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VIRTUAL WELDING AS A TOOL FOR SUPERCONDUCTING CAVITY COARSE TUNING *

A. Facco[1,2], C. Compton[1], J. Popielarski[1], G. J. Velianoff[1]
[1] Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI 48824, USA
[2] Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Legnaro, Padova, Italy

Abstract

Reaching the final frequency in the construction of Superconducting Half-Wave Resonators (HWR), either coaxial or spoke, is often a painful and time consuming process which requires several intermediate frequency tests and parts machining between subsequent welding steps. In spite of that, the final frequency error after final welding is often far from the target due to difficult to predict material contraction and cavity deformation induced by electron beam welding (EBW). Final coarse tuning is required by plastic deformation or differential etching. In coaxial HWR, both can decrease the cavity frequency but are not easily suitable to increase it. A novel method developed at MSU is “virtual” welding, i.e. deformation of the cavity shape by applying systematically EBW on the cavity outer surface to induce controlled Nb material contraction in strategic positions. This technique allows to increase the cavity frequency with excellent precision and predictability, thus simplifying and making less expensive and more reliable HWR coarse tuning. Method and experimental results will be described and discussed.

INTRODUCTION

Superconducting Half-Wave Resonators (HWR), in their coaxial and spoke versions, after being confined for decades in the R&D environment, have been recently used in a real accelerator [1] and are becoming fundamental components of large proton and ion linear accelerators under construction or planned [2]. These low- and medium-β resonators are closed cavities with relatively small apertures and their frequency is mostly determined by the length of their inner conductor. A common problem is the difficulty of building them with the right frequency, because it is not always easy to predict contraction of the Niobium material and thus the final cavity size after welding together its different parts. Coarse tuning of HWR cavities requires intermediate frequency measurements and length adjustments throughout the welding procedure. A large fine tuning range of the mechanical tuner is usually required to compensate for possible errors.

A typical problem is the difficulty of correcting the center frequency after the cavity is completely welded and closed. Two main methods are used, both well suitable for lowering the frequency:

1) Plastic deformation. It is often used in the beam port region for coarse tuning, but its application in HWRs is not always easy due to their structural stiffness and, for large frequency corrections, it can be dangerous for cavity mechanical integrity. Corrections are not very precise, nor smooth: initial elastic response is followed by a sudden adjustment to a new frequency, and the risk of going beyond the desired point is not negligible. Moreover, while it is easy to plastically push the beams ports in and lower the frequency, in HWRs it is rather difficult to pull them out safely to obtain the opposite effect.

2) Differential etching. Material from the rf surface inside the resonator is removed selectively by Chemical Polishing (CP). This is routinely applied since several years in QWRs [3][4], where it is possible to remove material either in the high B or in the high E region, causing frequency decrease or increase, respectively. It is easy to realize that in HWRs differential etching can be used without difficulty only to remove material from the end (shorting) plates, making the resonator longer and its frequency lower, while it seems almost impossible to increase the frequency by removing material only from the high E region near the beam port axis. So, at present, frequency corrections in closed HWRs are safely feasible only in the down direction, making final coarse tuning somehow difficult and time consuming.

TUNING BY VIRTUAL WELDING

In the original FRIB HWR construction plan, the beam ports were the last parts welded and their position was adjusted to reach the final goal frequency. We soon realized, however, that the mechanical contraction caused by such difficult full penetration weld from outside was moving the beam ports far from the initially planned position, and that a large and rather unpredictable frequency error was finally left. This method was then abandoned: the beam ports are now safely welded to the outer conductor from inside, at an early stage. Coarse tuning is made by adjusting the inner and outer conductor length before welding them to the shorting plates. Due to material contraction, however, this procedure is still leaving a large uncertainty on final frequency of several hundreds of kHz. It became clear that a good coarse tuning sequence required also a viable method to increase the final frequency.

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Virtual Welding Technique

In the FRIB project [5] more than 200, 322 MHz HWRs with β_0=0.29 and 0.53 are being built and a more reliable way to reach the final frequency was needed to reduce risk and construction cost. For this reason we developed a novel technique, nicknamed "virtual welding" (VW), which allows controlled shortening – thus also frequency increase - of the final cavity before installation of the Helium vessel. This technique consists of selectively heating up to melting temperature, by means of an electron beam, lines strategically located along the cavity outer surface, typically along the outer conductor circumference. This induces mechanical contraction, as it happens in normal electron beam welding, but being applied on an intact surface the beam power can be adjusted to obtain predictable shortening and frequency change.

Our standard virtual welding procedure includes drawing VW rings on the outer conductor starting right below the shorting plate weld. One or more rings at the typical EBW beam power can be applied at about 1 cm distance from each other, symmetrically on the two sides of the cavity, until a frequency close to the final one is reached. In order to avoid excess of stresses, if needed, VW can be applied on the inner conductor too. For final fine tuning, rings at a lower beam power, giving less contraction and consequently lower frequency change, are used.

Figure 1: Virtual Welding rings in FRIB β=0.29 (left) and β=0.53 HWR prototypes, before He vessel installation.

Experimental Results

We have tested this method in β=0.29 and β=0.53 prototype HWR cavities (Fig. 1), with OC wall thickness of 2 and 3 mm, respectively. VW rings at different beam power were made, and final contractions and frequency shifts were measured. The maximum applicable power was the one used for standard, full penetration EBW between shorting plate and outer conductor. This beam power is known to guarantee melting through the all Nb thickness while preserving good quality of the inner surface. Contraction at maximum power was found to be about 0.4 mm, resulting in about 140 KHz frequency increase per ring (See Table 1).

Table 1: Frequency Shift and Mechanical Contraction per Virtual Welding Ring at Maximum Beam Power, Measured in a FRIB HWRs

Cavity	**β=0.29**	**β=0.53**
Δf (kHz)	137	138
Δy (mm)	0.3	0.4
Wall thickness (mm)	2	3
Beam power (W)	2000	3679

Contraction and frequency change appeared to be rather proportional to the deposited beam power density, with an offset determined by the fact that melting, below a minimum power value, interests only a small part of the wall thickness and no contraction appears. No predictable effect was observed below the power which gave 30 kHz frequency change (Fig. 2).

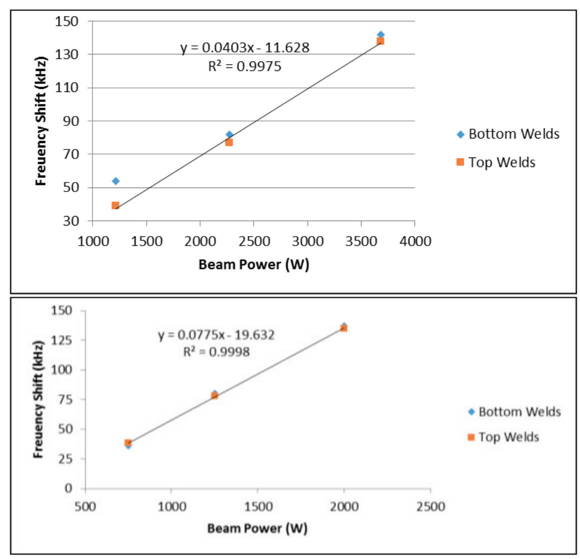

Figure 2. Frequency vs. EB power plot.

The linearity and predictability of the technique prompted us to use it for the FRIB production cavities. Conversely, longitudinal VW line on the beam port sides are expected to pull beam ports toward the inner conductor and decrease the frequency (this is part of our future development). Thus VW can be used to correct frequency errors in both directions, as a smoother alternative to plastic deformation.

RF Surface Quality After VW

Since the maximum electron beam power for VW is the same optimized one used for critical full penetration welds in high rf current areas of the cavity, and since VW is applied on an integer surface with no possible misalignment or bad contact between two margins to be welded, the quality of the inner rf surface after VW is excellent. This makes the contraction of VW safer and much more reproducible than the one of standard EBW used in cavity construction.

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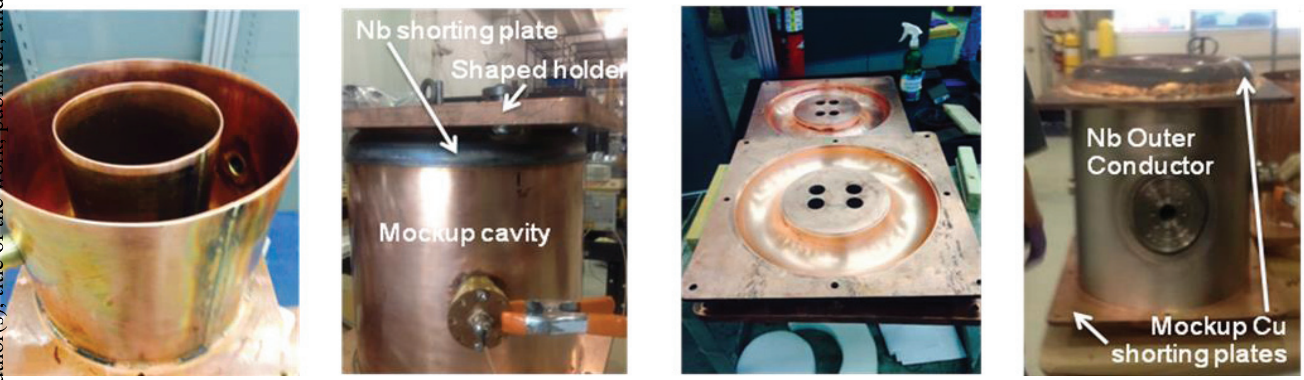

Figure 3: Mock-up cavities and stack up assemblies for FRIB HWRs coarse tuning.

RENEWED PROCEDURE FOR FRIB HWRS COARSE TUNING

Determining the right dimensions of the cavity parts to be welded is made by stack up measurements of the frequency. The goal frequency must take into account the Nb contraction after welding. A problem, in this procedure with many parts, is the difficulty of making all contacts good rf contacts: this requires somehow complicated tools to hold the part aligned and under pressure, and long preparation time. To speed this up we decided to build our cavities by welding together only four pre-assembled, built-to-print parts: the inner conductor, the outer conductor, and two equal shorting plate assemblies (Fig. 3). All parts are finished with all flanges and ports to reduce risk of flawing rf contacts. Frequency measurements before welding allow trimming IC and OC to final length. The dimensions of single Nb shorting plate assemblies are controlled by checking their rf shape on a mock-up copper cavity without one shorting plate, and measuring the frequency of the system. Similarly, the IC and OC length is verified by measuring the frequency of a stack up made of IC, OC and two dummy SP made of copper. This technique allows precise and reproducible measurements of the stack up and a considerably simpler test set-up. The conductors are kept slightly longer in order to guarantee that, after welding, the cavity frequency will not exceed the final target. After carefully measuring the frequency deficit, virtual welding power and number of rings can be calculated by means of calibration tables (Table 1), and VW can be applied. The method until now resulted in a very precise tuning of pre-production HWRs within a few kHz.

VIRTUAL TIG

Further departure from the target frequency is caused by assembly of the He vessel on the cavity, which in FRIB HWRs is made of Ti and usually causes unpredictable frequency increase. The final tuning step is then virtual TIG (Tungsten Inert Gas) welding on the vessel itself. Lines drawn longitudinally on the cylindrical part of the Ti vessel cause inward displacement of the beam ports, resulting in frequency decrease which can be adjusted by varying the number and length of the lines and the deposited power. In a β=0.53 HWR two, 10” long VTIG lines on the side of one beam port we measured $\Delta f \cong -61$ kHz, and $\Delta f \cong -130$ kHz in total after doing the same at the second beam port. Δf can be easily monitored during welding operation, making VTIG rather precise and suitable for very fine final adjustments.

CONCLUSION

Virtual welding (both with electron beam and TIG techniques) was developed at FRIB-MSU for final HWR tuning. These methods give precise and reproducible frequency changes in both positive and negative directions, providing an excellent tool for HWR final coarse tuning. This technique was transferred to FRIB cavity vendors, reducing the risk on final cavity frequency and reducing the number of intermediate tuning steps and the overall cost of the tuning procedure.

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