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 coupon, or plate, 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-
pon to a Faraday cup to measure field emission and breakdown current. (This is under the assumption that $E_c$ is highest 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.](image)

**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.

![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.](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TM$_{020}$-like</th>
<th>TM$_{041}$-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_0$</td>
<td>16,800</td>
<td>23,500</td>
</tr>
<tr>
<td>$E_c/E_s$</td>
<td>2.89</td>
<td>2.33</td>
</tr>
<tr>
<td>$H_c/H_s$</td>
<td>1.42</td>
<td>2.33</td>
</tr>
<tr>
<td>$R_e$ ($\Omega/m^2$)</td>
<td>$5.7\cdot10^3$</td>
<td>$3.10\cdot10^3$</td>
</tr>
</tbody>
</table>

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.](image)

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.
The TM\textsubscript{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\textsubscript{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.

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\textsubscript{020}-like cavity.

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\textsubscript{020}-like cavity would be simpler to construct and requires less RF power to obtain a given electric field; the TM\textsubscript{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\textsubscript{020}-like cavity.

Figure 4: Cross-section view of conceptual design for a coupon tester using a coaxial RF power feed; the TM\textsubscript{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\textsubscript{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\textsubscript{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.
REFERENCES


