FERMILAB Nb_3Sn R&D PROGRAM *

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Abstract

A substantial program has been initiated at FNAL for R&D on Nb_3Sn coated cavities. Since early 2015, design, fabrication, and commissioning has been ongoing on a coating chamber, designed for deposition via vapor diffusion. The volume of the chamber will be large enough to accommodate not just R&D cavities, but full production-style cavities such as TeSLA 9-cells. In this contribution, we overview the development of the chamber and we introduce the program planned for the coming years. We discuss research paths that may yield increased maximum fields and reduced residual resistances as well as new applications that could be explored with larger coated cavities.

BACKGROUND

Nb_3Sn is a very promising alternative material to niobium for SRF cavities. Its predicted superheating field H_{sh} is approximately twice that of niobium [1], giving it the potential to offer up to double the accelerating gradients used in accelerators today. Because of its high critical temperature T_c, Nb_3Sn also can offer higher quality factors Q_0 as a function of temperature than niobium. In 1.3-1.5 GHz cavities, Q_0 of 2×10^{10} has been demonstrated at 4.2 K [2] and Q_0 of 10^{11} has been demonstrated at 2 K [3]. These qualities would make it possible to reduce the number of cavities necessary to reach a given energy, reduce the infrastructure required for a cryogenic system, and reduce the power consumption of the cryogenic system. The resulting decrease in costs would make it feasible to build large new accelerators to answer questions on the frontiers of modern physics and to operate small scale accelerators for industrial applications. These applications could include medical accelerators in hospitals, scanners for border security, transmutation devices for nuclear waste, and treatment plants for flue gas and wastewater.

Pioneering work was performed in the 1970s to 1990s at various labs to develop Nb_3Sn as an SRF material [4–10]. By the end of this period, very high Q_0-values had been observed in Nb_3Sn accelerator cavities at low fields, and peak surface magnetic fields of up to 80 mT were reported. However, strong Q-slope was observed in these cavities above 5 MV/m limited their utility in real applications [3]. Recently, additional development at Cornell led to an important performance advance: single cell 1.3 GHz cavities were produced that did not suffer from strong high field Q-slope, as shown in Fig. 1. They maintained Q_0 on the order of 10^{10} at 4.2 K out to quench fields as high as 70 mT [11].

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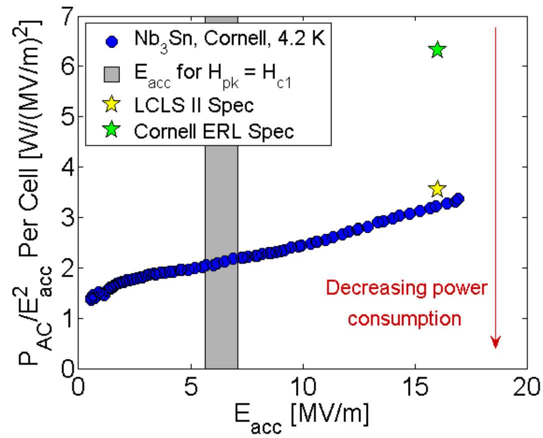

Figure 1: Recent promising results from a single cell 1.3 GHz Nb_3Sn cavity that exceeded the cryogenic efficiency and accelerating gradient specifications of LCLS II.

The proof of principle has been established: a Nb_3Sn cavity that met the cryogenic efficiency and accelerating gradient specifications of state the art high-Q_0 accelerator LCLS II [12]. Already this material is useful for industrial accelerators operating at 4.2 K. With additional development to find ways to further reduce residual resistance, Nb_3Sn could far outperform Nb for future high-Q_0 accelerators. With sustained development, preparation methods may be found that allow this material to significantly exceed the maximum fields obtained in niobium cavities.

To work towards realization of these possibilities, a substantial research and development program has begun at Fermilab on Nb_3Sn for SRF. With funding from the Laboratory Directed R&D (LDRD) program, the goals of the program include establishing Nb_3Sn fabrication facilities at Fermilab, material research and development, and coating of production-style cavities.

Nb_3Sn FACILITIES AT FERMILAB

A CAD model of the planned Nb_3Sn fabrication apparatus is shown in Fig. 2. A niobium coating chamber will be fabricated to hold the cavity and tin source, and an existing ultra-high-vacuum (UHV) furnace will be modified to host it. The coating chamber will be large enough to hold production-style cavities, including 9-cell TeSLA cavities and 650 MHz PIP-II cavities.

Having flexibility in cavity type to coat was planned when designing this coating chamber. Possible applications for Nb_3Sn cavities include a future multi-MW proton accelerator, the Future Circular Collider at CERN [13], an upgrade to the ILC, and industrial accelerators [14]. The chamber

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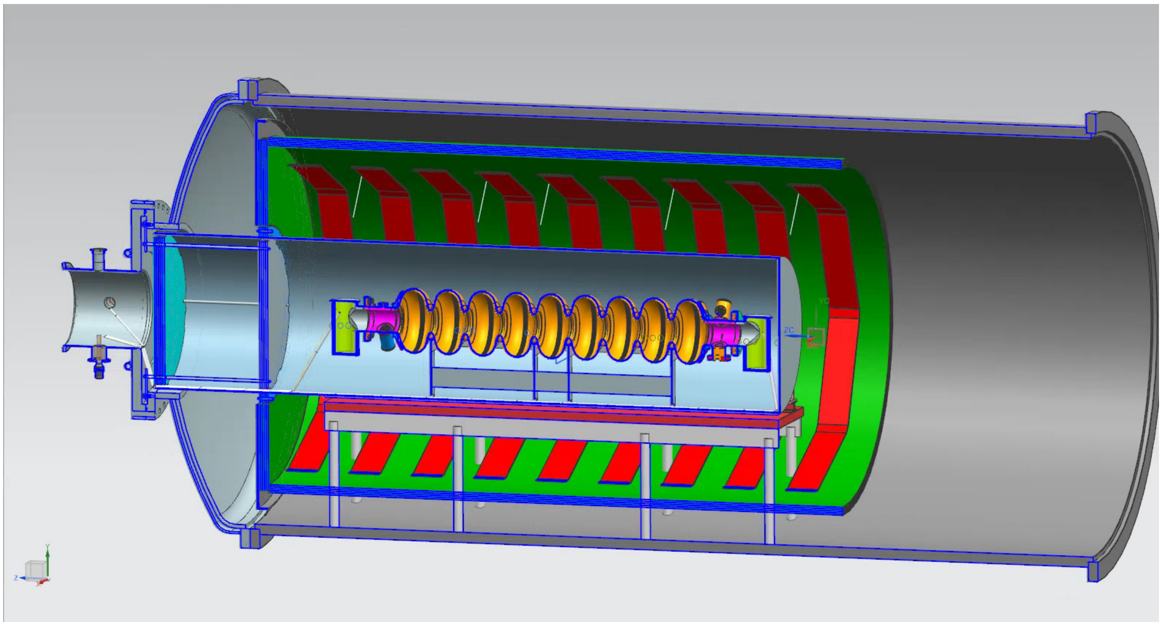

Figure 2: Design for Nb_3Sn fabrication apparatus at Fermilab. The niobium coating chamber will be large enough to accommodate 9-cell 1.3 GHz cavities or even 5-cell 650 MHz cavities. The chamber will sit inside an existing ultra-high-vacuum furnace.

was designed to accommodate large cavities for these applications.

MATERIAL STUDIES

While the cavity fabrication facilities are being established, material studies are being performed. In collaboration with Cornell, a Nb_3Sn cavity was tested at Fermilab with temperature map, identifying hot and cold regions and cutting them out. Results of microscopy studies are reported in [15, 16]. See Fig. 3 for sample images from the study.

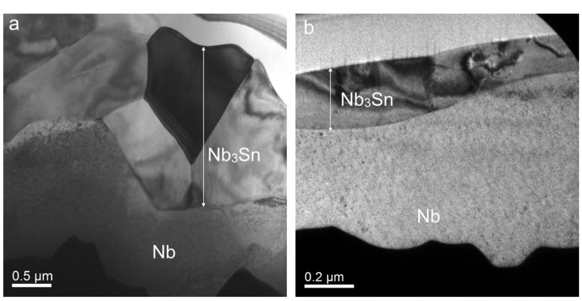

Figure 3: Transmission electron microscope image of cross-sections cut from a cold spot (left) and hot spot (right) of a poorly performing Nb_3Sn cavity. The hot spot shows a relatively thin layer of Nb-Sn alloy. The thin layer is not expected to be sufficient to screen RF fields with small surface resistance.

Areas of on which materials research will be focused include causes of quench and finding methods to avoid them and sources of residual resistance. The microscopy expertise and experience with niobium possessed by Fermilab researchers will be extremely beneficial when attempting to optimize the parameters used in the coating process.

OUTLOOK

The Nb_3Sn coating chamber is currently under procurement while the UHV furnace undergoes upgrades. Single cell cavities for the first coatings are also under procurement. Material investigations will continue in order to maximize the chance of success for future coatings.

ACKNOWLEDGEMENTS

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REFERENCES

[1] H. Padamsee, J. Knobloch, and T. Hays, *RF Superconductivity for Accelerators*, Wiley & Sons, New York, ISBN 0-471-15432-6, 1998.

[2] S. Posen and M. Liepe, *Phys. Rev. ST Accel. Beams*, 15, 112001 (2014).

[3] G. Müller et al., TESLA Report No. 2000-15, Hamburg, Germany (2000).

[4] B. Hillenbrand, H. Martens, H. Pfister, K. Schnitzke, and Y. Uzel, IEEE Trans. Magn. 13, 491 (1977).

[5] P. Kneisel, O. Stoltz, and J. Halbritter, *IEEE Trans. Magn.* 15, 21 (1979).

[6] M. Peiniger, G. Müller, H. Piel, and P. Thüns, in Proc. First Eur. Part. Accel. Conf. (Rome, Italy, 1988) pp. 1295-1297.

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[7] J. Stimmell, PhD Thesis, Cornell Univ., Ph.D. thesis, Cornell University, Ithaca, USA (1978).

[8] G. Müller, P. Kneisel, and D. Mansen, in Proc. Fifth Eur. Part. Accel. Conf. (Sitges, Spain, 1996).

[9] G. Arnolds-Mayer and E. Chiaveri, in Proc. Third Work. RF Supercond. (Chicago, USA, 1986).

[10] I. E. Campisi and Z. D. Farkas, in Proc. Second Work. RF Supercond. (Geneva, Switzerland, 1984).

[11] S. Posen, M. Liepe, and D. L. Hall, *App. Phys. Lett.*, 106, 082601 (2015).

[12] J. N. Galayda, in Proc. 5th Int. Particle Accel. Conf. (2014).

[13] E. Jensen, FCC Week 2015.

[14] B. Kephart et al., SRF 2015, Whistler, Canada, FRBA03.

[15] S. Posen et al., SRF 2015, Whistler, Canada, TUPB049.

[16] Y. Trenikhina et al., SRF 2015, Whistler, Canada, TUPB056.

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