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High temperature superconducting hybrid tape stacks - an enabling technology: challenges for DC and AC applications

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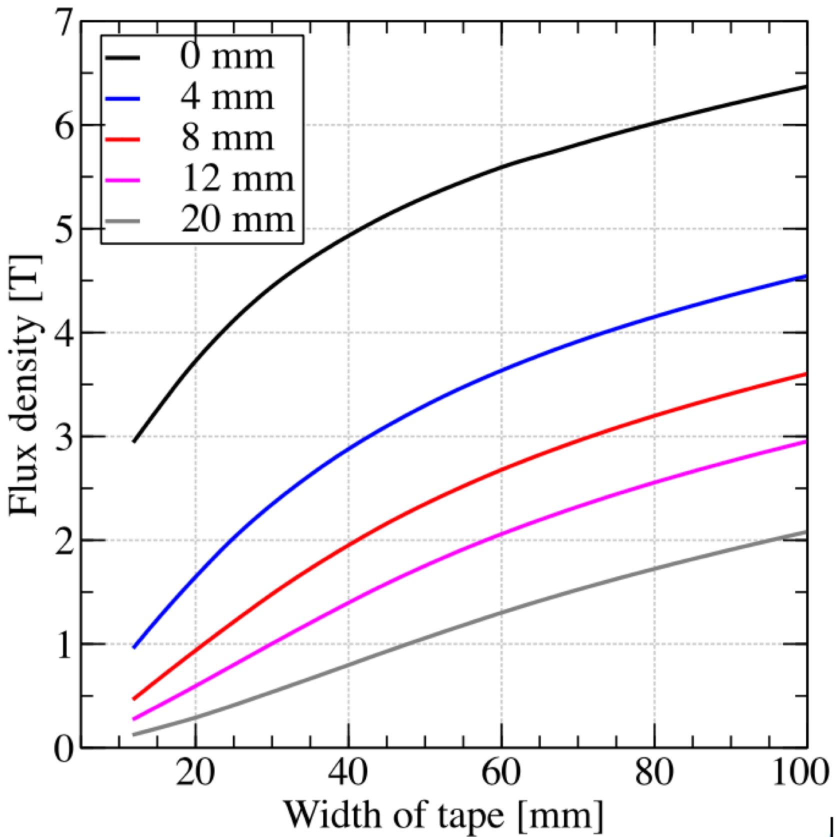
Role of the YBCO tape width on stack trapped flux value

“DC case”

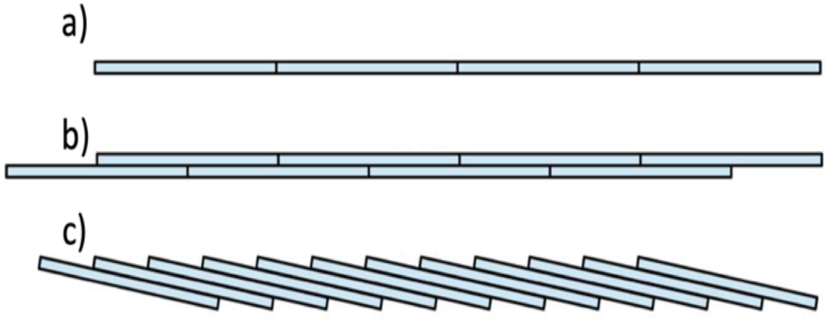


The main conclusion emerging from Fig. is that due to strong decay of magnetic field away from the superconducting stack, **narrow tape or arrays of narrow tape produce lower trapped flux**.

Field produced by HTS stack (T=25K)

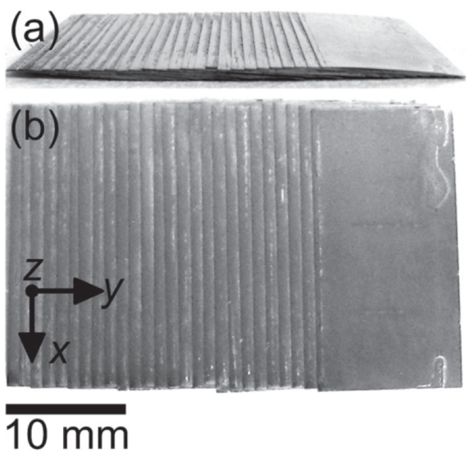
Calculation of magnetic flux density versus width of the model tape stack for different vertical distance perpendicular to the stack center (calculated curves are for distance 0, 4, 8, 12 and 20 mm away from the surface of the stack) temperature 25K.

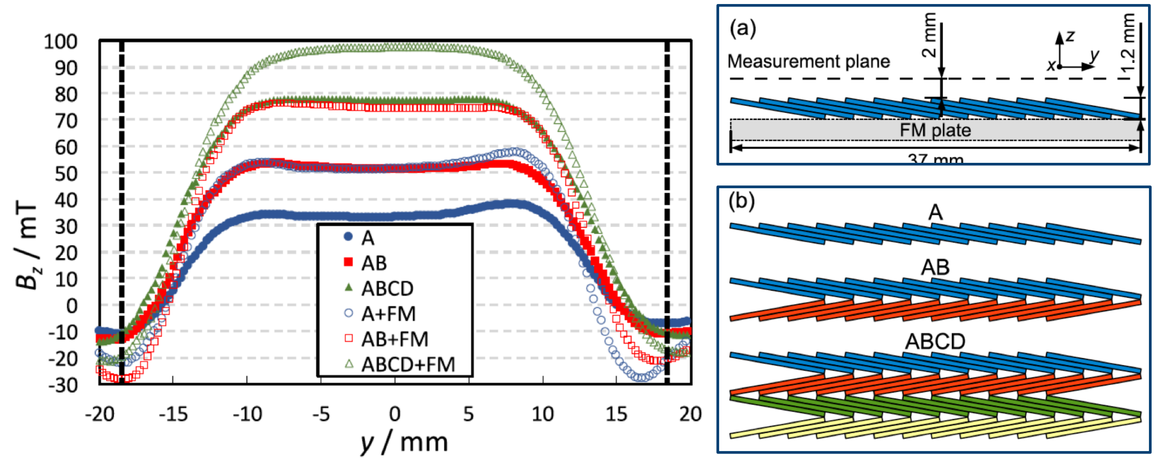
Angled stacking arrangement effect, using standard tapes



Comparison of the mean trapped flux, *B**, for configurations presented in Fig shows that **configuration b)** can trap 2.2 times higher value then configuration a)
configuration c) can trap 5 times higher value then configuration a)

Schematic of the transversal cross sections of the *flat* and *angled* stacks.

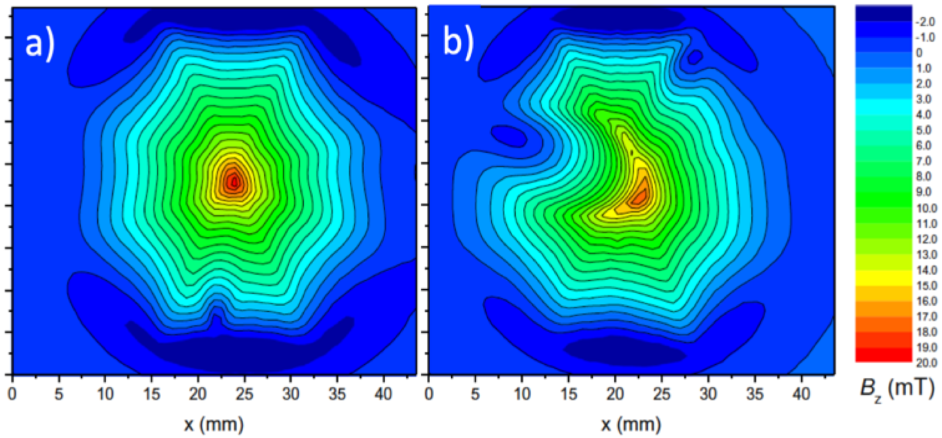




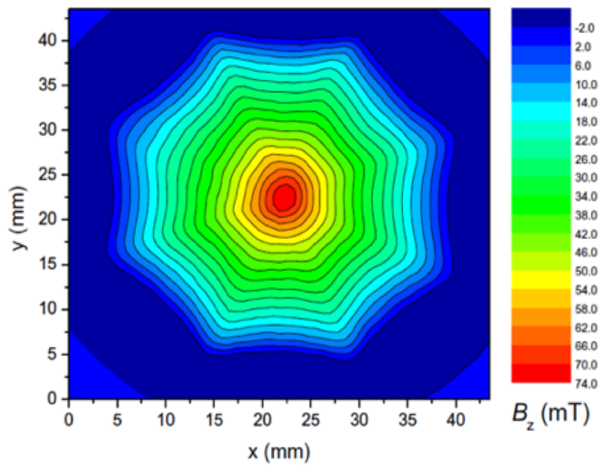
T. B. Mitchell-Williams, A. Patel, A. Baskys, S. C. Hopkins, A. Kario, W. Goldacker, B. A. Glowacki, *Towards Uniform Trapped Field Magnets Using a Stack of Roebel Cable Offcuts* IEEE Transactions on Applied Superconductivity, **26** (3) 6800404 (April 2016)

Wide tape stack - trapped flux imperfections smoothing effect

40 mm wide YBCO tapes - off cuts !!!



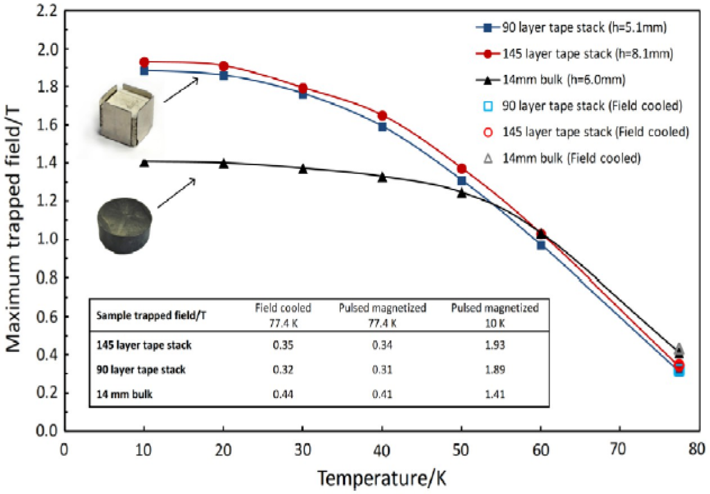
Trapped field profiles measured 0.6 mm above tape. B_z for various octagonal samples cut from 40-mm wide tape, where x is the transport axis.
a) Common trapped field for a layer showing a small defect on the sample edge.
b) Uncommon larger scale defect leading to an asymmetric trapped field profile.



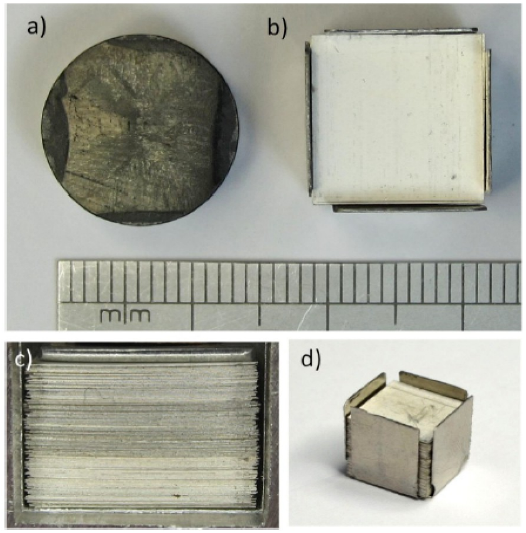
Trapped field profile measured at 0.8 mm above sample for a **stack of eight octagonal layers** cut from Tape B. Field cooling magnetization of the stack at 77 K results in a highly symmetric profile with a peak of 74 mT.

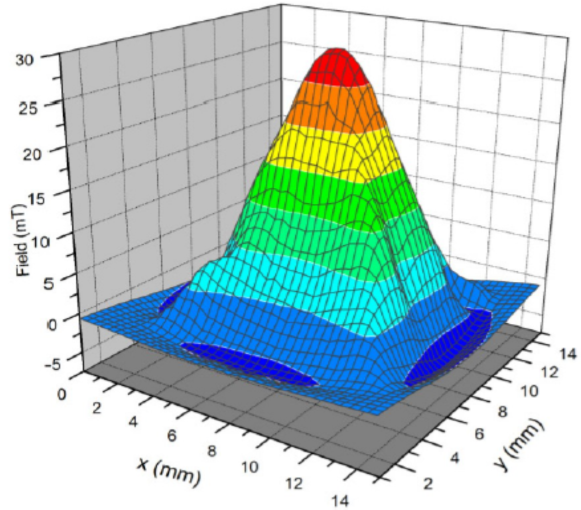
Patel A, Usoskin A, Baskys A, Hopkins S C, Glowacki B A, *Trapped Field Profiles for 40-mm Wide Superconducting Tape Pieces* Journal of Superconductivity and Novel Magnetism, **28** (2) 397-401 (February 2015)

Replacing YBCO bulks with consolidated stack of YBCO tapes

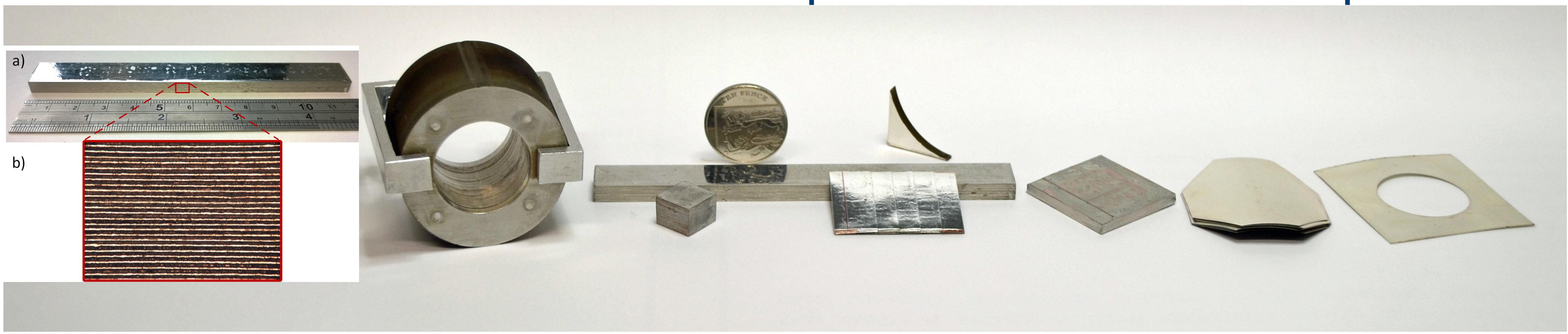


Sample trapped field/T	Field cooled 77.4 K	Pulsed magnetized 77.4 K	Pulsed magnetized 10 K
145 layer tape stack	0.35	0.34	1.93
90 layer tape stack	0.32	0.31	1.89
14 mm bulk	0.44	0.41	1.41

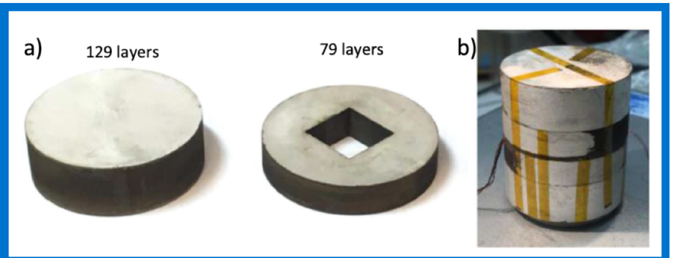


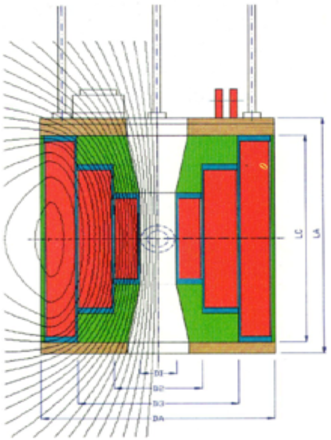


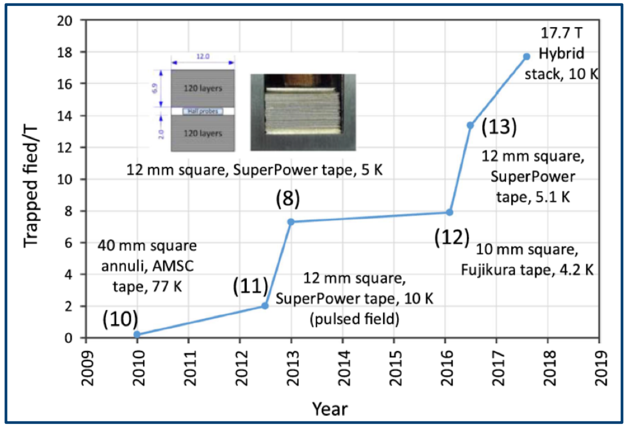
American Superconductor 46 mm tape



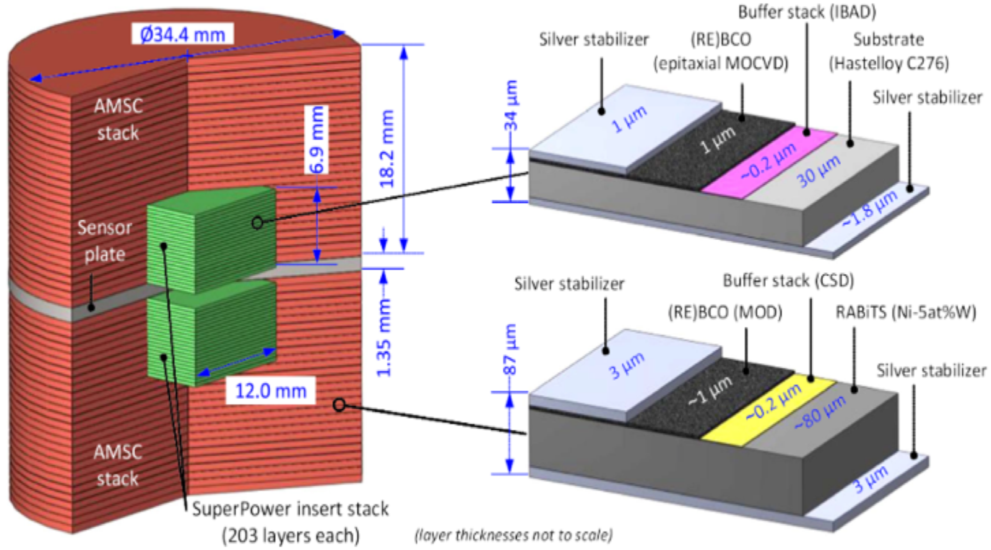
Hybrid stack as a ‘composite magnet’. 17.7 T







Schematic of the hybrid magnet made form LTS superconducting conductors: The external coil was made from NbTi , the middle one was made from Nb_3Sn and the central one was made from $NbTi_3(Sn,Ta)$ enabling generation of 22.59T.



Composition and geometry of the hybrid stack consisting of a 12 mm square stack made from SuperPower tape inside a 34.4 mm cylindrical stack made from AMSC tape. This hybrid structure in the analogue to composite hybrid NbTi and Nb_3Sn magnets was capable of trapping world record 17.7 Tesla.

Anup Patel, Algirdas Baskys, Tom Mitchell-Williams, Aoife McCaul, William Coniglio, Jens Hänisch, Mayraluna Lao, Bartek A Glowacki, *A trapped field of 17.7 T in a stack of high temperature superconducting tape*Superconductor Science and Technology, **31** 9 (2018)

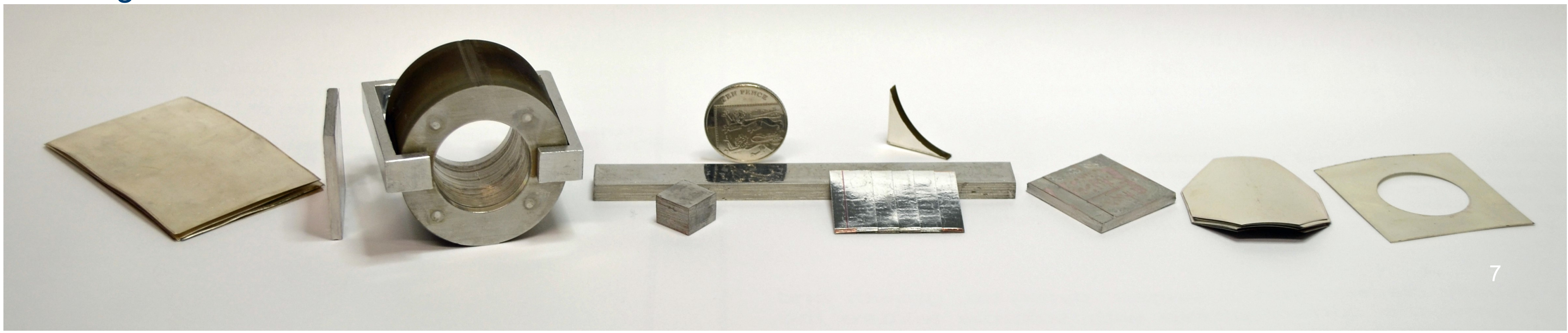
Introduction of new wider tapes from D-nano

RABiT substrates NiW

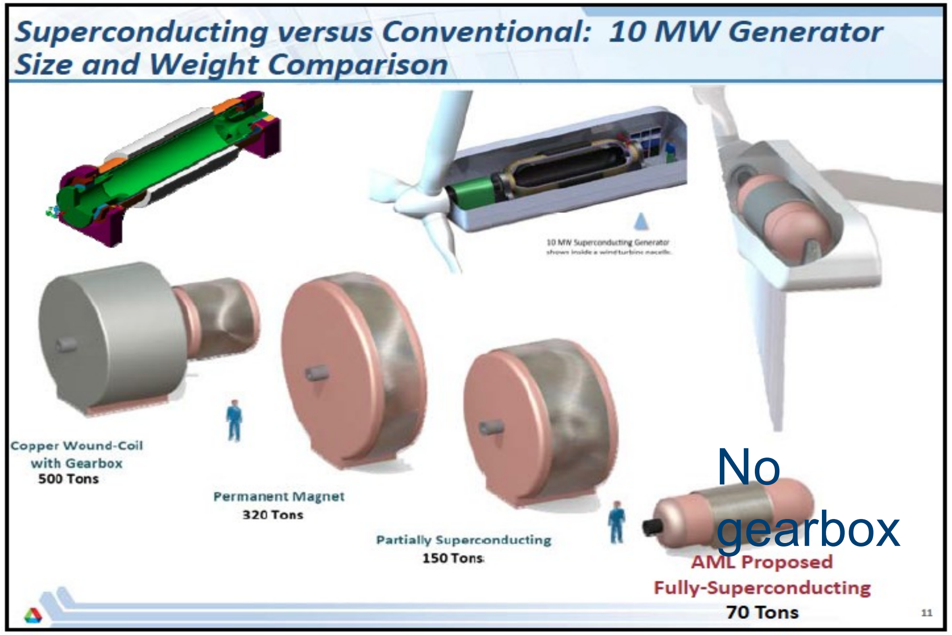
POSSIBILITY of replacement of the bulk YBCO round pellet like elements with superconducting fully stabilized almost 2D wide composite tape stacks opens up a new era of superconducting elements manufacture for levitation, energy generation and use applications.

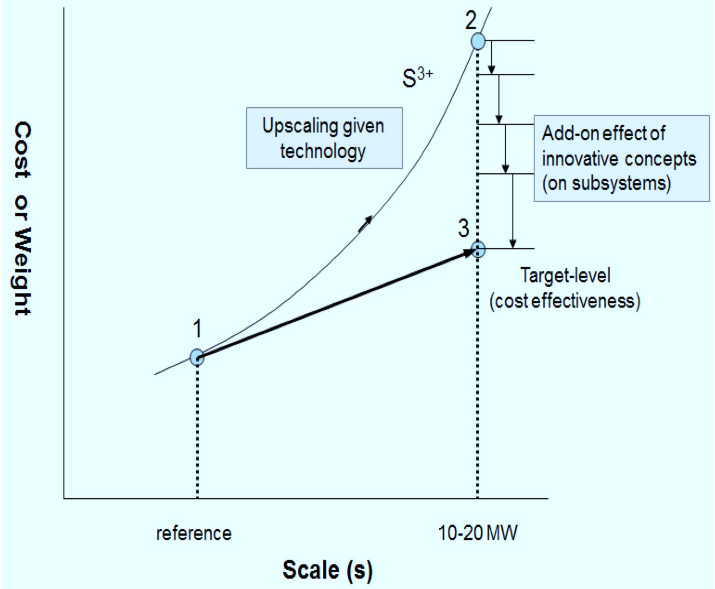
These novel tape-stack structures which can be currently made using industrial scale manufacture of **40 mm width tapes** with the best price/performance ratio. **D-Nano Company**, is implementing plans to deposit on **100 mm wide and hundreds of meters long tapes** which will become a template for large elements characterized with high in *a*-*b* plane persistent paramagnetic current without that eliminate current along the c-axis as it is in case of bulk YBCO materials.

The benefit of conducting R&D on such stacks of tapes is it relevance to application to the high-power cables for energy physics and energy transmission application as well magnetic screens and functional NMR.



10 ⇢ 20 MW superconducting wind generators cooled indirectly by stored LH_2

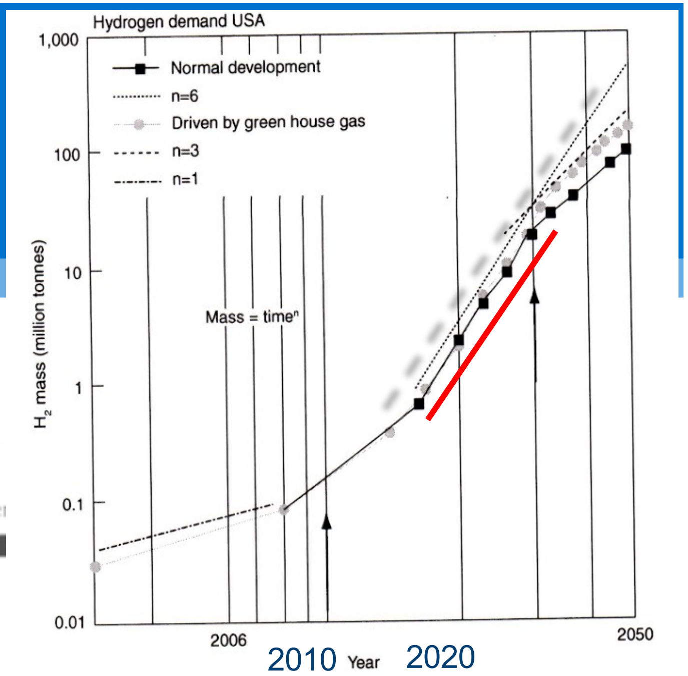




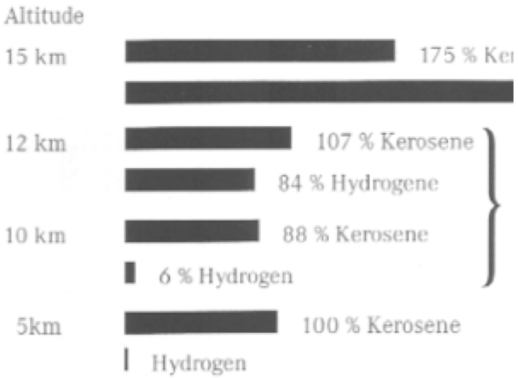
Depiction of the impact of technology innovations in reducing the cost of wind energy

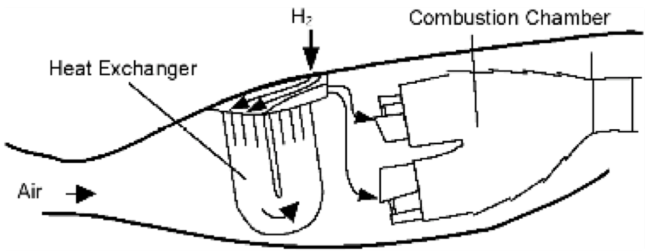
One of the key targets for the design of these large multi megawatt wind turbines is to beat the cubic law of weight (and cost) of classical up scaling, which renders a **10-20 MW offshore design cost-effective**

Cryoplane: decentralised production and storage of LH_2 (*designed in 1998*)

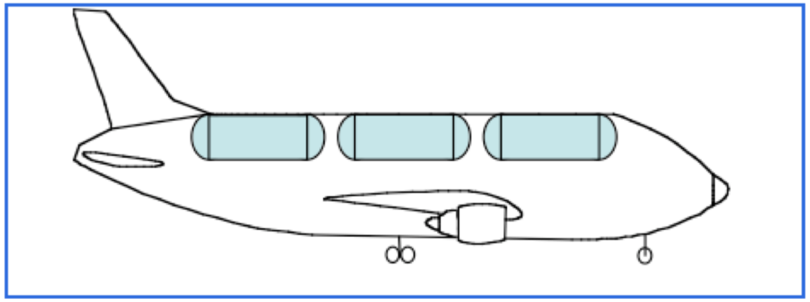


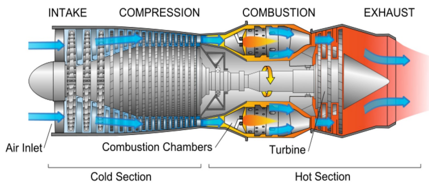
Hydrogen as a "fuel"





Altitude	kerosene	hydrogen
15km	175%	275%
12km	107%	84%
10km	88%	6%
5km	100%	1%



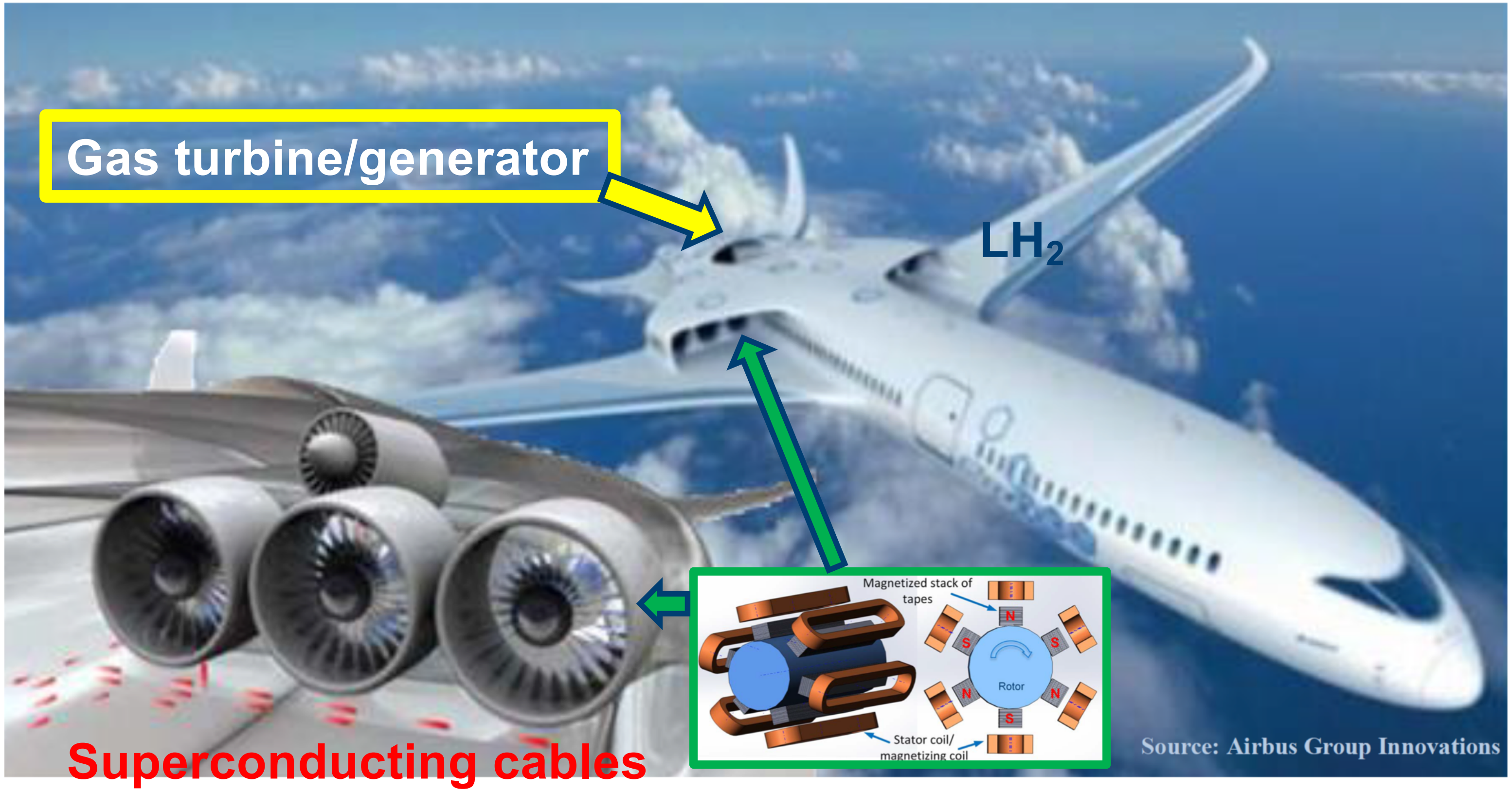


Distributed Electrical Aerospace Propulsion project

ASuMED

Funded by the European Commission Grant No 723119

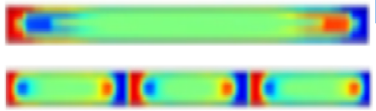
Hydrogen as a coolant and as a "fuel"



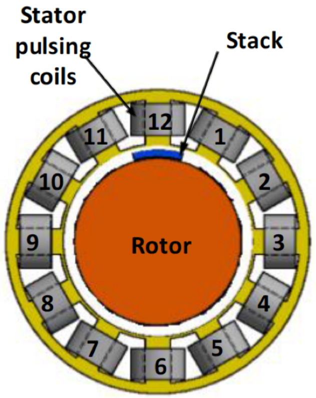
Fully superconducting motors

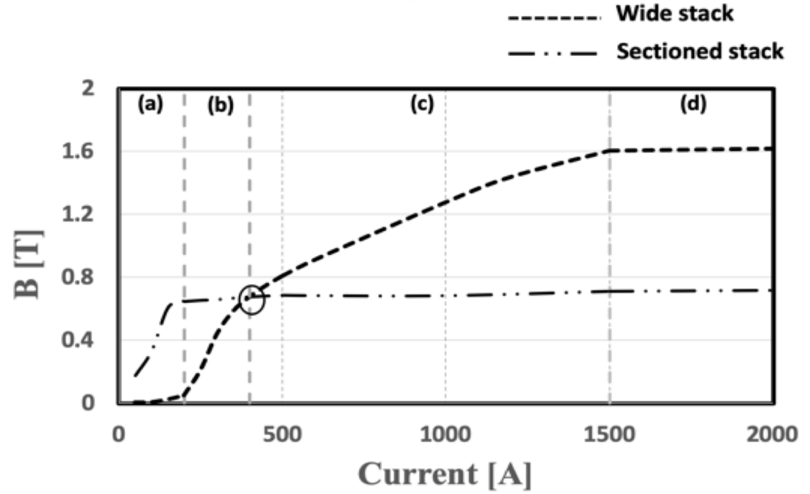
IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 25, NO. 3, JUNE 2015

Effect of the width of the tape on the pulse field trapped magnetic flux value



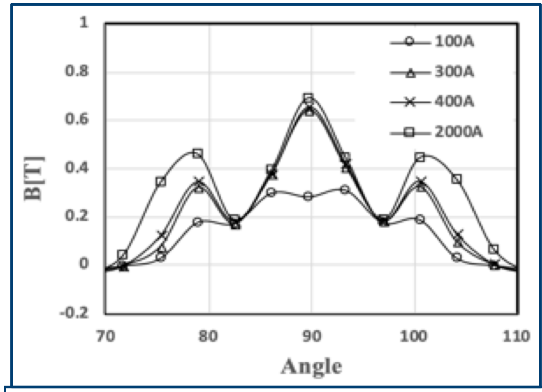
Current density distribution of straight wide and sectioned superconductor in the air with a normal field varying with a triangular shape in time: a) undersaturated case for the wide stack, b) case of undersaturated sectioned stack.



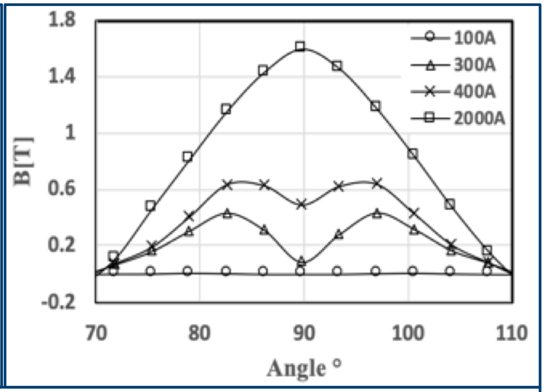


The peak of the trapped flux at the air gap by the sectioned and wide stack magnetized in an electrical motor. There are 4 distinctive zones on the graph representing characteristic different points between the stacks.

sectioned stack



wide stack

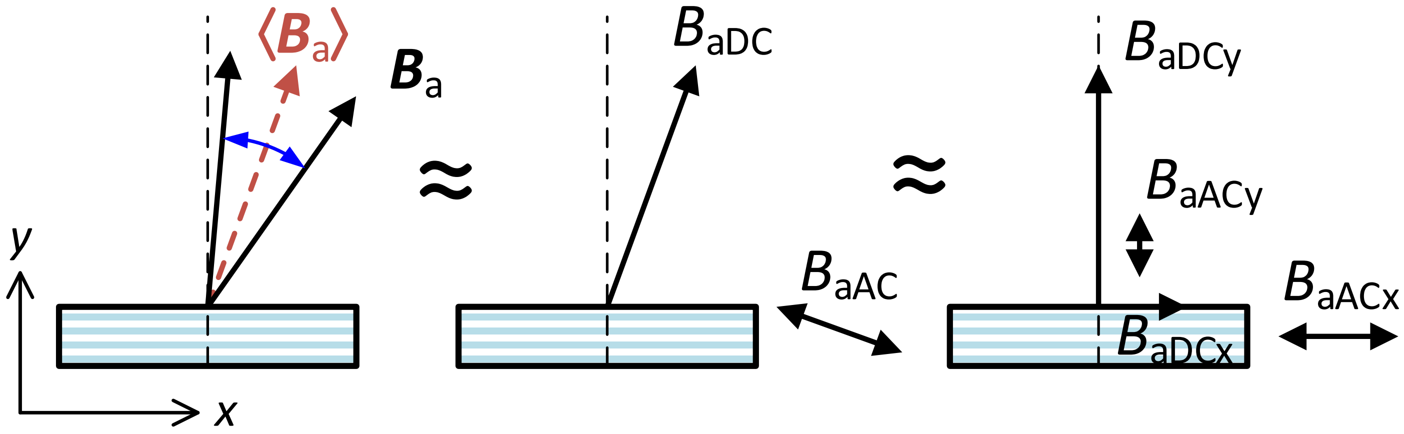


The flux density and current density distribution at different amplitudes of pulses for wide and sectioned stack.

a) flux density distribution for **sectioned stack**,
b) flux density distribution for **wide stack**.

It is evident that using wider tapes in a real motor environment is not always is beneficial at lower flux trapped components (in our case 0.65 T)

Problem of Crossed-field demagnetization
"AC case"



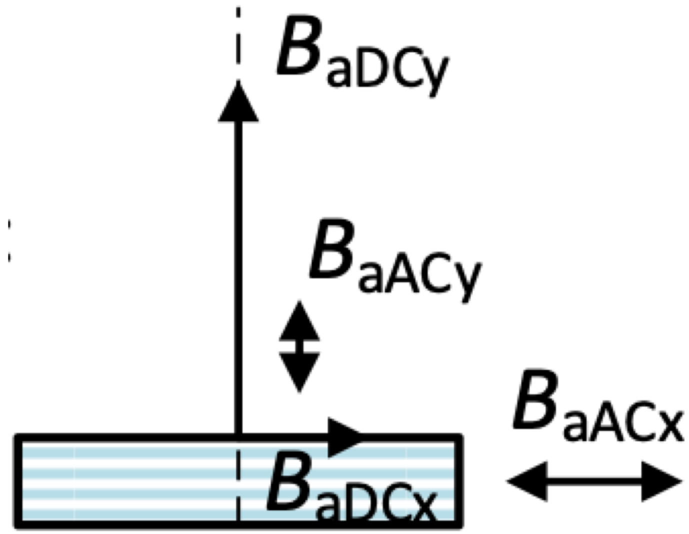
- Stacks in applications experience AC magnetic field that causes demagnetisation, but experimental studies for characterising the effect at complex operating conditions (such as magnetic-superconducting architectures) are still lacking.

- Figure above shows the external AC field experienced by a stack in applications. The field can be decomposed into perpendicular and parallel field components. It is the B_{aACx} component that causes largest demagnetisation rate.

HTS Stack in rotor application “paramagnetic current”

The effect of the $\boldsymbol{B_{aACy}}$ component on trapped field magnets is understood and current distribution in the interior of the sample does not fundamentally change

If direction of the external applied field is perpendicular to the tape layers $\boldsymbol{B_{aACx}}$, even a small applied field exceeds the penetration field of a single tape in that orientation, that reduces the magnetisation along the *y* axis.



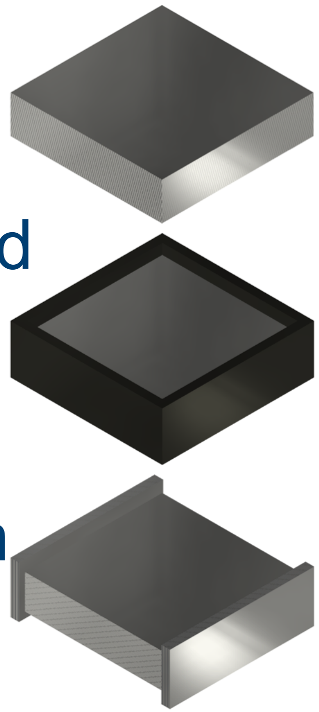
However, stacks in applications experience an AC magnetic field that causes demagnetization, there is data suggesting that the **demagnetization rate is actually slower in stacks of tape than in bulk** HTS superconductors.

Protection against demagnetisation: *stack shielding*

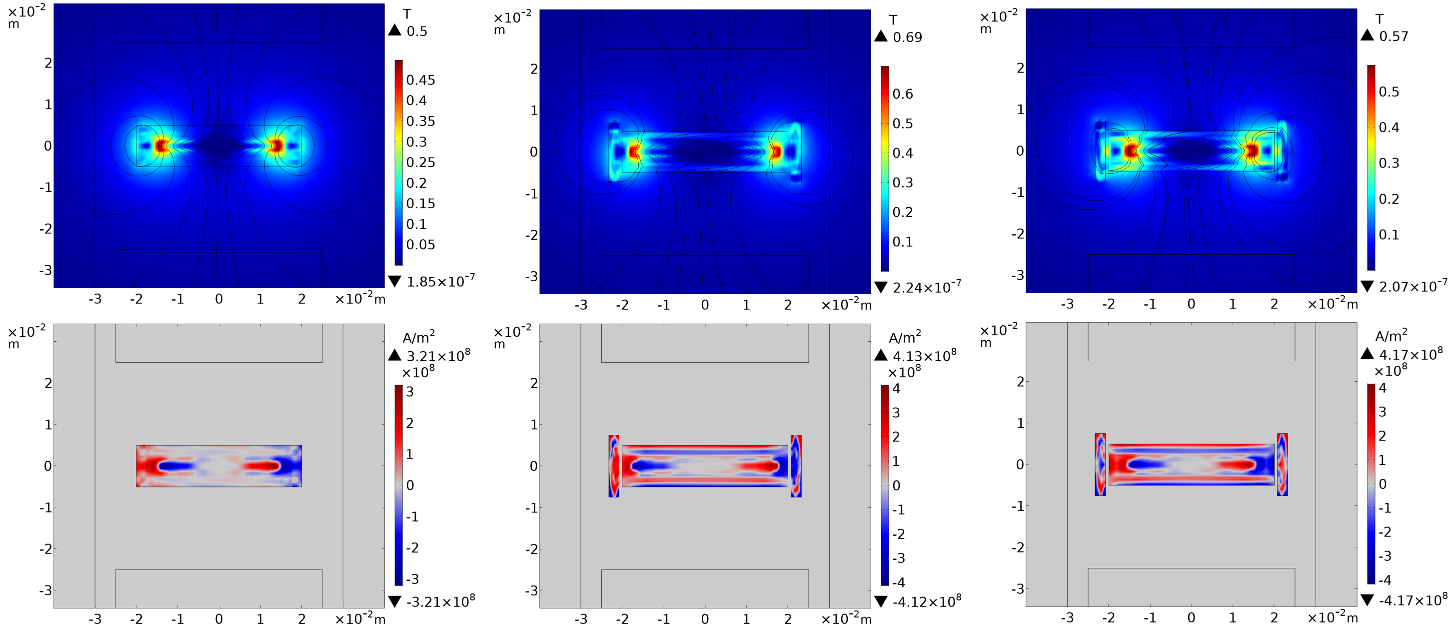
unshielded

closed

open



Shielding variants

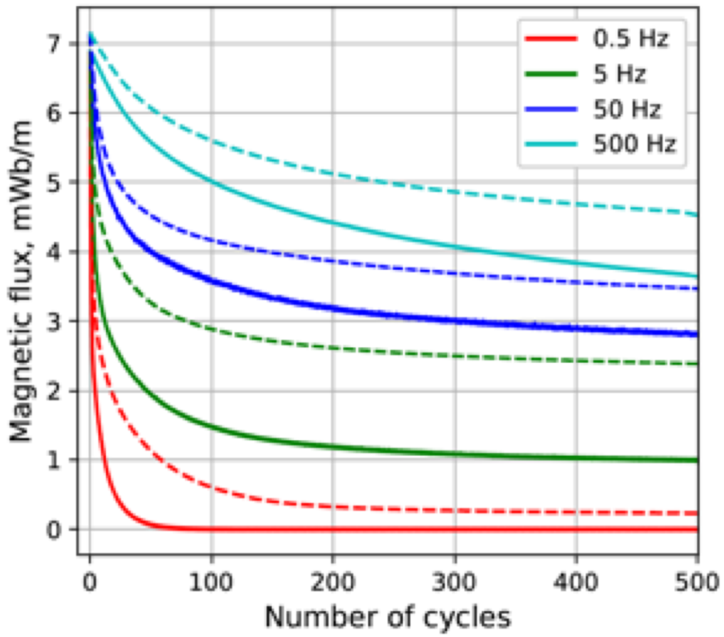


Unshielded | Closed shield | Open shield

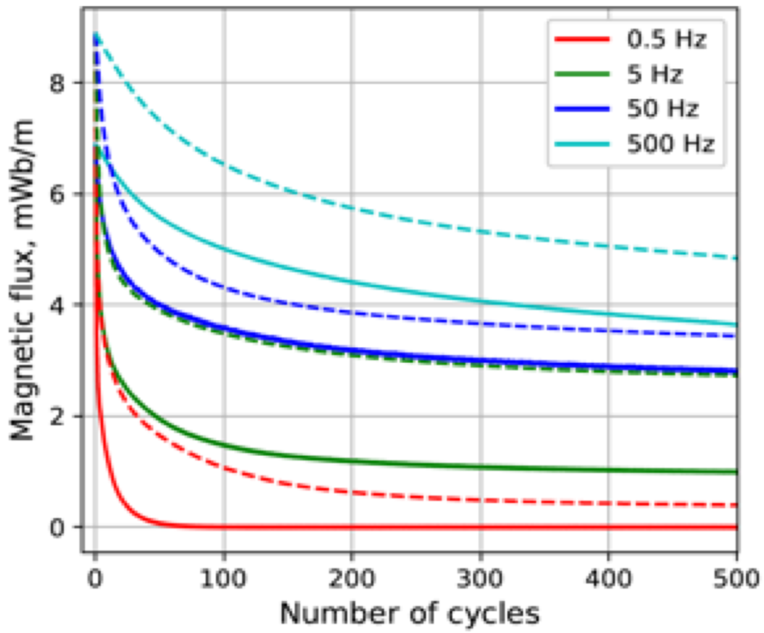
Distributions of magnetic induction and electric current density

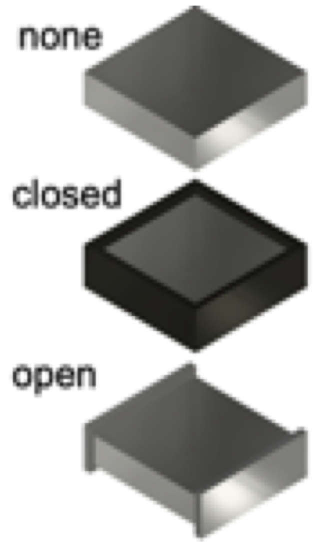
Stack screening in rotor applications dynamic demagnetization

open shield



closed shield





Magnetic flux *vs* number of cycles for the stack shielded with: a) an open shield, b) a closed shield (**solid lines - unshielded**, **dashed lines - shielded**); c) variants of shielding; unshielded stack, closed shield, open shield

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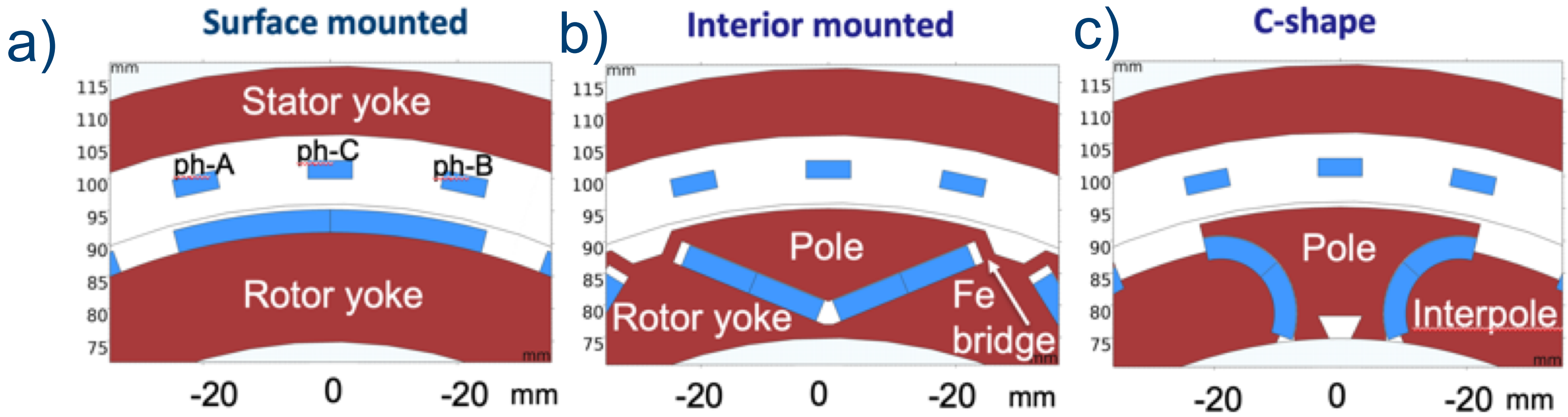
Trapped magnetic field is larger with the shielded stack for every configuration and frequency

HTS Stack architecture in rotor application C-shape



- Easy assembly
- Easy magnetization
- Easy demagnetization
- High losses
- Difficult construction

- Easy assembly
- Difficult magnetization
- Little demagnetization
- Low losses

- Difficult assembly
- Easier magnetization
- Lower demagnetization
- Low losses
- Novel geometry

Classical geometries considered for the ASuMED fully superconducting 1 MW, 3-phase motor demonstrator cooled by LH_2: a) surface mounted stacks; b) interior mounted stacks and c) C-shape (geometry finally accepted).

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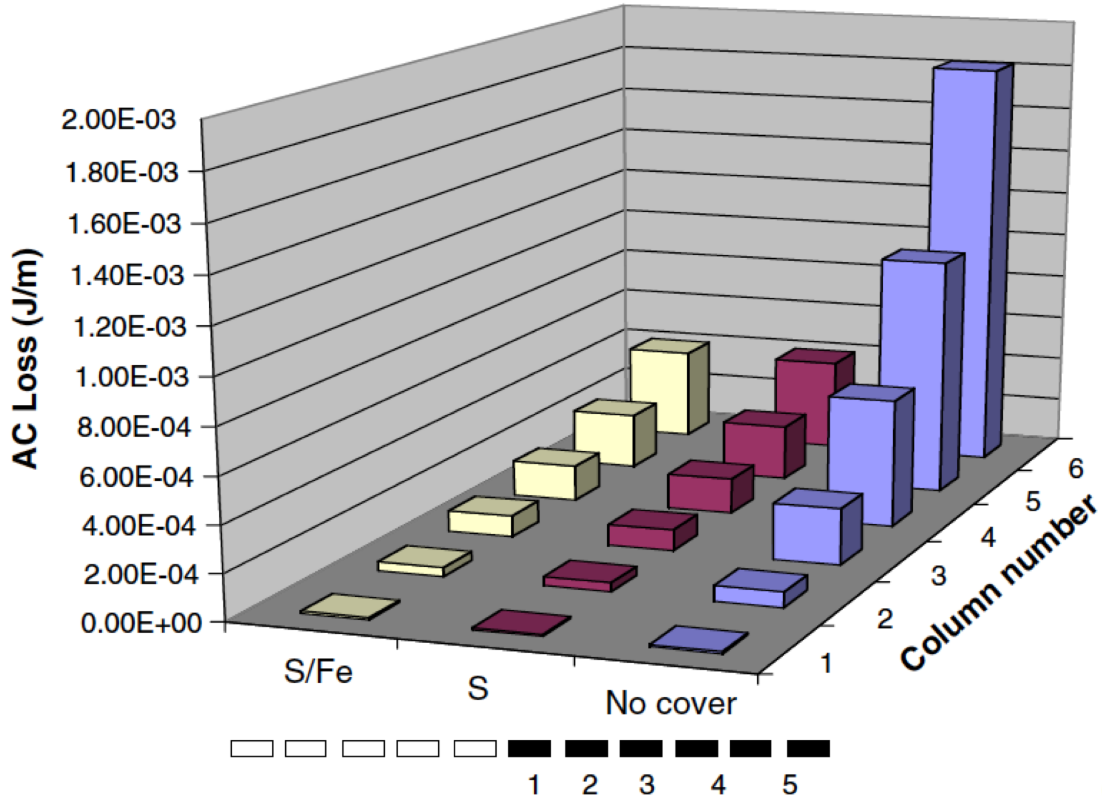
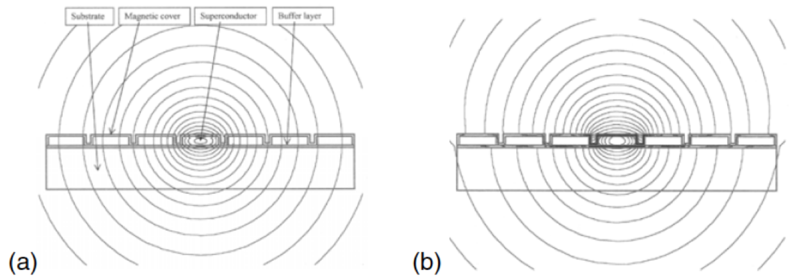
Magnetic superconducting architecture on losses
stator case



Proximity of ferromagnetic materials may benefit the performance of superconducting conductors in respect of the critical current and AC losses



YBCO cc

AC loss distribution in individual filaments when they are covered with Fe layers and without the covering. (S/Fe—total losses, S—component of the losses in the superconductor only.)

Conclusions

- HTS stacks for DC applications have a great potential if the pulse magnetisation procedures were optimised for desired temperature range.

- HTS stacks for AC applications are promising but in complex magnetic-superconducting architectures such as it is in rotating machines, much more novel tailored R&D is required to prevent detrimental demagnetization effect.

WIDER TAPES ARE NEEDED – they will be most likely based on RABiT substrates 10 - cm width