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DEVELOPMENT OF A SECONDARY Sn SOURCE FOR Nb_3Sn COATING OF HALF-WAVE COAXIAL RESONATOR*

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Abstract

Superconducting thin films have the potential of reducing the cost of particle accelerators. Among the potential materials, Nb_3Sn has a higher critical temperature and higher critical field compared to niobium. Sn vapor diffusion method is the preferred technique to coat niobium cavities.

Although there are several thin-film-coated basic cavity models that are tested at their specific frequencies, the Half-wave resonator could provide us data across frequencies of interest for particle accelerators. With its advanced geometry, increased area, increased number of ports and hard to reach areas, the half-wave resonator needs a different coating approach, in particular, a development of a secondary Sn source. We are commissioning a secondary Sn source in the coating system and expand the current coating system at JLab to coat complex cavity models.

INTRODUCTION

In the field of Accelerator science, most of the superconducting cavities are made out of bulk Niobium. For reduced cost and increased quality factor, thin-film coated cavities are investigated in modern research. Not only the niobium thin film, but also other substances as magnesium diboride, niobium nitride, and niobium-tin are also used in the experiments. Among these, Nb_3Sn has shown the promising T_c close to 18 K. [1]. 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.

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. The technique has been used since the 70's. Although there are several basic cavity models are coated and tested at their specific frequencies using this method, it has not yet applied to coat the cavities with complex geometries with hard to reach areas, increased area with more number of ports.

Half-wave resonator is one of such a complex cavity, which could provide us data across frequencies of interest for particle accelerators [2] and at the same time it is an investigation of coating Nb3Sn on complex geometries.But with its differences from the basic cavity models, the current coating system, which is initially designed for basic cavity types, needed some modifications. An addition of a secondary Sn-source with an independent heater to control its temperature is realized to be the primary modification needed to coat a half-wave resonator. This is expected to supply higher vapor pressure of tin during the coating, along with primary Sn-source, in order to deposit a uniform coating. This paper discusses the development of the secondary Sn source for Nb3Sn coating of Half-wave coaxial resonator at Jefferson Lab.

CAVITY DEPOSITION SYSTEM AT JLAB

The Nb_3Sn deposition system at JLAB as shown in Fig. 1, 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 [1]. The coating chamber was built out of niobium as a 40" long x 16" diameter cylinder, and the furnace is commissioned to reach 1250 ^{0}C with the furnace vacuum in 10^{-7} Torr range.

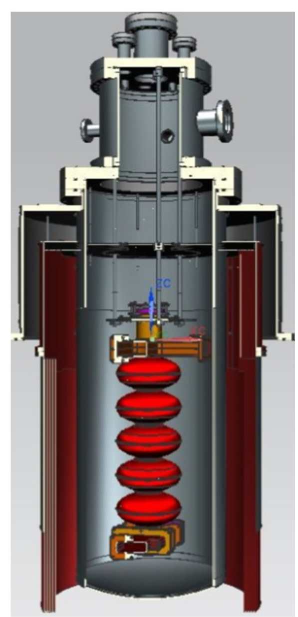

Figure 1: A sketch of the Jlab Nb3Sn coating system with a 5-cell cavity [3].

Figure 2 shows the typical coating process at JLab consists of a nucleation step that involves the tin chloride evaporation at 500 ^{0}C for 1-hour. Nucleation is followed by a deposition step which involves the evaporation of tin for 3-hours at 1200 ^{0}C, which is favorable to form Nb_3Sn phase on substrate niobium [4].

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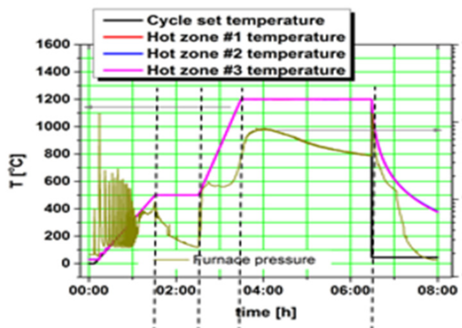

Figure 2: The temperature profile used for coating Nb cavities at Jlab [5].

HALF WAVE CAVITY

The half-wave cavity will allow the measurements of the temperature, RF field, surface preparation dependence of the surface resistance over a wide range of frequency along with its mechanical compatibility with various cavity treatments [2]. The Old Dominion University (ODU), Center for Accelerator Science (CAS) is currently developing another half-wave cavity that could provide data at a frequency range of 325MHz to 1.3GHz. Cavity parameters are shown in the Table 1. We plan to coat this cavity with Nb_3Sn.

Table 1: Cavity Parameters (CST Microwave Studio)

Parameter	Unit	Value
Cavity length	mm	459
Outer conductor radius	mm	111
Inner conductor radius	mm	20
Peak electric field, $E_p{}^*$	MV/m	15.6
Peak magnetic field, $B_p{}^*$	mT	56
TEM1, TEM2, TEM3, TEM4 frequencies	MHz	327.1,654.3, 981.4,1308.3#
Geometric factor, G	Ohm	61,123,185,247#

* For 1J energy content
\# For the TEM modes respectively

Electromagnetic design and cavity parameters

A half-wave cavity is a cylindrical-coaxial resonator which has TEM modes other than TE and TM modes. The high surface magnetic field is concentrated on the inner cylinder as appeared in the Fig. 3. The cylindrical-coaxial geometry allows analytical solutions to Maxwell's equations as;

$$\boldsymbol{E}_T = \hat{r}\,\frac{V_0}{ln\left(\frac{b}{a}\right)}\,\frac{1}{r}\,sin\left(\frac{n\pi z}{L}\right)e^{-i\left(\omega t-\frac{\pi}{2}\right)} \quad (1)$$

$$\boldsymbol{H}_T = \hat{\varphi}\,\frac{V_0}{ln\left(\frac{b}{a}\right)}\,\frac{1}{r}\sqrt{\frac{\varepsilon_0}{\mu_0}}\,cos\left(\frac{n\pi z}{L}\right)e^{-i\omega t} \quad (2)$$

where a is the radius of the inner cylinder, b is the radius of the outer cylinder, V_0 is the peak voltage at the inner conductor, and ω is the RF frequency.

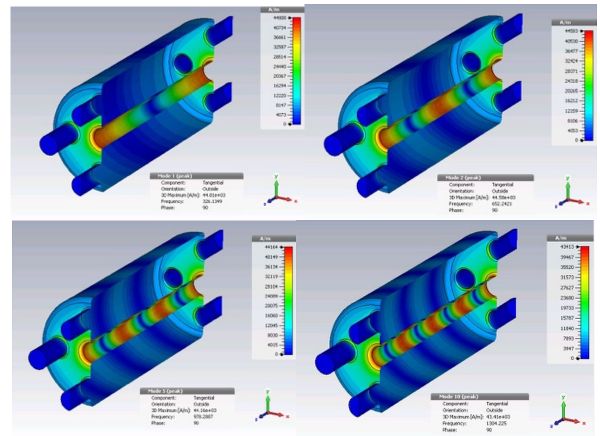

Figure 3: Surface magnetic field distribution from CST Microwave studio (from top left to right TEM1, TEM2, and bottom left to right TEM3, TEM4).

Fabrication

Half wave resonator is fabricated with 1/8" thick high RRR niobium sheets. Figure 4 shows the completed cavity and the center conductor assembly before welding the outer conductor. It is ready for the HPR and then progresses to the baseline test.

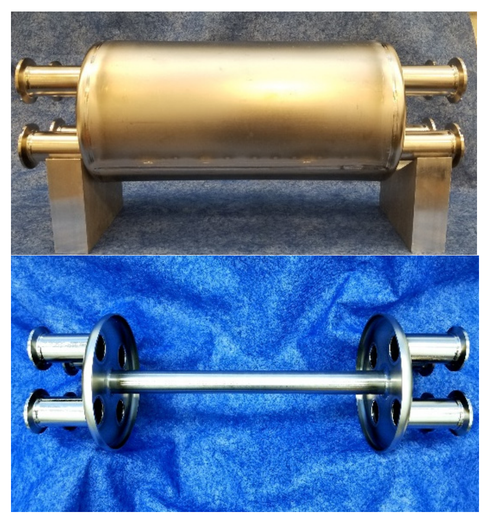

Figure 4: Complete half-wave coaxial resonator [top] and the inner conductor subassembly [bottom].

SECONDARY TIN SOURCE

A typical procedure to coat cavity involves only one Sn source, which is placed at the bottom of the cavity. The temperature of the cavity and the Sn-source remains same through out the coating process. This sometimes results in non-uniform coating inside a cavity, especially in multi-cell cavities with larger surface areas.The non-uniformity is believed to be caused by a low tin flux away from the tin source. Therefore, a new crucible was designed to host a secondary Sn source, which will be placed on top of the

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cavity. Secondary Sn source will heat from a newly introduced secondary heater (Fig. 5). The secondary heater allows the new tin source to be held at a temperature higher than that of the cavity, which can control the tin flux reaching to the cavity surface adjusting the formation rate of Nb_3Sn [6]

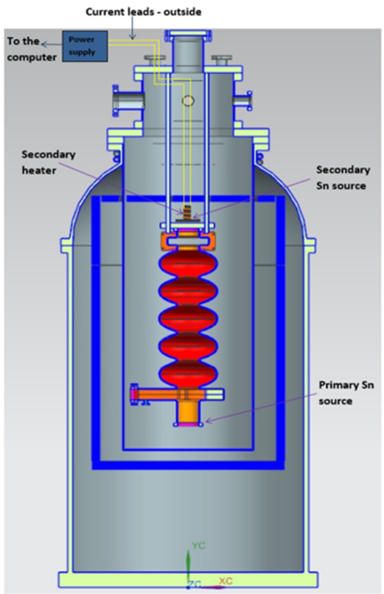

Figure 5: Cavity coating system model with the secondary Sn source and the heater

The crucible to host the secondary tin source is built with niobium (2.5” outer diameter). Sn and $SnCl_2$ are placed in the space between the two tubes allowing the vapor to flow through the inner tube (Fig. 6).The secondary heater was procured from HeatWave Labs, Inc. California according to our design. It is made out of Molybdenum coil leads, insulated with fish spine beads.

Figure 6: Secondary Sn source and the heater

The setup of secondary tin source and the secondary heater was tested with TE1NS001 single cell cavity after assembled as in Fig. 7. The same heating profile for the furnace was followed with the secondary heater, which was powered manually with the power supply. The heater power was ramp up by increasing the power supply voltage in steps of 5 V up to 25 V (maximum) following the furnace temperature. The voltage was increased to its maximum, and parked there for 2 hours. Figure 8 displays the temperatures of the cavity and the secondary heater. The voltage was then ramped down gradually, and the system was allowed to cool down. (Voltage and the current values was made sure no to exceed the design parameters, of 25 V and 40 A).

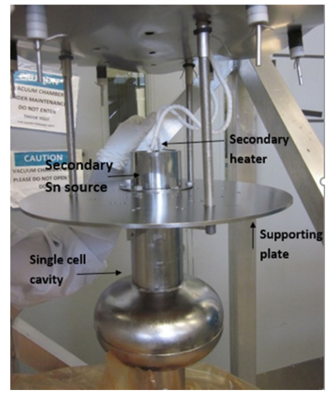

Figure 7: TE1NS001 single cell assembly with the secondary Sn source and the heater

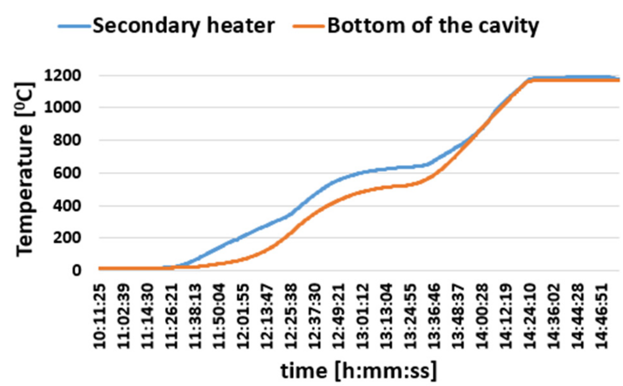

Figure 8: Heat profile for testing the secondary heater with the secondary Sn source (with the TE1NS001 single cell)

SUMMARY AND FUTURE PLANS

We plan to coat a half-wave coaxial cavity with Nb3Sn for the first time at JLab. The half-wave cavity to be coated with Nb3Sn is at the finishing stage prior to the base line test. We have designed and fabricated a new crucible to host the secondary tin source, which we believe will help to produce a uniform coating inside a cavity with complicated geometry. The secondary Sn source and the heater have been commissioned with a single-cell cavity. We plan to coat a half-wave cavity within the next few months.

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