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A COUPON TESTER FOR NORMAL CONDUCTING HIGH-GRADIENT MATERIALS*

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Abstract

A coupon tester cavity allows a material in the form of a simple removable "coupon," or plate, to be exposed to high-strength radiofrequency (RF) fields, without the need to fabricate a complete cavity from each material to be explored. As we are interested in the breakdown performance of materials intended for high-gradient, normal-conducting structures, we must apply both electric and magnetic fields to the coupon.

We present the design criteria for our coupon tester cavity, nominal operating parameters, and our structure concepts. The cavity design will be finalized over the next several months, and is intended to be constructed and in-service near the start of 2022.

INTRODUCTION

A coupon tester is an RF structure used to subject a material sample to very high RF fields, with the fields on the sample, or coupon, being higher than elsewhere in the cavity. To date, most such cavities were originally intended to explore the RF properties of superconducting materials, specifically magnetic field limits, and can expose the sample to strong magnetic fields, but weak to no electric fields [1, 2, 3].

As part of a program to develop materials and structures for high-gradient (>100 MV/m), low-breakdown-rate normal-conducting accelerators [4, 5], we are designing C-band (5.712 GHz) coupon tester cavities intended to subject samples to both magnetic and electric fields comparable to those experienced in high-gradient structure designs, using a TM-mode cavity; the electric and magnetic fields along the sample coupon can be directly compared to the fields on the irises of high-gradient structures, and is intended to allow maximization of the modified Poynting vector [6] to the material to be tested.

The design of the coupon tester is bounded by criteria on the RF fields within the coupon tester; the RF structures used to deliver power to the cavity; and other features relevant to the usability of the coupon tester.

COUPON TESTER DESIGN CRITERIA

RF Fields Within the Cavity

We define E_c (H_c) as the maximum electric (magnetic) field amplitude on the surface of the removable coupon, and E_s (H_s) maximum amplitudes on the interior surface of the coupon tester cavity, excluding the coupon. The basic criteria for the coupon tester cavity are therefore $E_c > E_s$ and $H_c > H_s$. In terms of an optimization problem, we wish to concurrently maximize E_c/E_s and H_c/H_s.

The mode of interest for coupon testing should be well-separated in frequency from the next-nearest mode.

RF Structure Design

The coupon plate should attach to the cavity in a region where the surface magnetic field, and thus surface current, is as close to zero as possible. By minimizing the current across the plate-to-cavity joint, the chances of arcing and thermal damage at the joint is minimized.

We intend to use a coaxial power coupler, and in such designs, field emission at the coupler tip is of concern; we therefore wish to minimize the E-field at the coupler tips. The fields at the coupling iris between the coaxial coupler and the coupon tester cavity should also be as low as possible.

The quality factor Q_0 of the coupon tester cavity will depend on the surface resistivity of the coupon material, and also upon the temperature of the tester; there is increasing interest in cryogenic operation of normal-conducting accelerators [7, 8], which will alter the Q_0 as well as the operating frequency. For this reason, it is advantageous to be able to adjust the loaded Q by varying the coupling to the cavity.

Finally, a means of adjusting the cavity's resonant frequency is desirable; but this need not be included into the cavity structure itself.

Mechanical Design

The test coupon itself should be as simple as possible to fabricate; features such as RF or vacuum sealing surfaces should be located, to the extent possible, on the cavity body rather than the coupon itself.

As mentioned above, having the ability to vary the cavity coupling is important. This can be accomplished in a number of ways, such as a replaceable portion of the coupler; however, having an externally adjustable coupling system would be preferable.

The coupon tester should be able to provide good vacuum pumping to all areas of the cavity and power coupler system; provide for temperature regulation and heat removal from the coupon as well as the cavity body; and provide sufficient access for assembling RF joints, etc. Finally, it would be preferable if the cavity could be separable from the RF power coupler; this allows for less-expensive and faster fabrication of alternate coupon tester geometries.

For facilitating measurements beyond reflected power, it would be beneficial to have an on-axis path from the cou-

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pon to a Faraday cup to measure field emission and breakdown current. (This is under the assumption that E_c is highest on at the center of the coupon.). Optical viewports placed to view different regions of the coupon plate would also be useful to monitor the locations of breakdown as they occur.

CAVITY DESIGN

We are evaluating two cavity options for the basic coupon tester: one with a TM_{020}-like mode, and one with a TM_{041}-like mode. Figure 1 compares the cavity profiles. The TM_{041}-like mode has a better ratio of H_c/H_s, and uses a somewhat smaller radius coupon, but would be more complex to fabricate. The TM_{020}-like mode cavity, while having a notably lower H_c/H_s ratio, can be machined from a single piece of copper, and is physically considerably smaller. Optimizing the TM_{041}-like cavity shape to meet the criterion of low H-field at the coupon-to-cavity joint has also been somewhat more challenging. We are presently considering which to fabricate as a first item.

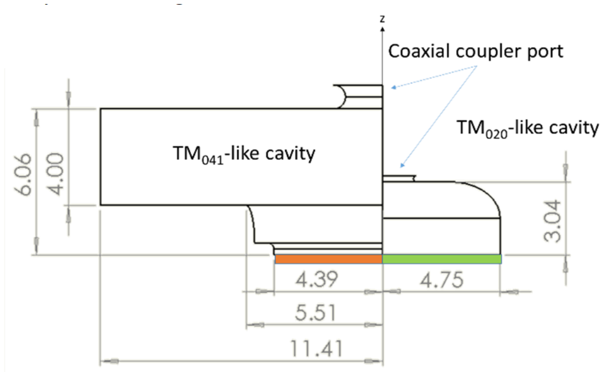

Figure 1: Cross-section comparison between TM_{041}-like (left) and TM_{020}-like (right) coupon tester cavities. Locations of the coupons are indicated by orange and green blocks. All dimensions are in cm.

RF Performance

The electric and magnetic field profiles of the coupon tester cavity variants are shown in Fig. 2. Both designs have a minimum H-field at the joint between the coupon (cavity back wall) and the body of the cavity, to minimize heating at the joint and the possibility of arcing.

Table 1 presents a summary of relevant parameters, assuming an OFE copper body for the cavity tester, and an OFE coupon plate. Both cavities are nominally resonant at 5.712 GHz; parameters were calculated using CST's eigenmode solver.

The parameter R_e in Table 1 is an effective shunt impedance for the cavity, in terms of peak electric field at the middle of the coupon: $P_{RF} = E_o^2/R_e$, where E_o is the desired electric field at the coupon center and P_{RF} is the required RF power. It does not take into account cavity coupling β.

Oil-can style tuners could be included in the design, but would increase complexity.

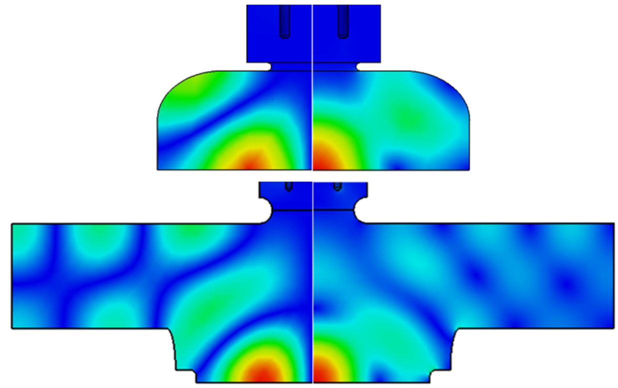

Figure 2: E (right-hand side) and H (left-hand side) field relative magnitudes for the TM_{020}-like (top) and TM_{041}-like (bottom) cavities.

Table 1: Summary of RF Parameters

Parameter	**TM_{020}-like**	**TM_{041}-like**
Q_0	16,800	23,500
E_c/E_s	2.89	2.33
H_c/H_s	1.42	2.33
R_e (MΩ/m^2)	$5.7 \cdot 10^3$	$3.10 \cdot 10^3$

If needed, a shallow depression or short protrusion in the center of the coupon can be used to tune the cavity. The radius of the "tuning cut," and depth or protrusion, determine the frequency shift (A similar approach has been used to tune 1.6-cell SLAC/UCLA/BNL-type S-band photoinjectors [9].). Figure 3 shows, for the TM_{020}-like structure, the results of tuning cuts applied at various radii and depth / height.

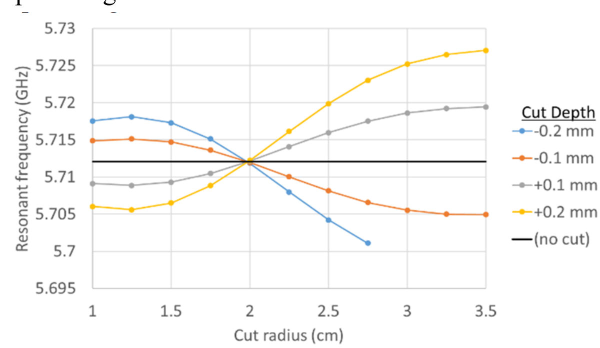

Figure 3: Frequency shift vs. tuner cut radii and depth, for the TM_{020}-like cavity. Positive values for depth represent a protrusion into the cavity.

The CERF-NM klystron has a bandwidth of 10 MHz, so built-in provisions for tuning the cavity may be unnecessary; however, tuning cuts on the coupon plate are available as a tuning method if necessary.

Mechanical Design

A cross-section view of the conceptual mechanical design is shown in Fig. 4, with a TM_{020}-like cavity installed on the power coupler.

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The TM_{020}-like cavity itself can be machined from a single piece of copper, and only one brazing cycle would be required to attach the power coupler and coupon vestibule flanges. Given the bandwidth of our klystron, and the option of tuning cuts on the coupon, the current design does not include tuners on the cavity.

The coupon is designed to require a minimum of machining, and forms the entire back wall of the coupon tester cavity. Thru holes at the periphery of the coupon allow it to be fastened securely to the cavity body; an elliptical spring seal provides RF contact. Tapped holes in the back of the coupon are used to attach a cooling plate.

The vacuum and RF seals are separated, with a Conflat flange and "vestibule" providing the vacuum seal outboard of the coupon, feedthroughs for the cooling plate, and pumping ports. A similar mechanical approach would be taken for the TM_{041}-mode cavity, in terms of the coupon plate mounting system and separated vacuum seal. The same approach has been verified to work at considerably higher surface currents across the RF joint [10].

A cooling line (not shown) would also be brazed onto the cavity body near the front of the cell, adjacent to where surface magnetic field on the cavity body are highest.

A standard 3.38" Conflat flange is used to connect the cavity to the power coupler, with a copper gasket with an ID of 4 cm to match the outer radius of the coax coupler; while not shown in Fig. 4, these flanges would be copper-plated to reduce RF losses. A slotted copper blank flange is used at the shorted end of the rectangular waveguide to provide additional pumping.

The cavity coupling can be varied by adjusting the short location in the WR187 waveguide, or by adjusting the spacing between the coaxial center conductor and the cavity iris. The latter can be done without disassembly of the power coupler by incorporating a translation mechanism such as a constrained bellows. Two elliptical coil springs, held in grooves inside the coaxial line "doorknob," are used to ensure good electrical contact between the central coax and coupler body, and to help keep the center coax supported and centered.

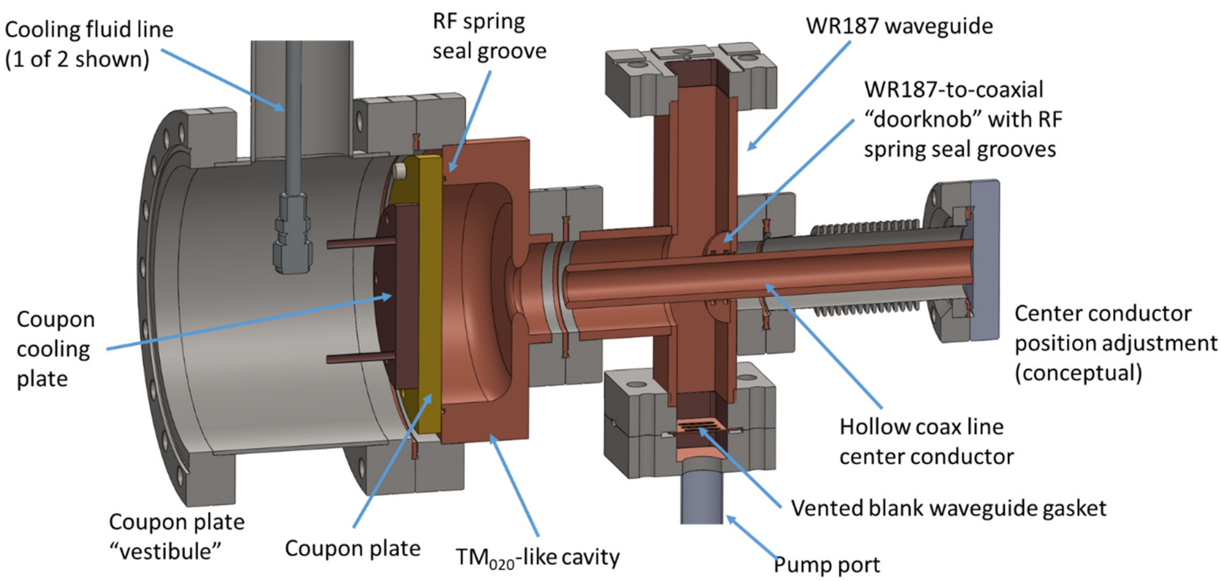

Figure 4: Cross-section view of conceptual design for a coupon tester using a coaxial RF power feed; the TM_{020}-like mode cavity is shown installed on the rectangular-to-coax power coupler.

Diagnostic Considerations

Instead of being held on a blank flange, the center coax could be terminated on a collar, providing both a location for a field-emission probe, and additional pumping for the cavity.

Considering Fig. 2, there are several candidate locations for placing observation ports on the cavities. However, the coupler and coupon plate vestibule flanges constrain the port placement on the TM_{020}-mode cavity to high magnetic field regions, with the result that a port would increase the local magnetic field strength at the port's aperture beyond that on the coupon. For the TM_{041}-mode cavity, there are several candidate locations for ports along the cavity back wall, outboard from the coupling iris, where the magnetic field is at a null.

CONCLUSIONS

We present the basic RF properties for two candidate designs for a coupon test cavity, intended to characterize the performance of materials intended for high-gradient, normal-conducting accelerators. A TM_{020}-like cavity would be simpler to construct and requires less RF power to obtain a given electric field; the TM_{041}-like variation offers higher coupon-to-cavity field ratios for the magnetic field, and better options for placing diagnostics such as optical ports to observe the coupon plate.

A rectangular-to-coaxial RF power coupler is used for both designs. A conceptual mechanical design of an assembled tester is presented using the TM_{020}-like cavity.

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REFERENCES

[1] A. Canabal *et al.*, "Superconducting materials testing with a high-Q copper RF cavity", in *Proc. 22nd Particle Accelerator Conf. (PAC'07)*, Albuquerque, NM, USA, Jun. 2007, paper WEPMS018, pp. 2370-2372. doi:10.1109/PAC.2007.4441253

[2] L. Laurent *et al.*, "Experimental study of rf pulsed heating," *Phys. Rev. Accel. Beams*, vol. 14, p. 041001, Apr. 2011. doi:10.1103/PhysRevSTAB.14.041001

[3] H. Oikawa, T. Higashiguchi, and H. Hayano, "Design of niobium-based mushroom-shaped cavity for critical magnetic field evaluation of superconducting multilayer thin films toward achieving higher accelerating gradient cavity," *Japanese Journ. Appl. Phys.,* vol. 58, no. 2, p. 028001, Feb. 2019. doi.org/10.7567/1347-4065/aaf46a

[4] J.W. Lewellen, D. Gorelov, E. Simakov, and D. Perez, "CERF-NM: The C-band engineering research facility in New Mexico," presented at the International Workshop on Breakdown Science and High Gradient Technology (HG2021), LA-UR-21-23725 V. 2

[5] D. Gorelov *et al.*, "Status of the C-hand engineering research facility (CERF-NM) test stand development at Los Alamos, presented at the 12th International Particle Accelerator Conference, Campinas, SP, Brazil, May 2021, paper MOPAB146, this conference.

[6] E.I. Simakov, V.A. Dolgashev, and S.G. Tantawi, "Advances in high gradient normal conducting accelerator structures," *Nucl. Instrum. Methods*, vol. 907, pp 221-230, 2018. doi:10.1016/j.nima.2018.02.085

[7] J.B. Rosenzweig *et al.*, "Next generation high brightness electron beams from ultrahigh field rf photocathode sources," *Phys. Rev. Accel. Beams*, vol. 22, p. 023403, 12 Feb. 2019. doi:10.1103/PhysRevAccelBeams.22.023403

[8] A.D. Cahill, J.B. Rosenzweig, V.A. Dolgashev, S.G. Tantawi, and S. Weathersby, "High gradient experiments with X-band cryogenic copper accelerating cavities," *Phys. Rev. Accel. Beams* vol. 21, p. 102002, Oct. 2018. doi:10.1103/PhysRevAccelBeams.21.102002

[9] S.G. Biedron, private communication, 2005.

[10] W. S. Graves, R. Heese, E. D. Johnson, S. Krinsky, J. Rose, and B. Sheehy, "Modeling and Measurements of the DUVFEL Photoinjector Cavity RF Properties", in *Proc. 19th Particle Accelerator Conf. (PAC'01)*, Chicago, IL, USA, Jun. 2001, paper WPAH057, pp. 2221-2223.