(July 25, 2023)

In the manuscript "Improving Nb_3Sn Cavity Performance Using Centrifugal Barrel Polishing," the authors investigate the viability of centrifugal barrel polishing (CBP) as an innovative method for polishing Nb_3Sn cavities, achieving surface roughness comparable to that of Nb after traditional electropolishing (EP). The surface analysis employs confocal laser microscopy, SEM, and TEM. The results reveal a substantial improvement in Nb_3Sn SRF cavity performance when CBP is combined with a short, low-temperature Sn coating, making it a promising technique to enhance the performance of Nb_3Sn coated cavities. The manuscript could be suitable for publication if the author addresses the following points.

Comments

[Section I: Introduction]

1. 2nd paragraph, line 8. The authors should cite appropriate references for the superheating field of Nb_3Sn (not only Ref. [1] but also Refs. [A, B, C]), which would be very helpful for readers.
    - A) G. Catelani and J. P. Sethna, "Temperature dependence of the superheating field for superconductors in the high-κ London limit," Physical Review B 78, 224509 (2008).
    - B) F. P-J. Lin and A. Gurevich, "Effect of impurities on the superheating field of type-II superconductors," Physical Review B 85, 054513 (2012).
    - C) T. Kubo, "Superfluid flow in disordered superconductors with Dynes pair-breaking scattering: Depairing current, kinetic inductance, and superheating field," Physical Review Research 2, 033203 (2020).

    References [A, B, C] calculate the superheating field B_{sh} using BCS theory, which remains valid even at $T \ll T_c$. In Ref. [A], Catelani and Sethna consider the clean limit with $\kappa_{GL} \gg 1$, making it applicable to clean-limit Nb_3Sn. This is further detailed in the review article Ref. [1]. However, material may not always be in the clean limit, necessitating an understanding of impurity effects. Ref. [B], by Lin and Gurevich, also assumes $\kappa_{GL} \gg 1$ but accommodates arbitrary impurity concentrations. In Ref. [C], Kubo assumes the dirty limit and solves the Usadel equation. Notably, from Refs. [B, C], $B_{sh} = 0.8B_c$ at $T = 0$ for a dirty-limit material, independent of its clean-limit value of κ_{GL}.

2. 5th paragraph, line 1. The authors should consider citing relevant papers that discuss how roughness impacts performance, providing valuable insights for the readers. Some exemplary papers that could be cited include Refs. [D, E, F]. These citations will enhance the readers' understanding.
    - D) J. Knobloch, R. L. Geng, M. Liepe, and H. Padamsee, High-Field Q Slope in Superconducting Cavities Due to Magnetic Field Enhancement at Grain Boundaries, Proceedings of SRF1999, La Fonda Hotel, Santa Fe, New Mexico, USA (JACoW, CERN Geneva, 1999), p. 77.
    - E) T. Kubo, Magnetic field enhancement at a pit on the surface of a superconducting accelerating cavity, Progress of Theoretical and Experimental Physics vol. **2015**, 073G01 (2015).
    - F) C. Xu, C. E. Reece, and M. J. Kelley, Simulation of nonlinear superconducting rf losses derived from characteristic topography of etched and electropolished niobium surfaces, Physical Review Accelerators and Beams **19**, 033501 (2016).

3. 7th paragraph, line 1. The authors are encouraged to cite pertinent papers on CBP, including the

pioneering work [G], in addition to Ref. [8]. Properly referencing the relevant literature, especially the pioneering paper, will strengthen the credibility of the study.

G) T. Higuchi, K. Saito, S. Noguchi, M. Ono, E. Kako, T. Shishido, Y. Funahashi, H. Inoue, and T. Suzuki, Proceedings of SRF1995, Gif-sur-Yvette, France (JACoW, CERN Geneva, 1995), p. 723.

H) C. Cooper, K. Saito, B. Bullock, S. Joshi, and A. Palczewski, Proceedings of SRF2011, Chicago, IL, USA (JACoW, CERN Geneva, 2011), p. 571.

[Section II A: Centrifugal barrel polishing]

4. 1st paragraph, line 2. The authors need to revise the statement regarding the development of CBP. As documented in Cooper's paper [H], the pioneering work on CBP was carried out by Saito's group at KEK in 1995 [G]. Subsequently, around 2012, Cooper and Cooley made further advancements to CBP, achieving a mirror surface. It is essential for the authors to correct this sentence and cite the relevant papers [G, H] to accurately acknowledge the contributions of each group in the development of CBP.

5. It is crucial for the authors to provide detailed information about the operating parameters of CBP, including the rotating speed. Without this critical information, even if the same machine is used, it would be challenging for anyone to reproduce the authors' results accurately. Including these specific parameters in the study will ensure transparency and enable other researchers to replicate and validate the findings.

[Section II B: Coupon cavity]

6. The authors should acknowledge the pioneering work of the coupon cavity in their CBP study, a technique that was also initiated by Saito's group at KEK in 1995 [G]. In this method, small Nb samples were placed at the equator section of a cavity made of SUS (see Section 2.2 of Ref. [G]). Studying CBP using coupon cavities allowed for valuable insights, and acknowledging this earlier work will enhance the readers' understanding of the research's context and contributions.

[Section II C: Nb3Sn coating using Sn vapor-diffusion]

7. It is crucial for the authors to provide detailed information about the coating procedure, including the temperature profile of the coating furnace, akin to Figures 5 in Ref. [10]. This essential information is crucial for ensuring the reproducibility of the authors' results. Without such specifics, replicating the study accurately would prove to be challenging for other researchers. By including the temperature profile and other pertinent details, the authors will enhance the transparency and credibility of their work

[Section II D: Surface Analysis of Mechanically Polished Nb3Sn Coated Samples]

8. Figure 4 and Figure 5 are currently not referenced in the main text, and their significance is not explained. The authors should ensure to refer to Figures 4 and 5 in the main text and provide detailed explanations for these figures.

[Section III: Polishing a Nb3Sn cavity using CBP]

9. 1st paragraph, line 5. The authors should provide a comprehensive explanation for why utilizing alumina is favored over Si. While the authors already mention that alumina helps avoid Si contamination of the furnace, it is essential to clarify whether alumina has any adverse effects on the furnace. This clarification is particularly valuable for readers who are not experts in coating processes, as it sheds light on the significance of this choice.

[Section III A: Low temperature recoating procedure]

10. 2nd paragraph, line 5. The authors should provide clarity on whether using "one third of the normal

amount of Sn" in the recoating process is considered optimal. It would be beneficial for readers to understand if the recoating process has been optimized and if not, the authors can mention the areas that require further investigation or improvement. Addressing this point will add important insights to the study, giving readers a better understanding of the methodology and its potential for refinement.

[Section III C: Testing the polished Nb3Sn SRF cavity]

11. The authors should include relevant information about the Nb cavity below the Nb3Sn layer, such as the Residual Resistivity Ratio (RRR) of the Nb material, the thickness of the Nb cavity, and other pertinent parameters. These factors play a crucial role in influencing the performance of the Nb3Sn cavity, particularly concerning thermal resistance.

12. The authors should clarify if they have tested only one cavity in their study. If this is the case, they should emphasize this fact and underscore the need for further testing in the future. Conducting tests on a single cavity may limit the generalizability of the results, and it is crucial to acknowledge this limitation and highlight the importance of conducting more extensive testing to validate and broaden the study's findings. Emphasizing the necessity for additional testing will encourage further research in the field.

13. The authors should provide a more extensive discussion and interpretation of Figure 8. Specifically, they should address why the curve of the "recoated" cavity follows that of the "as-coated" cavity at 4.4 K but not at 2.0 K. This discrepancy warrants further explanation and analysis to help readers understand the underlying factors influencing the behavior observed in the graph.

[Section IV: Discussion]

14. 4th paragraph, line 2. After addressing several potential causes of performance degradation in the third paragraph, the authors introduce their speculation about the function of recoating, stating, "We theorize that the polishing step..." However, this speculation may not necessarily align with the aforementioned potential causes of performance degradation. To ensure coherence in the discussion, it is essential for the authors to clarify the relationship between their speculation and the identified causes, allowing readers to better understand the context and implications of the recoating process in mitigating performance issues.

[References]

15. To ensure the best readability for readers, especially those new to the topic, the authors should consider citing a more extensive selection of relevant papers. This will facilitate understanding for students who have recently joined the field, ensuring they can access all the necessary literature to grasp the article's background and contents correctly. In addition to Refs. [A, B, …, H], the authors are encouraged to include citations for all other pertinent papers that contribute to a comprehensive understanding of the subject matter.