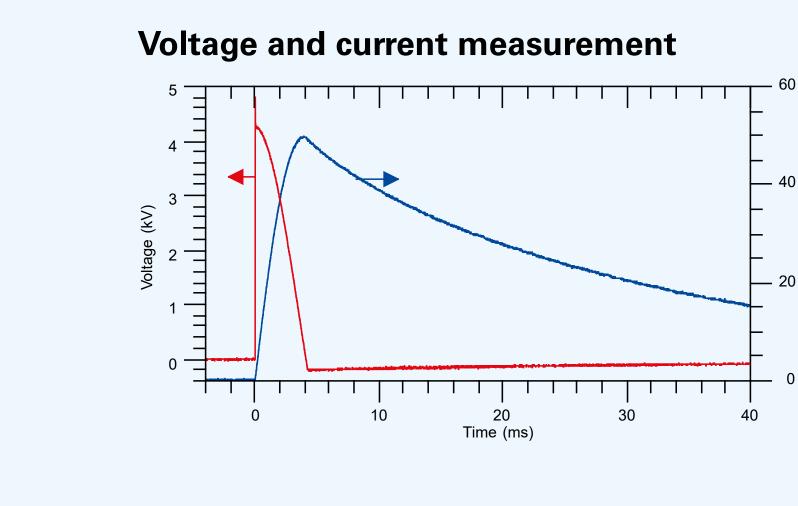




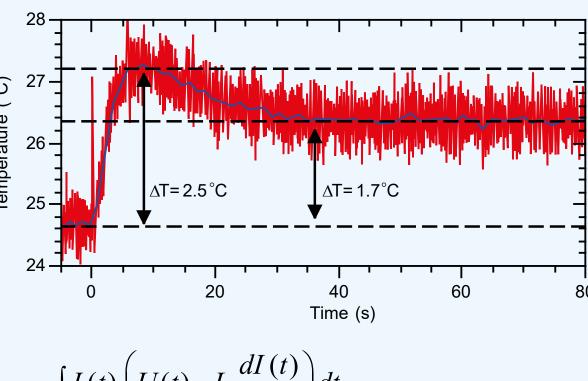
Comparison with simulation

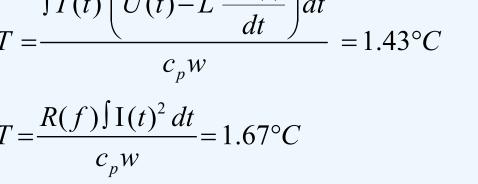






Temperature measurement



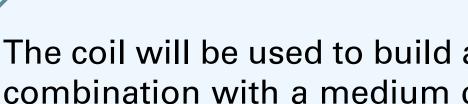


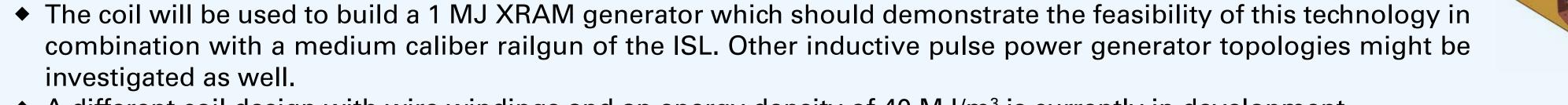
the center (contracting forces). observed.

Conclusio



- ◆ A toroidal storage coil was realized by milled and slit D-shape copper discs with screw connections and GRP discs for insulation. ◆ The coil design provides large strength with respect to Lorentz forces perpendicular to the coil surface but suffers from a pronounced skin effect.
- Resistance increases with frequency according to $R(f) = 5 \text{ m}\Omega + 3.88 \text{ m}\Omega \times \sqrt{f}$
- Coil was tested with pulsed current up to 50 kA (1.25 MJ)
- ◆ Coil meets the requirement for the envisaged inductive pulsed power generator experiments.
- ◆ Modular design allows for variation of windings and thus different generator setups (i.e. XRAM, pulse transformer, etc.).

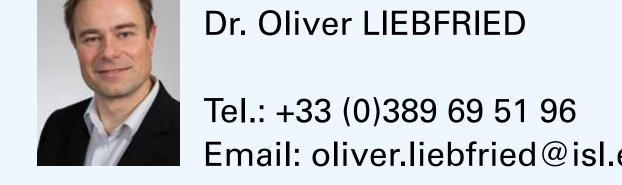




◆ A different coil design with wire windings and an energy density of 40 MJ/m³ is currently in development.

Acknowledgement

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Dr. Oliver LIEBFRIED

