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Nb_3Sn COATING OF TWIN AXIS CAVITY FOR ACCELERATOR APPLICATIONS*

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Abstract

A Superconducting twin axis cavity consisting of a modified cell with two identical beam pipes that can accelerate and decelerate beams within the same structure has been proposed for the Energy Recovery Linac (ERL) applications. Two niobium twin axis cavities fabricated at JLab are processed to deposit the Nb_3Sn layer inside using the vapor diffusion method for the first time. Nb_3Sn is a potential alternative material for replacing Nb in SRF cavities for better performance and reducing operational costs of the accelerators. Because of advanced geometry, larger surface area, increased number of ports and hard to reach areas of the twin axis cavities, the usual coating approach developed for typical elliptical single-axis cavities must be evaluated and requires to be adjusted. In this contribution, we report the first results from the coating of a twin axis cavity and discuss current challenges with an outlook for the future.

INTRODUCTION

The high-intensity Energy-Recovery Linac (ERL) is a promising technology for many applications in which a beam makes at least two transits through with one pass for accelerating a high-quality beam, and the other for decelerating the used beam to recover the beam energy [1]. Most of the ERL designs use standard TM010-type accelerating structures, in which beam must pass along the same accelerating axis and thus occupy the same transverse position. The idea of using two beam-axis structures to improve the performance of the ERL was first proposed by Noguchi and Kako in 2003 [2]. The similar concept was suggested again by Wang, Noonman and Lewellen in 2007 [1] with a proposal of Superconducting cavity with two equivalent but separate axes for accelerating and decelerating beams while energy recovery is still performed within the same physical cavity. Though the accelerated beam is physically separated from the parallel accelerated/decelerated beam, they interact with the same rf dipole mode [3].

Regardless the advantages, such multi axes cavities have never been built with the challenges of fabrication with the complex geometry. But as proposed by the Jefferson Lab (JLab) and optimized by Center for Accelerator Science (CAS) at Old Dominion University (ODU), two elliptical twin axes single cell cavities have fabricated [4]. These cavities are fabricated with the intention of later coating of a Nb_3Sn layer inside, which is a promising material to increase the qualityfactor of SRF cavities and therefore to reduce cost of accelerators with T_c close to 18 K and lower surface resistance [5]. This gives a lower dissipation than that of the niobium at the same temperature. Its superheating field of about 400 mT gives a higher breakdown field [6]. Many methods have been used to coat thin films on Niobium cavities, but here at Jefferson Lab, the vapor diffusion technique is being used to deposit Nb_3Sn thin layers on SRF cavities. Although there are several basic cavity models coated and tested at their specific frequencies using this method, it has not yet applied to coat the cavities with complex geometries like twin axis cavity. This paper discusses the recent Nb_3Sn coating of twin axis cavity at Jefferson Lab.

JLAB/ODU TWIN AXIS CAVITY

The new cavity designed by ODU CAS , was optimized to minimize the peak RF surface fields while providing the same longitudinal electric field profile in both beam tubes by operating in the TM110 rf dipole mode with 1497 MHz frequency [4] using the CST Microwave Studio (Fig. 1). The design was further optimized to eliminate multipacting using Track3P code in SLAC ACE3P suite simulations [3]. The cavity design also provided a relatively strong cell-to-cell coupling so that several cells can be joined together for a multiple cell cavity design [4].

Figure 1: Twin axis cavity model (top) and electric (left) and magnetic (right) field profile at the twin cavity cross section (bottom) from CST microwave studio [3].

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Making the cavity compatible with the Jefferson lab Nb_3Sn deposition system was also a goal of the mechanical design. Since the deposition chamber allows only niobium inside the furnace, cavity flanges were made of niobium instead of typical niobium titanium [7]. Figure 2 shows one of the completed cavities.

Figure 2: Twin axis cavity #1.

Table 1: Cavity Parameters and RF Properties of the Fabricated 1497 MHz Twin Axis Cavity #1 [4]

Parameter	Value	Unit
Cavity height	202.5	mm
Cavity width	300.0	mm
Cavity length	100.13	mm
Beam aperture	60.0	mm
Beam axis seperation	136.5	mm
E_p / E_{acc}	2.68	-
B_p / E_{acc}	5.5	mT/(MV/m)
[R/Q]	60.1	Ω
Geometric factor, G	320.8	Ω

RF test results of the twin axis cavities are given in the Fig. 3. Cavity #2 has reached an accelerating/decelerating gradient of 23 MV/m with a maximum quality factor of 1.2×10^{10} in the low field regime while the cavity #1 quenched around 7 MV/m due to weld defects at the equator [4].

Figure 3: RF test results of the twin axis cavities[4].

CAVITY DEPOSITION SYSTEM AT JLAB

The Nb_3Sn deposition system at JLAB as shown in Fig. 4, contains two main parts: the coating chamber that hosts a cavity to be coated and the furnace that provides the desired heating to the coating chamber [5].

Figure 4: A sketch of the Jlab Nb3Sn coating system with a 5-cell cavity [8].

Figure 5 shows the typical coating process at JLab consists of a nucleation step that involves the tin chloride evaporation at 500 °C for 1-hour. Nucleation is followed by a deposition step which involves the evaporation of tin for 3-hours at 1200 °C, which is favorable to form Nb_3Sn phase on substrate niobium [9].

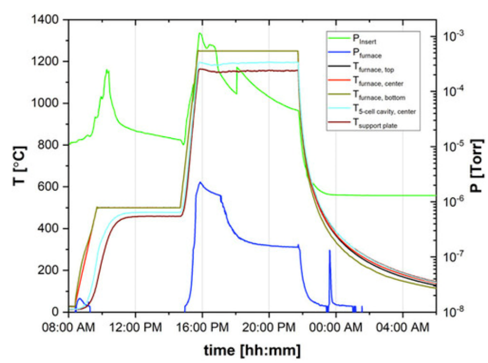

Figure 5: The temperature profile used for coating Nb cavities at Jlab [10].

COATING OF TWIN AXIS CAVITY #1

At JLab, typical procedure to coat cavity involves only one tin source, which is placed at the bottom of the cavity. But with its advanced geometry with hard to reach areas, larger surface area and increased number of ports, the usual coating approach developed for typical elliptical single-axis cavities required to be adjusted. It could result non-uniform coating inside the cavity caused by low tin flux coming from a single tin source [6]. Therefore, a new tin source was introduced which will be from the other port so that enough tin vapor is allowed to flow in to the both sides of the cavity equally.

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We planned to coat the twin axis cavity #1 (cavity with limited rf performance due to the weld defects) to optimize the coating parameters and then to use well informed set of parameters to coat the cavity #2, which does not have weld defects.

Cavity flanges were soaked with nitric acid to remove any leftover indium from the previous assembly and then followed by ultrasonic degreasing. Cavity was then setup for the coating as in the Fig. 6. We used 1.5 g of Sn and 0.5 g of $SnCl_2$ on each tin sources. Here the Sn and $SnCl_2$ amounts were selected from the previous coatings to avoid patchy regions and Sn residue and devided equally among the two tin sources. Witness samples were also placed inside to evaluate the coating after the process.

Figure 6: Twin cavity #1 setup for coating (top) and tin sources (bottom).

Cavity setup was then inserted into the furnace. After the pump down the usual temperature profile in Fig. 5 was followed for the coating.

Coating Evaluation

After the cavity is cooled down the cavity is taken from the system and the coating is evaluated before the rf test. The cavity is coated uniformly with consuming almost all the tin that we placed. There were no any visible tin spots on the cavity coating (Fig. 7).

Figure 7: Inside the twin axis cavity #1 before (left) and after the coating (right).

The SEM and the AFM is used to further analyze of the samples. We could not see any patchy regions from the SEM images (Fig. 8) and the EDS data provided that the Nb to Sn atomic ratio of 75.14% to 24.86%. We could identify some tin residue on the sample from the AFM images (Fig. 9).

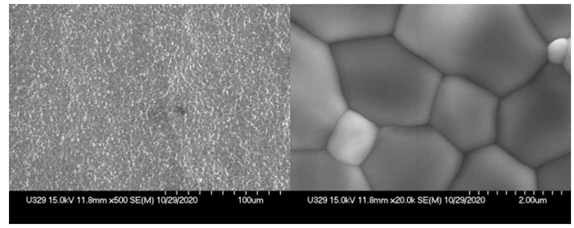

Figure 8: SEM images of the coated samples.

Figure 9: AFM analysis of the coated samples.

RF Testing

Cavity is processed to rf testing.Unfortunately the cavity is deformed after pumping down.Heating up to 1200 ˚C might have soften the material. And this deformation limited the rf performences of the coated cavity compared to the bulk niobium cavity (Fig. 10).

Figure 10: Q curve from the rf testing.

SUMMARY AND FUTURE PLANS

We coated the twin axis cavity with a complex geometry, which is proposed for ERL applications with Nb_3Sn for the first time at JLab. We could produce a uniform coating with two tin sources but the cavity is deformed after pumping down.We introduced new hardware to prevent such mechanical deformations in the future. We are planing to coat the second cavity with well informed set of parameters shortly.

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REFERENCES

[1] C. Wang, J. Noonan, and J. Lewellen, "Dual-Axis Energy Recovery Linac", in *Proc. 41st Advanced ICFA Beam Dynamics Workshop on Energy Recovery Linacs (ERL'07)*, Daresbury, UK, May 2007, paper 18, pp. 122-125.

[2] S. Noguchi and E. Kako, "Multi-Beam Accelerating structures", in *Proc. 11th Workshop on RF-Supercunductivity,* Lubeck*,* Germany, Sep. 2003, paper TUP16, pp. 317-319.

[3] S. U. De Silva, J. Delayen, A. Hutton, F. Marhauser, and H. Park, "Electromagnetic Design of a Superconducting Twin Axis Cavity", in *Proc. 28th Linear Accelerator Conf. (LINAC'16),* East Lansing, MI, USA, Sep. 2016, pp. 203-205. doi:10.18429/JACoW-LINAC2016-MOPLR030

[4] H. Park, S. U. De Silva, J. Delayen, A. Hutton, and F. Marhauser, "First test results of Superconducting Twin axis cavity for ERL applications", in *Proc. 29th Linear Accelerator Conf. (LINAC'18),* Beijing, China, Sep. 2018, pp. 398-401. doi:10.18429/JACoW-LINAC2018-TUP0032

[5] G. Eremeev, W. Clemens, K. Macha, H. Park, and R. Williams, "Commissioning of Nb_3Sn cavity vapor diffusion deposition system at JLAB", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 3512-3514. doi:10.18429/JACoW-IPAC2015-WEPW1011

[6] J. K. Tiskumara, H. Park, J. R. Delayen, G. Eremeev, and U. Pudasaini, "Development of a secondary Sn source for Nb_3SN coating of half-wave coaxial resonator", in *Proc. North American Particle Accelerator Conf. (NAPAC'19),* East Lansing, MI, USA, Sep. 2019, pp. 735-738. doi:10.18429/JACoW-NAPAC2019-WEPLM63

[7] H. Park, A. Hutton, F. Marhauser, S. U. De Silva, and J. R. Delayen, "Development of a Superconducting Twin Axis Cavity", in *Proc. 28th Linear Accelerator Conf. (LINAC'16)*, East Lansing, MI, USA, Sep. 2016, pp. 932-935. doi:10.18429/JACoW-LINAC2016-THPLR037

[8] U. Pudasaini *et al.*, "Nb3Sn Multicell Cavity Coating at JLab", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 1798-1803. doi:10.18429/JACoW-IPAC2018-WEYGBF3

[9] U. Pudasaini, M. J. Kelley, G. V. Eremeev, C. E. Reece, and J. Tuggle, "Insights into Formation of Nb3Sn Film During the Vapor Diffusion Process", in *Proc. 18th Int. Conf. RF Superconductivity (SRF'17)*, Lanzhou, China, Jul. 2017, pp. 539-542. doi:10.18429doi:10.18429/JACoW-SRF2017-TUPB067

[10] G. Eremeev *et al.*,"Nb_3Sn multicell cavity coating system at Jefferson Lab", *Rev. Sci. Instrum.*, vol. 91, p. 073911, 2020. doi:10.1063/1.5144490