Influence of field cycle on coated conductor magnetization and decay for accelerator applications

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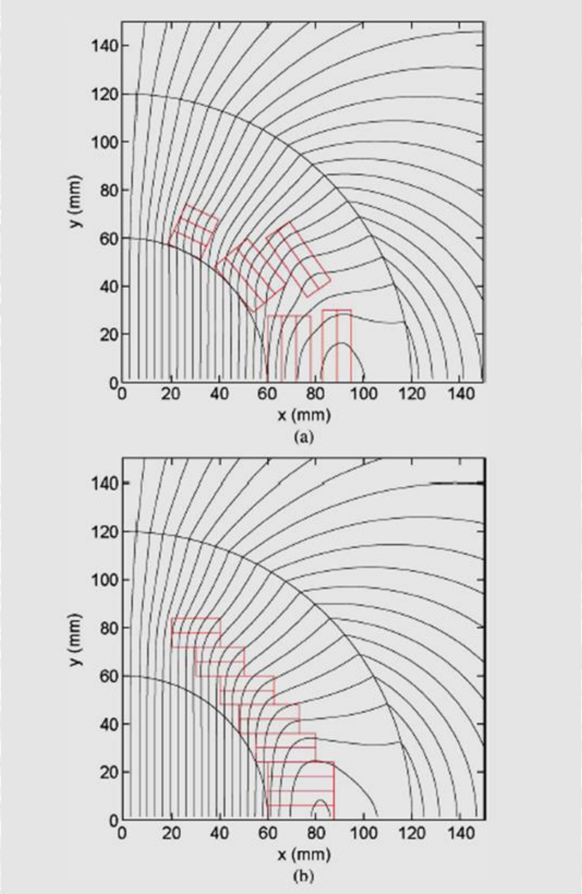
Department of Materials Science and Engineering

Motivation – error fields and drift

- ***A Future Circular Collider, or Energy upgrades*** of the LHC may require ***HTS/LTS hybrids***
- The fact that strand and cable magnetization lead to field errors is well known, and YBCO strand and cable are particularly prone to this, depending on the cable and magnet structure
- If the YBCO can be used with the field always parallel to the field, then this would not be an issue, but this is perhaps not the favored design, and may be difficult to do fully in any case, given the field lines distribution throughout the magnet



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Field Errors at collision and injection

In accelerator operation, there is

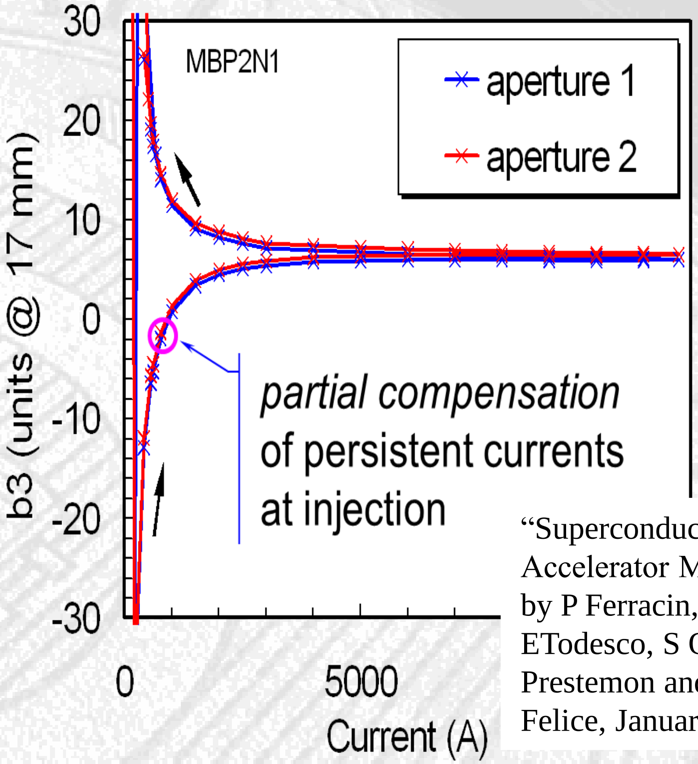
(1) ***a low field injection phase***, where the dipole magnets operate for some ***20 minutes or more at a nominal 1 T*** injection “porch”

(2) An energy ramp, coast (beam collision)

(3) An energy dump, where the magnets are then ***cycled back to near zero, followed by a rise to the beam injection*** field to repeat the cycle

Any strand magnetization leads to deviations from the pure dipole field which tend to defocus the beam.

Such errors are described in terms of the high order multipoles of the field, ***a good measure is the sextupole component, b3***

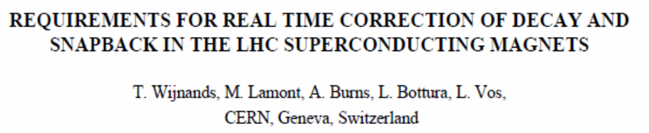


partial compensation of persistent currents at injection

“Superconducting Accelerator Magnets” by P Ferracin, ETodesco, S O. Prestemon and H Felice, January 2012

*The above process leads to a partial compensation of the error fields at injection, a (hopefully small) negative value usually dominated by the **sextupole component, b3**.*

Drift on the injection Porch



REQUIREMENTS FOR REAL TIME CORRECTION OF DECAY AND SNAPBACK IN THE LHC SUPERCONDUCTING MAGNETS

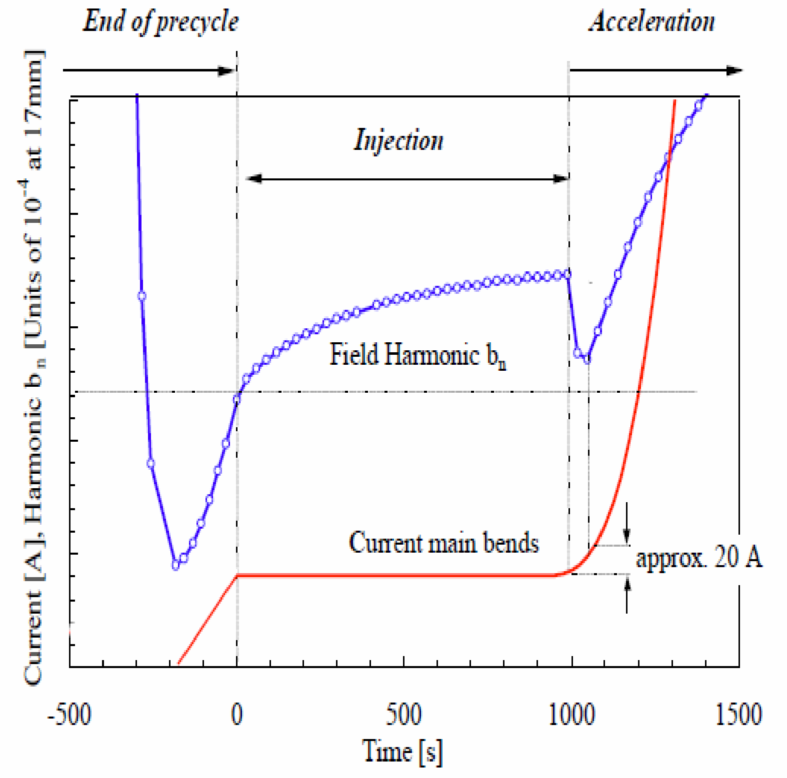
T. Wijnands, M. Lamont, A. Burns, L. Bottura, L. Vos,
CERN, Geneva, Switzerland

- Just as important as the absolute value of b_3 is any ***change with time*** during the injection porch

- It is possible to compensate for error fields with corrector coils, but the presence of ***drift*** makes this much more difficult

- At right is shown the drift of the error fields as a function of time from zero to 1000 seconds for LHC magnets, followed by a snap-back once the energy ramp begins

- The underlying mechanism for drift in NbTi magnets is the decay of coupling currents, (especially inhomogeneous and long length scale coupling currents) and their influence on the strand magnetization



Need to keep both b_3 and its drift below 1 unit

For NbTi and Nb_3Sn based magnets, this is possible

Important to control drift

So, right now we are at several units of drift

Drift in LTS is due to influence of long range coupling current decay on strand magnetization

But HTS materials famously exhibit Giant Flux Creep (Y. Yeshurun and A. P. Malozemoff)

But, Creep goes like kT, so its not a problem at Low Temperatures, ***right?***

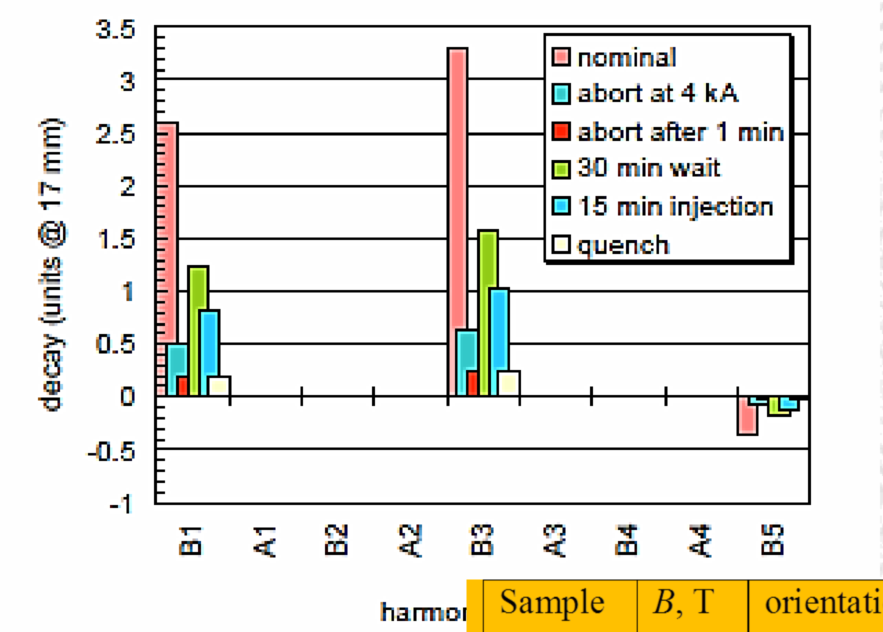
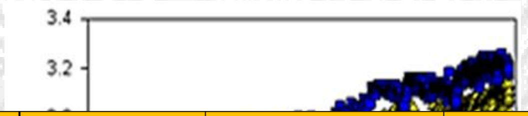


Figure 2: The magnitude of the
the main bends (in units of 10
for various operational scenari

REQUIREMENTS FOR REAL TIME
SNAPBACK IN THE LHC SUPER

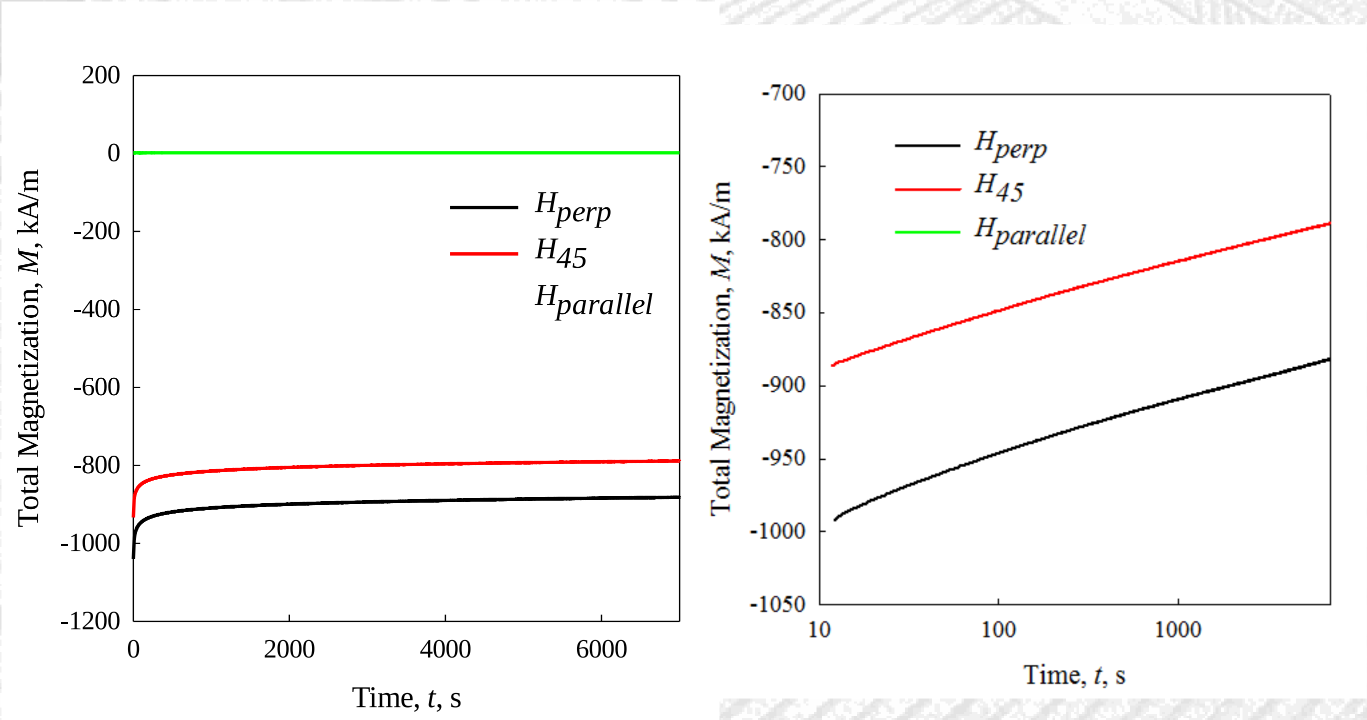
T. Wijnands, M. Lamont, A. B
CERN, Geneva, S



No – at right is data of PRB

Sample	B, T	orientation	$-M_0$, kA/m	$-M_{20min}$, kA/m	M_{20min}/M_0	ΔM, kA/m	$\%b_3$
Bi:2212	1 T	⊥	15	12	0.80	3.0	20
	12 T	⊥	2.7	1.5	0.58	1.1	42
YBCO							
	1 T	⊥	991	906	0.91	90	10
	1 T	45°	933	811	0.86	120	14
	12 T	⊥	280	187	0.67	93	33
	12 T	45°	229	200	0.87	29	13

Measurements of 4 mm wide Superpower coated Conductor



- So if we associate 10 kA/m with 3 units, then we have about 30-40 units of drift below
- FO 12 mm wide tape would give 90-120 units
- This would be mitigated by hybrid magnets or field parallel orientations

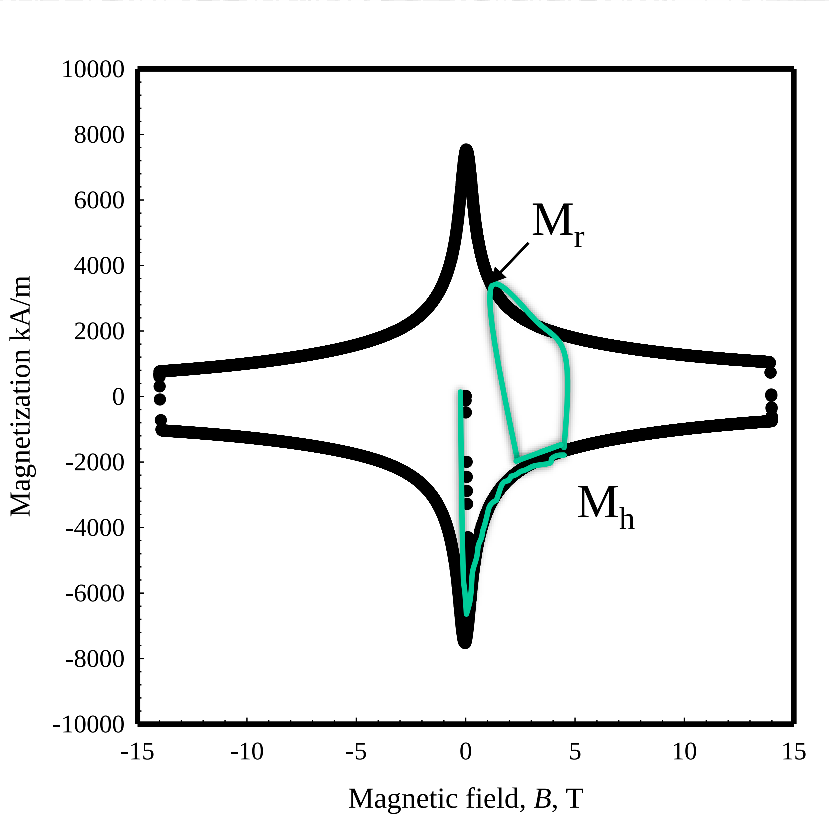
Angle	M_o, kA/m	M_{20min}, kA/m	M_{20min}/M_0	ΔM, kA/m	delB3
⊥	991	906	0.91	90 kA/m	27
45°	933	811	0.86	120 kA/m	36

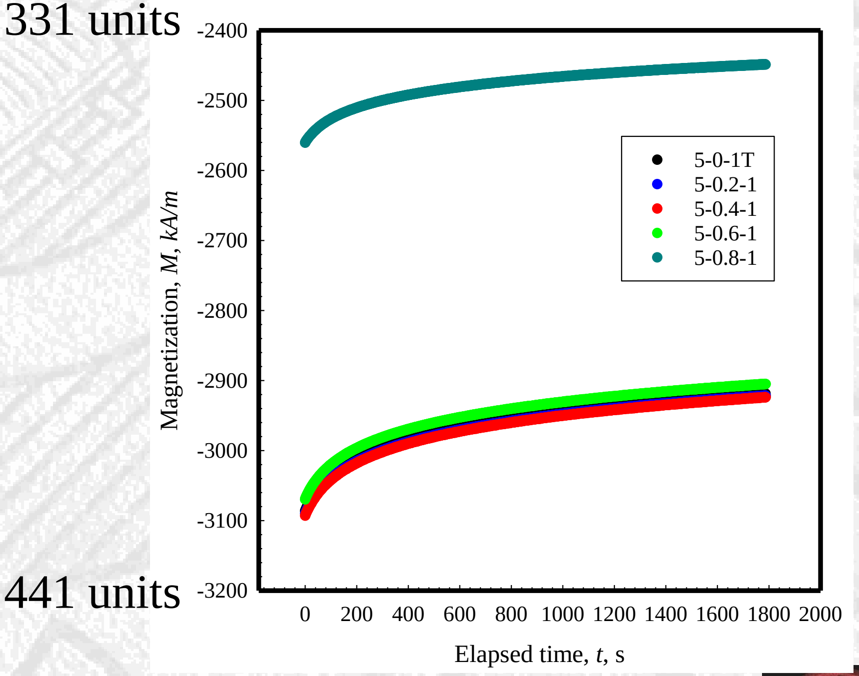
Creep at injection with HTS

Here we show that we can reduce both the Remanant magnetization and creep at injection using a modified field cycle

First from zero go to high field (5 T), then a lower rest field (0-1 T), and then to 1 T for "injection"

Results – M_r up to 0.6 T did not change results, but at 0.8 T, decrease is seen

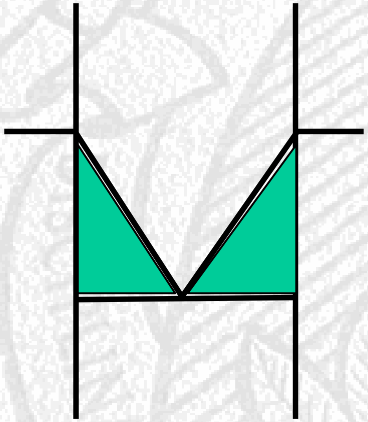




Why are Magnetization and Creep (Drift) reduced?

0 T →5T (“collision”)

→ 0 T → 1 T (inj)

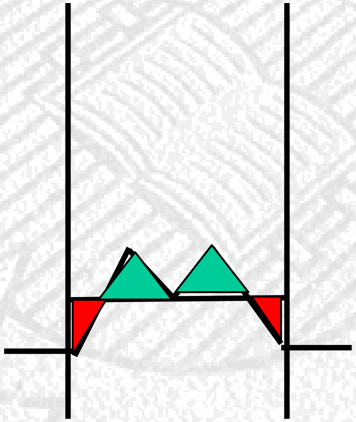


$M_{inj} \propto$ green area

$M_{inj}(t) \propto (A_G)*(1-Ln(t))$

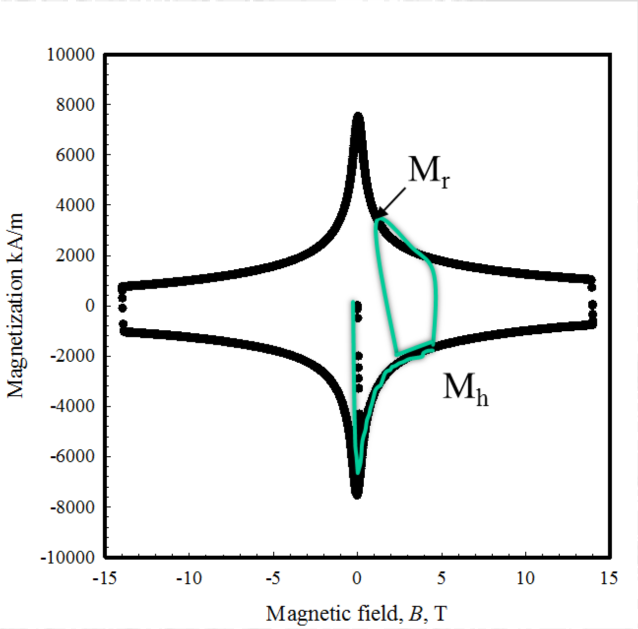
0 T →5T (“collision”)

→ Mr (0-1 T) → 1 T (inj)

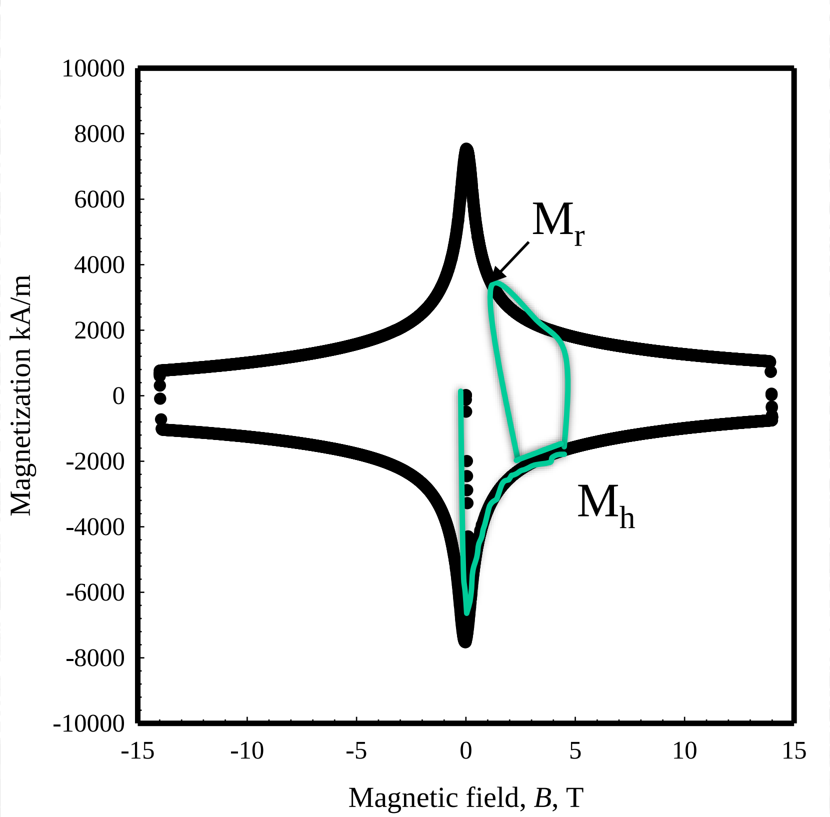


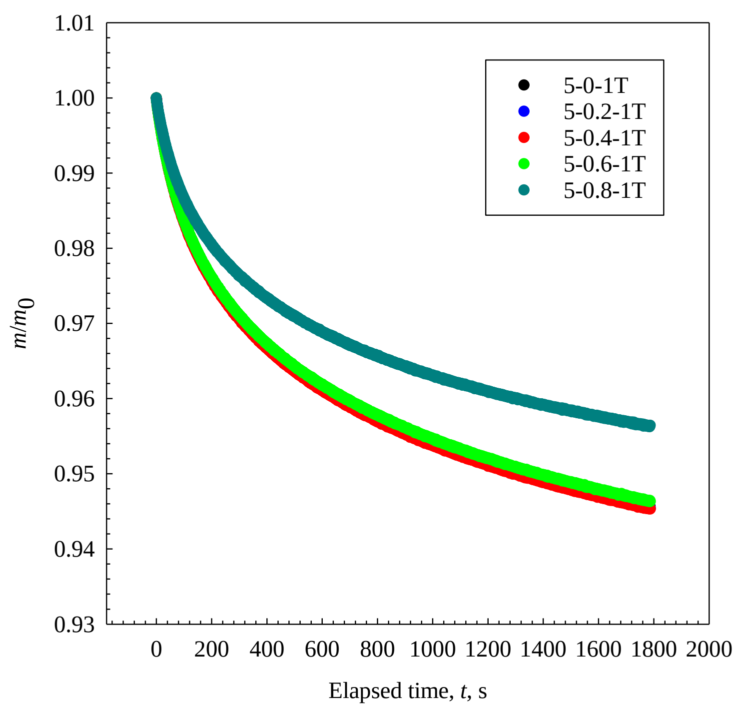
$M_{inj} \propto$ green area-red area

$M_{inj}(t) \propto (A_G-A_R)*(1-Ln(t))$



Normalized relaxation using modified protocol

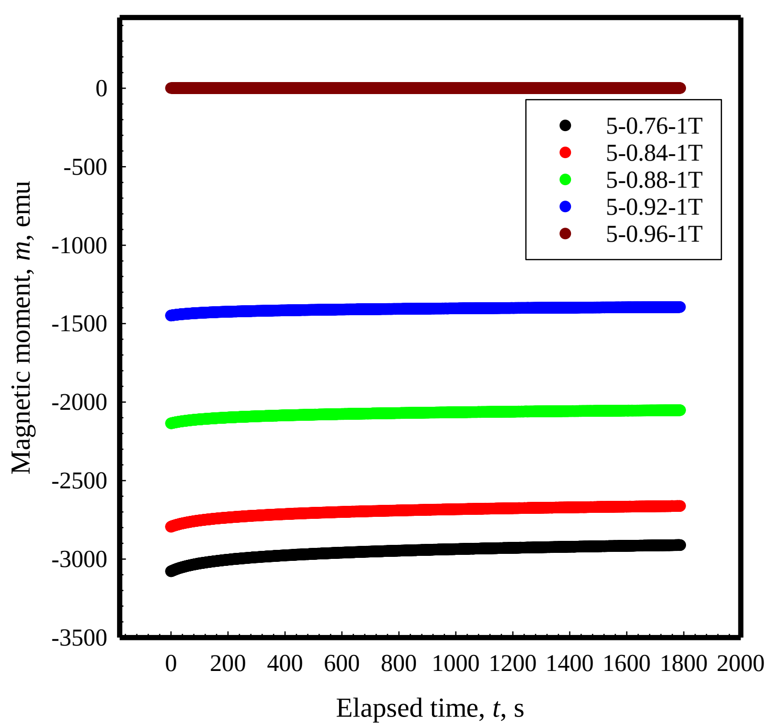


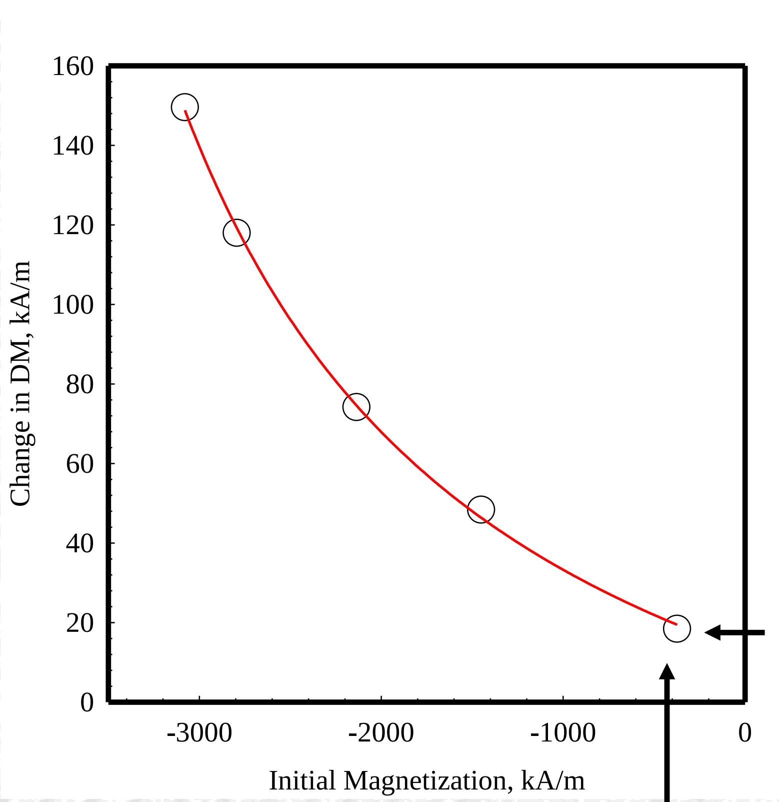


M_{inj} decreases, also ΔM_{inj}

Need to push further

A Finer approach to Injection





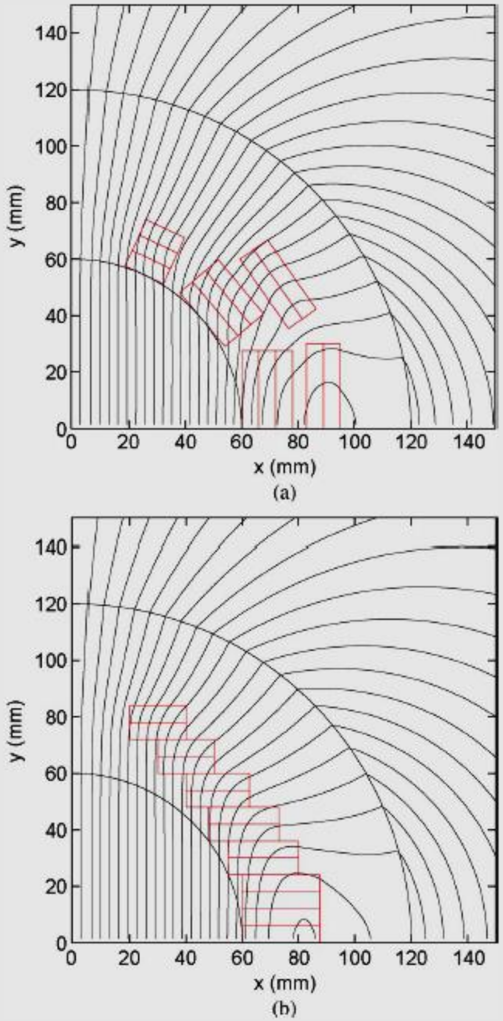
6 units drift

90 units fixed

With a resting field of 0.96 T, we can highly suppress both remanent magnetization, and its drift

The field Spread in the magnet will make this approach only partially successful

- cos theta dipoles and block magnets of different designs magnet cross section will have different magnetization to error field correlations
- It may be difficult to achieve the same rest field for all strands/cables, so that many strands may have some larger residual M and decay.



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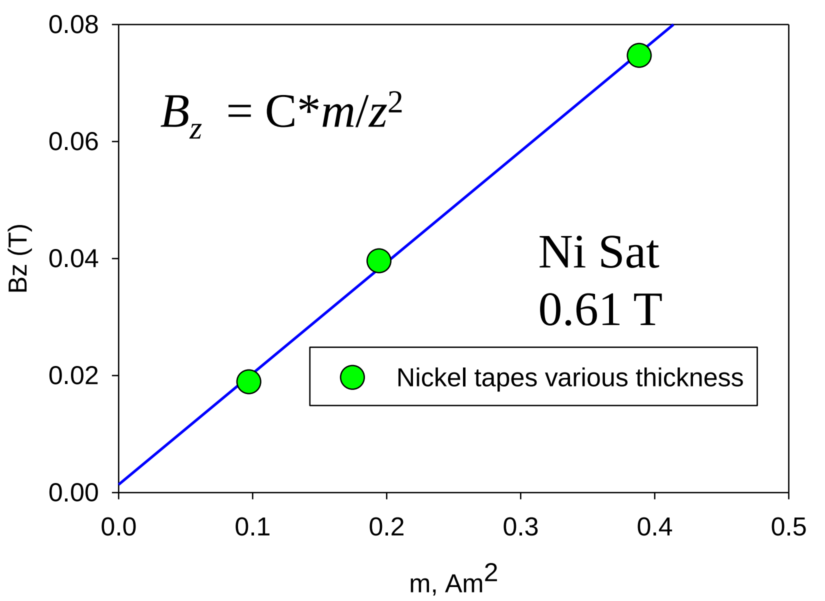
Next Steps

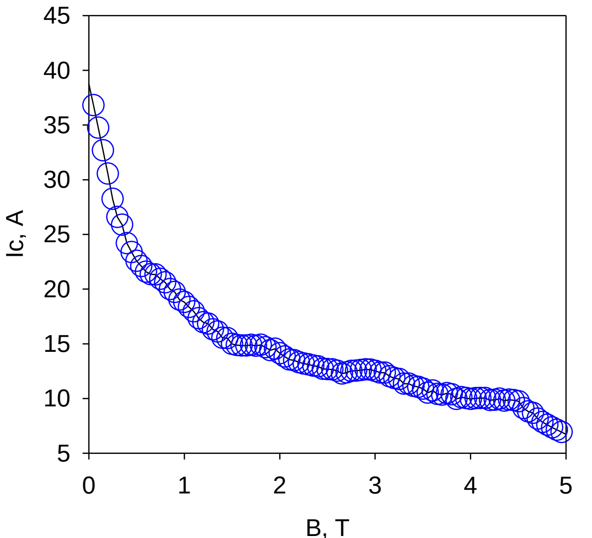
- The experiments to date have been on very small segments of tape, to fit a PPMS – but such measurements on longer tapes, and cables, are needed
- Also, it is useful to do such measurements in the presence of applied current
- We have developed a 12 T dry magnet with a hall probe measurement technique to explore these measurements

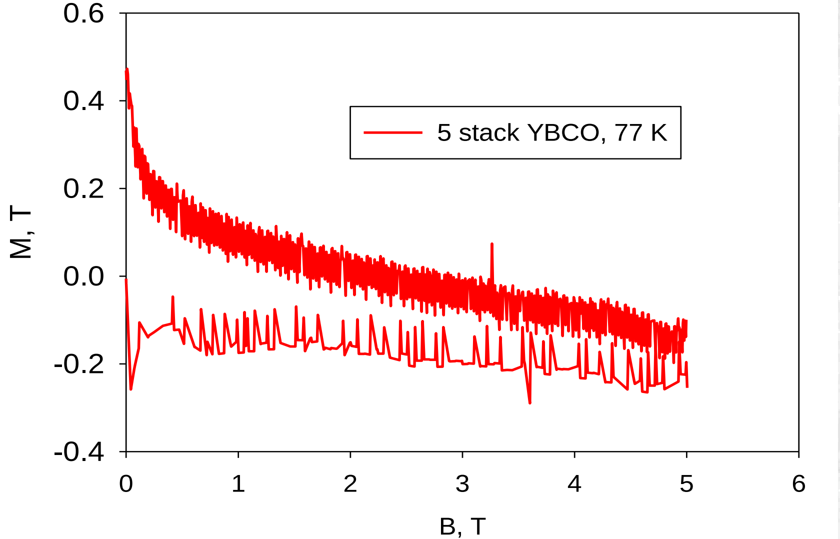
Hall Probe Magnetization in dry magnet with tail dewar – for tapes, short cables



Made for magnetization of tapes and short cables

- Sample up to 6 cm long
- Current + field
- Drift, Drift +





Conclusion

- Both the magnetization and the creep of HTS materials are important at 4 K for accelerator magnet applications – the first leads to b3, the second leads to drift in b3
- Both magnetization and its creep (b3 and its drift) might be minimized by an appropriate field cycle – a reduction of an order of magnitude is seen in this study
- The reason for this is the balanced critical state if we have a field rest within a field penetration excursion of the injection field
- This may be difficult to employ completely in a magnet, given the different fields the conductors are exposed to within the magnet, but the benefit should still be substantial