FROM MULTISTUB RESONATORS TO INTERMODULATION MEASUREMENTS: SRF ACTIVITIES AT ANU IN 2005-2007

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Abstract

The design of a 150 MHz λ/4, 3- and 4- gap structures with two and three loading elements, for the velocity range $\beta = 0.015 - 0.12$ has been accomplished. Rotary and displacement tuners are developed for multi-stub superconducting RF resonators. The effectiveness of these tuners is made possible because the resonators have low currents between their outer conductors and tuner elements. Computer simulations and experimental data show that the devices provide a tuning range up to 100 kHz with a frequency resolution of about 1 Hz. The manufacturing of the 150 MHz 2-QWR with rotary tuner has been completed. A credible design of 2-QWR and its rotary tuner have been developed and tested at room temperature. The PbSn plating, exercised on the existing split loop resonators, will be extended to the 2-QWR as a straightforward step to quickly explore the superconducting performance of the new geometry. The commissioning of the plating equipment has been started. In the longer term, the Nb sputter coating will be researched because, in principle, it can produce films competitive to the much more expensive solid niobium option and performs at higher fields than plated lead. The twelve split loop resonators have been electroplated with 96%Pb4%Sn film to the final thickness of 1.5 micron using methyl sulfonic acid chemistry achieving average acceleration field of 3.5 MV/m off-line. Measurement of the non-linear surface impedance and intermodulation distortion (IMD) has been conducted on the full-scale split-loop resonators (SLR). IMD measurements allow more sensitive detection of non-linearity as compared to surface impedance measurements. The source of the non-linearity in the resonator structure, such as magnetic flux penetration can be located by its contribution to the non-linear IMD response above a critical RF power level.

THE 2-QWR AND 3-QWR DESIGNS

The design of a 150 MHz *λ/4,* 3- and 4- gap structures with two and three loading elements, for the velocity range $\beta = 0.015 - 0.12$ is described in [1,2].

The MWS calculations for the 2-QWR indicate relatively low peak surface electric field ratio of E_p/E_{acc} = 5.4 MV/MV/m as compared to conventional resonators. The peak magnetic field ratio is also low at H_p/E_{acc} = 13.6 mT/MV/m.

The use of a column between the stubs and the shorting plate in multi-stub cavities provides a tool to achieve low H-fields, below 2 mT at 4.7 MV/m, where the outer conductor joins the shorting plate. This enables the use of a removable flange connected, with an RF gasket, which allows easy access to the interior of the resonator for manufacture, inspection, mechanical polishing, chemical surface treatment, high pressure rinsing, coating, and repair. The free choice of the column length enables the frequency of non-accelerating mode to be shifted 33 MHz below the accelerating mode frequency.

The 3-QWR provides 50% more acceleration length as compare to 2-QWR because of the existence of an eigen-mode that provides acceleration in each gap. Thus, for similar investments in electronics, cryogenics and laboratory space, it is more efficient than an equivalent 2-QWR though the transit time effect reduces its efficiency by ~ 2% and narrows its velocity acceptance by ~28%. The MWS calculations for the 3-QWR indicate an acceptably low peak surface electric field ratio of E_p/E_{acc} = 6.0. The peak magnetic field ratio is H_p/E_{acc} = 18.2 mT/MV/m.

The RF current in the gasket in 3-QWR is about one half that in the 2-QWR. An Nb on copper 3-QWR, operating at its magnetic field limit would have an accelerating field of E_{acc} = 6.6 MV/m and of 1.8 mT in the gasket area. For the case of a Pb on Cu 3-QWR, the magnetic field limits the accelerating field to E_{acc} = 2.9 MV/m when there would be 0.8 mT in the gasket area. As in the case of the 2-QWR, these low magnetic fields in the joint locations allow the use of removable flanges and RF gaskets. Such flanges facilitate access to the interior of the resonator for manufacture, mechanical polishing, chemical surface treatment, high pressure rinsing and coating with superconducting film. The ponderomotive forces on the outer stubs can be balanced by the introduction of a window in the center stub.

The high stiffness of the 2-QWR and 3-QWR provides mechanical stability against microphonics. The frequencies of the lowest mechanical modes are strongly affected by the distortion of the shorting plate but are above 77 Hz in 2-QWR and 59 Hz in 3-QWR for a 25 mm thick plate. This, combined with low energy content allows RF stabilization with a self-excited loop.

THE ROTARY AND DISPLACEMENT TUNERS

A credible design of rotary and displacement tuners for the 2-QWR and the 3-QWR cavities respectively, [1, 2], have been developed and tested at room temperature [3]. The OHFC 2-QWR prototype and its rotary tuner are shown in figure 1. Future tests at 4.2 K will explore the adequacy of the RF and thermal connection from the tuning bar to the resonator body, the performance of the bearings and frequency stability against vibration.

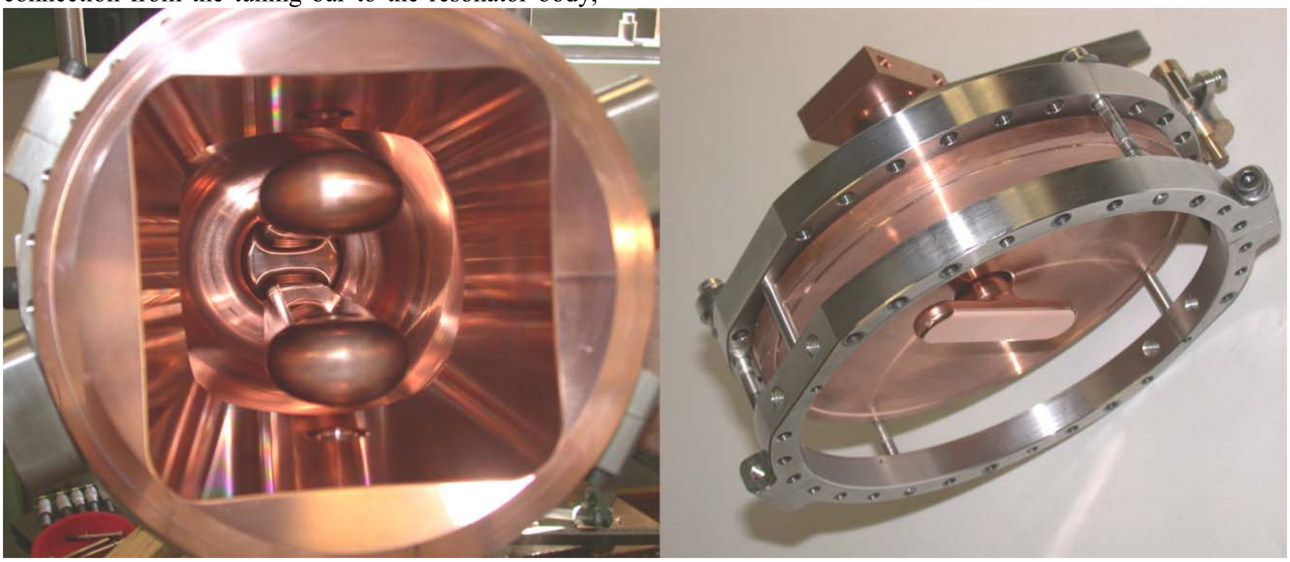

Figure 1: The OHFC 2-QWR prototype (left) and rotary tuner (right)

The multi-stub resonators intrinsically have low currents between the outer cylinder and the tuner elements. This allows the use of rotary or displacement tuners instead of the conventional deflection plate. The small driving force required for these tuners allows for low-backlash mechanisms. The use of the rotary tuner is limited to the resonators with two loading elements such as 2-QWR, conventional split loop resonator, and 2-stub, half wave resonators. The displacement tuner is more versatile and can be used for any TEM-like resonators with more than two loading elements.

The MWS calculations for the displacement tuner indicate adequate tuning range up to few tens kHz with low insertion loss and sub-Hz precision. The frequency resolution of displacement tuners is expected to be somewhat larger than that of the rotary tuner and thus the rotary option is chosen for the 2-QWR.

The tuners are superior to mechanical devices presently used due to their high frequency precision and response bandwidth. The designs allows one to select the middle of the tuning range simply by inserting spacers, thus allowing more generous manufacturing tolerances for the geometry of the cavity. In addition, the new tuners have the desirable characteristics of wide tuning range, absence of sliding contacts, relatively high Q and compact physical size.

The manufacturing of the 150 MHz 2-QWR with rotary tuner has been completed. The PbSn plating, exercised on the existing split loop resonators, will be extended to the 2-QWR as a straightforward step to quickly explore the superconducting performance of the new geometry. The commissioning of the plating equipment has been started. In the longer term, the Nb sputter coating will be researched because, in principle, it can produce films competitive to the much more expensive solid niobium option and performs at higher fields than plated lead.

THE LEAD-TIN PLATING AND SUPERCONDUCTING FILM CHARACTERIZATION

The twelve split loop resonators have been electroplated with 96%Pb4%Sn film to the final thickness of 1.5 micron using methyl sulfonic acid chemistry achieving average acceleration field of 3.5 MV/m off-line. Measurement of the non-linear surface impedance and intermodulation distortion (IMD) has been conducted on the full-scale split-loop resonators (SLR) [4].

In figure 2, the surface resistance R_s and the output power of the IMD third-order products as a function of the dissipated P_{diss} in the resonator power are presented at the reduced temperature $t= T/T_c = 0.6$. P_{diss} was calculated from the measured incident power P_{in} and the S-parameters S_{11} and S_{21}, $P_{diss}=P_{in}(1-S_{11}^2-S_{21}^2)$. P_{diss} and P_{in} are expressed in dBm. Dissipated power P_{diss} is proportional to the square of the peak amplitude of the RF field B_p, which is the relevant intrinsic property of superconducting coating. At very small input power the IMP signals are below the spectrum analyzer noise floor and become observable when $P_{IMD3} \geq -66$ dBm. In figure 2, the dashed line illustrates slope 3 and solid line slope 2. The arrows indicate the threshold field $B_{ptr} \sim P^{0.5}_{diss}$ separating domains with different effects causing non-linear response in the Pb-Sn film. An operation above B_{ptr2} = 35 mT gives rise of R_s due to FE.

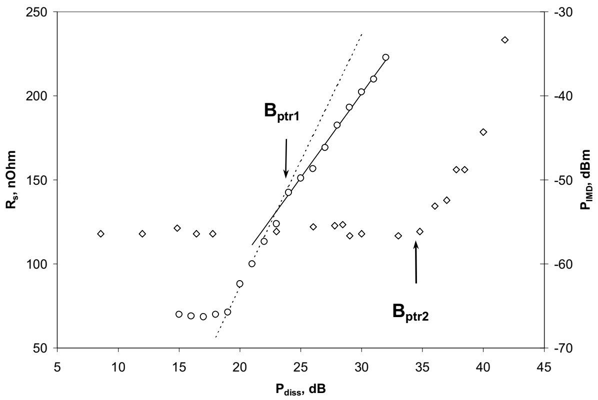

Figure 2: The surface resistance R_s (⑦) and the output power of the IMD products P_{IMD3} (⑥) as a function of the dissipated power at the reduced temperature $t=T/T_c$=0.6. Dashed line illustrates slope 3 and solid line slope 2. The arrows indicate the threshold field $B_p \sim P_{diss}^{0.5}$ separating domains with different nonlinear effects.

At $B_p < B_{ptr1}$ the IMD products scale with respect to input power at 3:1. For B_p larger than B_{ptr1}, a sudden transition from slope 3 to slope 2 occurs. The behaviour above is similar in SLRs plated under identical conditions. IMD measurements allow more sensitive detection of non-linearity as compared to surface impedance measurements. The source of the non-linearity in the resonator structure, such as magnetic flux penetration can be located by its contribution to the non-linear IMD response above a critical RF power level.

Using the harmonic balance algorithm, Mateu *et al* [5] have calculated the power dependence of the IMD products for the power-law nonlinearity in the different forms. These authors have found that the slope 2 of the third-order IMD may correspond dissipation due to Abrikosov or Josephson vortex [5]. The estimated B_{ptr1} = 9 mT is significantly lower than the B_{c1} = 53 mT value estimated for 96%Pb4%Sn superconducting film. This may be explained by the fact that ANU Pb-Sn coating process involves mechanical hand polishing of the superconducting layer just before deposition of the final cosmetic layer. The mechanical polishing can damage the film and introduce voids and non-superconducting inclusions, the magnetic field can penetrate through the film at much lower field $B_{ptr1} < B_{c1}$.

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