Solenoid/Magnetic Shielding Test Results in FRIB-1&2 Cryomodule

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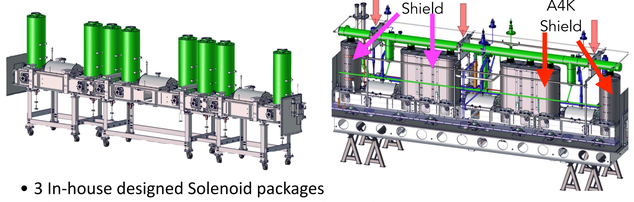
Introduction

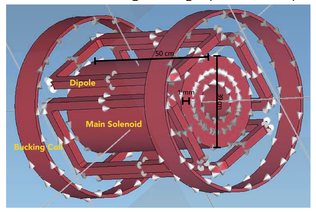
FRIB-1 Cryomodule (CM-1)



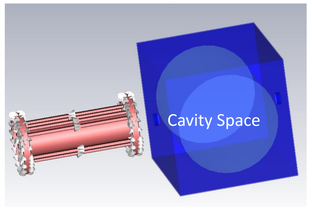
- 3 In-house designed Solenoid packages
- 8 beta=0.085 Quarter wave resonators(QWRs)
- Local Magnetic shield
  - Lower material cost
  - Shield from both earth magnetic field and solenoid magnetic field
- Adopting low cost Mu-metal for promising shield material test
- CM-2 has the same design as CM-1, except using A4K for all cavities and solenoid produced by vendor

Solenoid Package

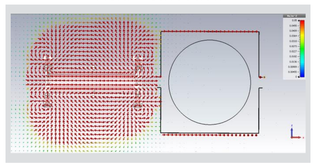
Solenoid Package Design (CST Studio)



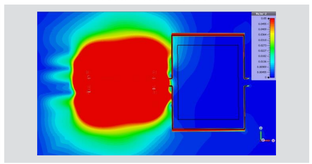
Solenoid Package Position



Field Distribution



Field Distribution



- Main solenoid: focusing
- Dipoles (Steering Coils): direction changing
- Bucking coils: Magnetic fringe field cancelation (No Yoke)

Table 1: FRIB 50 cm Solenoid Package

Operation temperature	$4.5 + 0.5/-0.0$	K
Solenoid nominal current	$\leqslant 90.9$	A
$\int B^2 dz$	$\geqslant 13.6$	T^2m
Peak solenoid field on beam axis	$\geqslant 8.0$	T
Fringe field	$\leqslant 270$	G[1]

[1] At magnetic shield on the magnetic shield surface.

Local Magnetic Shielding

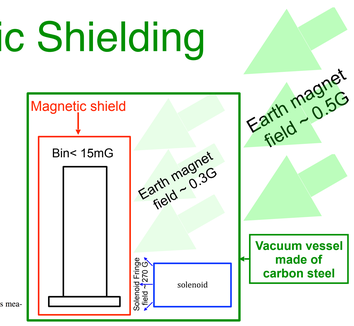
Table 2: FRIB Magnetic Shield

Magnetic permeability	$\geqslant$ 10000 at 25 K
Thickness	1 mm for QWR

Table 3: Dynamic Heat Load for Cavities @ 2 K

Cavity	Dynamic heat load [W]	Shielding Material
C#1[2]	6.2	Mu-metal
C#2	2.4	Mu-metal
C#3	2.5	Mu-metal
C#4	1.0	Mu-metal
C#5	2.4	A4K
C#6	2.5	A4K
C#7	2.4	A4K
C#8	2.6	A4K

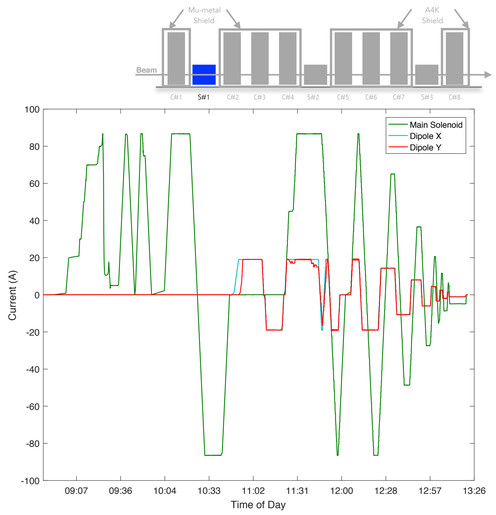
[2] C#1 was mis-performed calibration, and the dynamic heat load was measured under 7 MV/m instead of 5.6 MV/m for all other cavities.



CM-1 Solenoid Package Test

Procedures
- Excite solenoid, change ramping rate (9:00 - 10:17)
- Polarity change (10:19 - 10:28)
- Excite dipoles alone and together (10:41-11:22)
- Excite all coils (11:50-12:20)
- Integral test: package and nearest cavities were all turned on (not shown)
- Degaussing

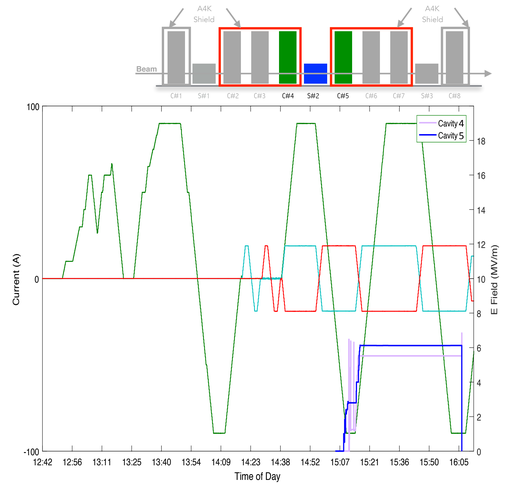
Result
- Ramping rate maximum: 0.5 A/s
- Stable during Polarity changing
- Stable work together
- Stable and not influence cavity performance
- Validated Mu-metal (μ>10000 @ 25 K, 1/3 cost of A4K) not worse than A4K



CM-2 Solenoid Package Test

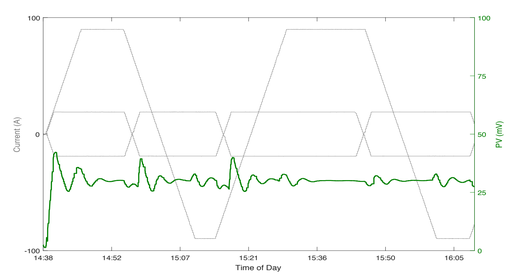
Procedures
- Same procedures as in CM-1
- Integral test as shown in right figure (15:07-16:06)

Result
- Ramping rate maximum: 0.5 A/s
- Stable during Polarity changing
- Stable work together
- Stable and not influence cavity performance
- Validated Mu-metal (μ>10000 @ 25 K, 1/3 cost of A4K) not worse than A4K

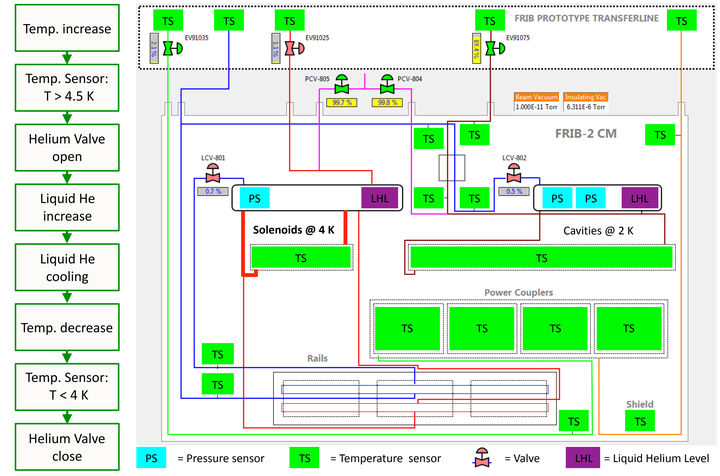


PID Controller

- Set-point is 30 mV
- Picked 14:38 - 16:10, within the test time, see upper graph time line
- Work combine with cooling system



Cryomodule Cooling System



Conclusion

1. Both CM-1 in-house-made solenoid packages and CM-2 first-vendor-produced solenoid packages showed robust and stable quality.
2. Bucking coils + local magnetic shield give enough shielding and successfully prevented magnetic-field-caused cavity quench.
3. Mu-metal (μ>10000 @ 25 K) showed similar reliability, we will order Mu-metal shielding for future use due to low cost (1/3 of A4K).

Reference

[1] Z. Zheng *et al*, LINAC 16, *Proc. 28th LINAC*, East Lansing, USA, Sep. 25-30, 2016, paper THPRC023, this conference

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[3] K. Saito *et al*, LINAC 14, *Proc. 27th LINAC*, Geneva, Switzerland, Aug. 31 - Sep. 5, 2014, paper TH10A02

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[5] J. Simon *et al*, Internal report, FRIB, East Lansing, USA, Rep. FRIB-T30602-PR-000349-R002, Sep. 13, 2016

[6] J. Simon *et al*, Internal report, FRIB, East Lansing, USA, Rep. FRIB-T30602-PR-000369-R002, Sep. 13, 2016

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

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