Impact of solenoid induced residual magnetic fields on the prototype SSR1 CM performance

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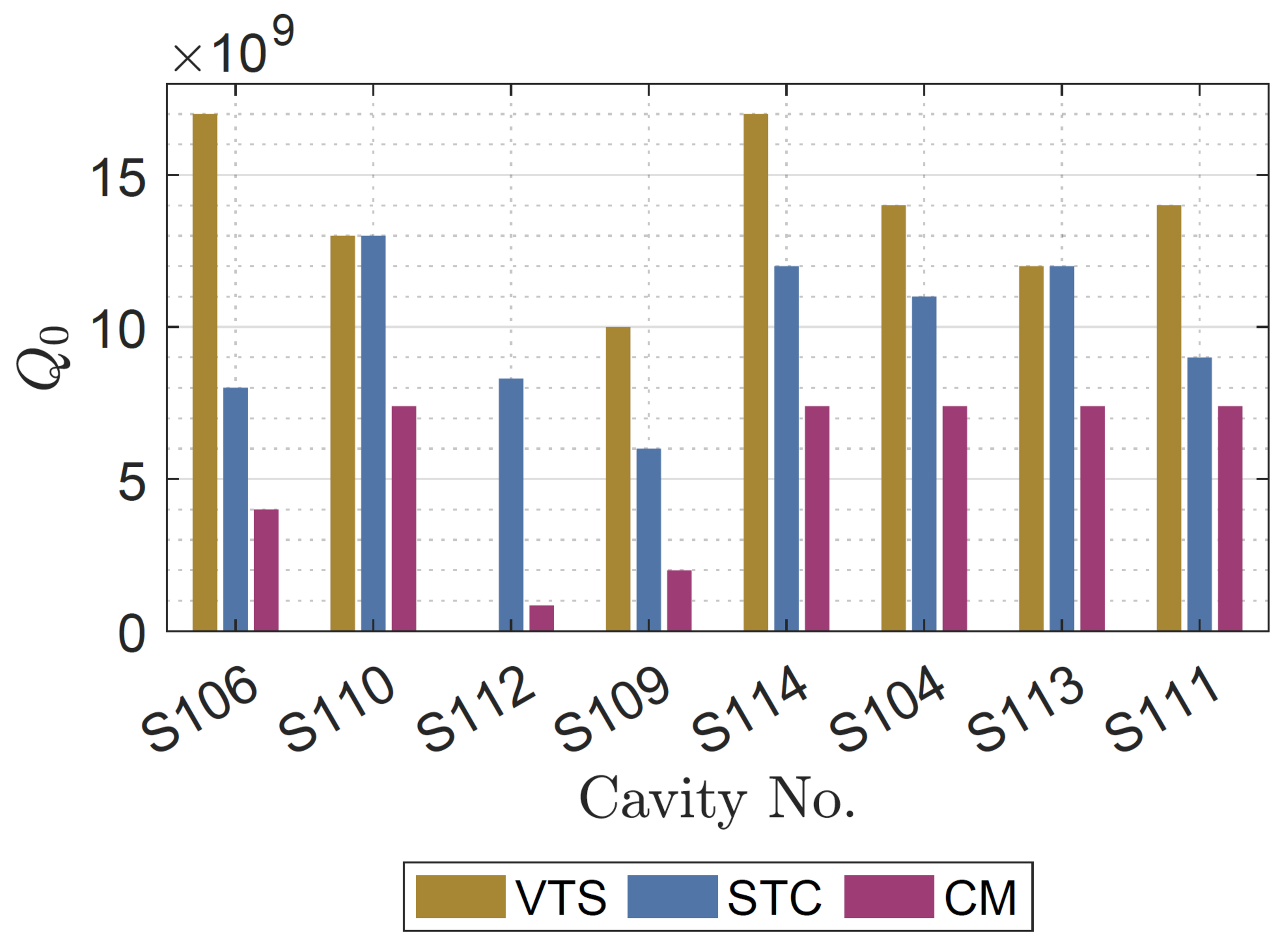
Abstract

A prototype cryomodule containing eight Single Spoke Resonators type-1 (SSR1) operating at 325 MHz and four superconducting focusing lenses has been successfully assembled and cold tested in the framework of PIP-II project at Fermilab. The impact of induced residual magnetic fields from solenoids on performance of cavities is presented in this contribution. In addition, design optimizations for the production cryomodules as a result of this impact are highlighted.

Performance of Cavities

The plot below reports comparison of the measured quality factor (Q_0) for the eight SSR1 cavities installed in the prototype module. The measurements were conducted in the Vertical Test Stand (VTS) where the cavities were tested as bare units in the VTS at an E_{acc} of 10 MV/m; in the Spoke Test Cryostat (STC) where the cavities were tested as jacketed units with high power couplers and tuners at an E_{acc} of 10 MV/m, and finally in the Cryomodule (CM) where the cavities were tested at the operating Phase-II gradients.

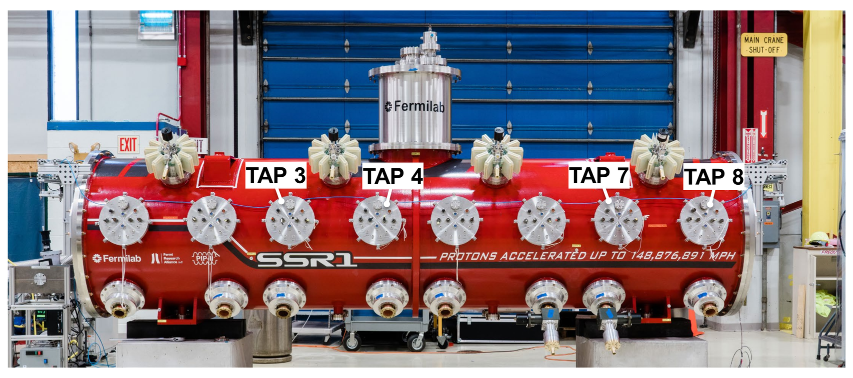


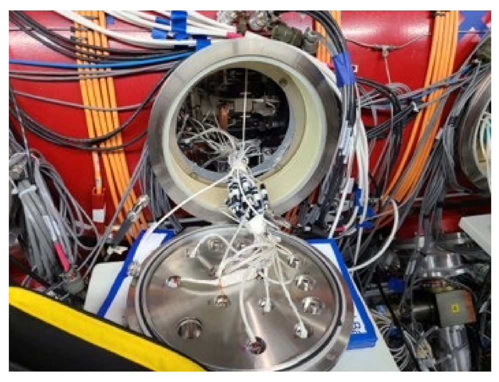
Eacc (VTS) 10 MV/m	Eacc (STC) 10 MV/m

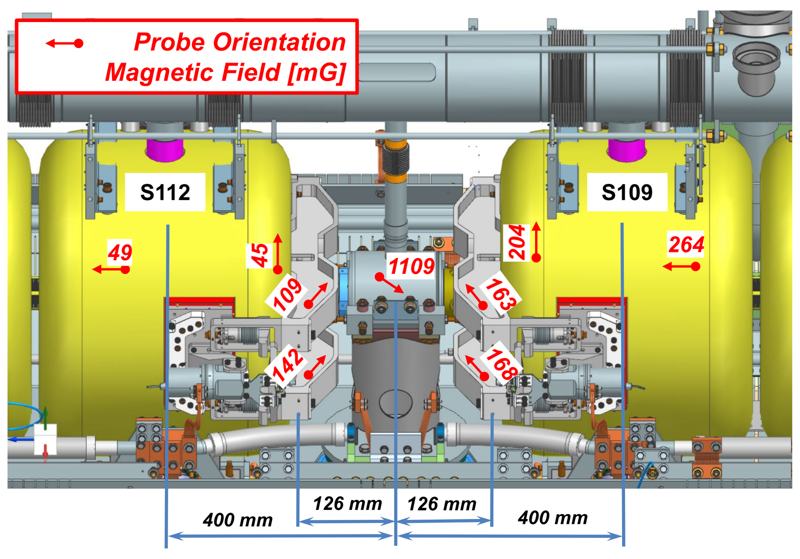
Eacc (CM) [MV/m]	S106	S110	S112	S109	S114	S104	S113	S111
	10	8.8	8.1	10	9.8	10	8.5	10

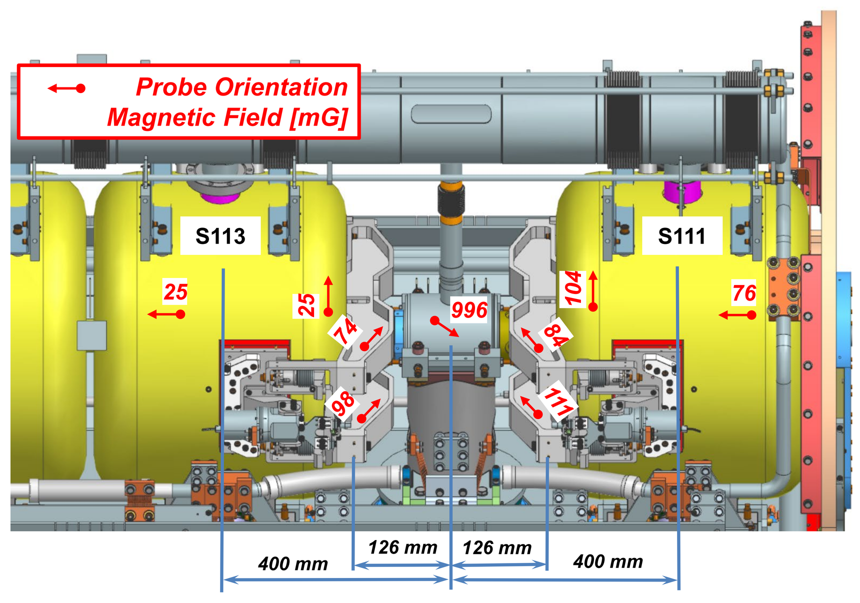
Sources of Q_0 Degradation

The additional degradation in Q_0 between STC and CM is primarily due to **high residual magnetic fields induced by the magnets** in the coldmass. Cavities S112 and S109 in the CM were also limit by radiation effects caused by **field emission.** The figures below report the measured residual magnetic field after Phase-II CM cold testing through tuner access ports (TAP) 3, 4, 7, and 8.









The trapped magnetic field (ΔB) was calculated for cavities with no field emission in the SSR1 cryomodule using the measured Q0 values in STC and CM, the G factor (84 Ω), and the sensitivity of surface resistance (Rs) to ambient magnetic field (0.05 nΩ/mG).

	S106	S110	S114	S104	S113	S111
$Q0_{STC}$	8E09	13E09	12E09	11E09	12E09	9E09
$Rs_{STC} = G/Q0_{STC}$ [nΩ]	10.5	6.46	7.00	7.63	7.00	9.33
$Q0_{CM}$	4E09	7.4E09	7.4E09	7.4E09	7.4E09	7.4E09
$Rs_{CM} = G/Q0_{CM}$ [nΩ]	21.0	11.3	11.3	11.3	11.3	11.3
$Rs_{CM} - Rs_{STC}$ [nΩ]	10.5	4.89	4.35	3.71	4.35	2.01
ΔB [mG]	210.0	97.8	87.0	74.3	87.0	40.4

Conclusions

The observed degradation in Q_0 highlights the importance of carefully evaluating and addressing the effects of jacketing, as well as the impact of the cryomodule environment, to maintain high-quality factor values for low beta cavities.

We learned that when an active source of magnetic field, such as a magnet, is located within the coldmass near the cavities, the global magnetic shield and magnetic hygiene practices aimed at attenuating the Earth's magnetic field and at reducing residual magnetic fields before component installation may not be sufficient to mitigate the impact on SRF cavities performance. Even if the cavities are low beta (0.22) spoke resonators operating at low frequency (325 MHz).

To avoid magnetization of coldmass components affecting the performance of SRF cavities in presence of magnets:

- Non-magnetic materials, such as titanium, aluminum, silicon bronze, shall be used to the greatest extent possible.
- Whenever the use of ferromagnetic materials cannot be avoided (i.e., piping, tuners), final parts shall have the lowest possible magnetic permeability (<1.02). 316L stainless steel or 316LN stainless steel may meet this requirement, however provision for annealing after welding and machining should be considered.
- A demagnetization procedure operating the magnet may be required to effectively remove the induced magnetization and its detrimental effects on cavity performance. The maximum residual magnetic field shall be less than 5 mG at zero distance.
- The design of local shielding may be considered for low beta and low frequency cavities to preserve their performance.

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