HIGH POWER CO-AXIAL COUPLER*

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Abstract

A superconducting RF (SRF) power coupler capable of handling 500 kW CW RF power at 750 MHz is required for present and future storage rings and linacs. There are over 35 coupler designs for SRF cavities ranging in frequency from 325 to 1500 MHz. Coupler windows vary from cylinders to cones to disks and RF power couplers will always be limited by the ability of ceramic windows and their matching systems to withstand the stresses due to non-uniform heating from dielectric and wall losses, multipactor, and mechanical flexure.

We have fabricated and tested a novel robust co-axial SRF coupler (400 MHz, 6 kW CW) design that uses two windows manufactured with compression ring technology and no matching elements in the coax line. This technology allows the use of high thermally conductive materials for cryogenic windows because the braze joint will be in compression. We have also incorporated "explosion bonded" technology into this design to reduce needed parts and simplify fabrication. In this phase, a scaled down version of the 500kW CW double window assembly has been built and tested.

A compressed co-axial window was designed and fabricated using standard ceramics [1]. Low power tests confirmed the broadband match characteristics of a double window design.

Double-window, coaxial input couplers or coaxial pressure barriers have high power CW applications ranging from RF guns for injectors to high power magnetron sputtering systems. Single half-wavelength coaxial windows built with our compression technology will handle significantly more power than standard windows.

INTRODUCTION

Dual-Window Concept

When two coax windows are placed in a length of line, the distance between them can be adjusted to create a perfect match. That distance is approximately a quarter-wavelength. The thickness of the window and its dielectric constant determine the exact distance for the cancellation of reflections. For EIA 3-1/8 50Ω coax line, the ceramic window has the same dimensions as the coax (76.9 mm and 33.4 mm). In our Phase I construction of a compressed window we used a window thickness of 7.6 mm. Using those dimensions the optimum spacing for various frequencies can be determined by various simulation tools. For EIA 3-1/8 coaxial line, Figure 1 shows the window spacing as a function of frequency, which provides a near perfect match.

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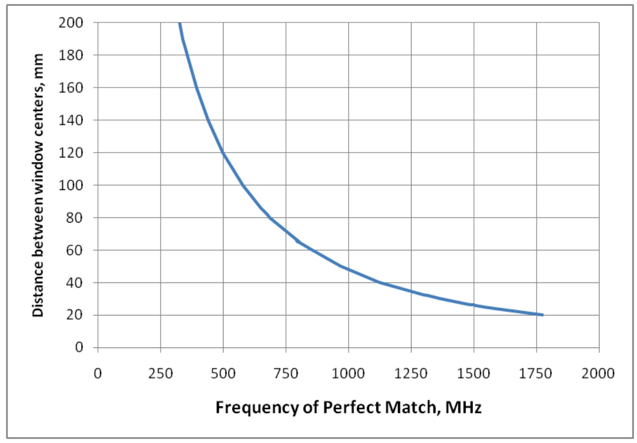

Figure 1: Two alumina windows 7.6 mm thick modeled in EIA 3-1/8 coax for the distance between them which creates a near perfect match.

As the thickness of the window becomes large compared to the wavelength of the match frequency, the actual distance to cancel reflections becomes smaller than the theoretical $\lambda_g/4$. The bandwidth of the match was calculated to be about 2-3% at a VSWR of 1.01:1.

Two windows of different materials can be matched in a similar manner by slightly changing the thickness of one window or the spacing between the two windows.

Explosion Bonding

Our coupler design was discussed previously [2], and illustrates the usefulness of fabricating the outer conductor, vacuum assembly, and window Compression Rings as one piece. A braze joint between the copper outer conductor and stainless vacuum tube, would be very difficult to make due to the large surface areas involved. Explosion Bonding (EB) a thin layer of copper onto the inner surface of a stainless steel tube then machining to size is a good and cost effective solution.

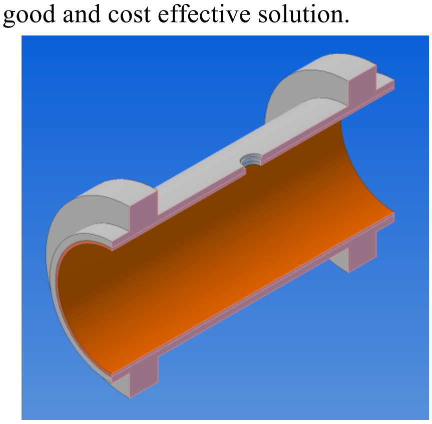

Figure 2: Explosion bonded copper outer conductor, compression rings, and vacuum tube assembly.

One challenge in getting a useable tube lies in the explosion "expanding" the tube in a non-uniform way (bulging), the strength of the explosion, the desired final machined dimensions, and thickness of the copper layer. This is a learning process and depends upon factors such as material, diameter, tube thickness, desired copper thickness, etc. It took two iterations before we determined acceptable initial (pre-explosion) dimensions, and the EB fabricator determined the proper amount of explosive.

Figure 3 is a graphic of the relevant dimensions for the third EB tube. The graphic clearly shows the bulging of the 1" thick stainless steel tube due to the explosive charge. With the earlier trials we, along with the supplier High Energy Metals, Inc., determined that the pre-bonding ID of the stainless steel tube needed to be ~3 inches, after bonding the ID of the Cu sleeve was as shown by the red squares, and the bond line between the Cu and the stainless steel is shown by the green triangles. Thus, the thickness of the Cu layer is approximately 0.300". The ID of the Cu was machined to 3.032" as shown by the dashed line, which leaves the Cu thickness as half the distance between the dashed line and the triangle at that axial location. The gray rectangles indicate the approximate location of the coax windows, and the Cu layer radial thickness is about 0.050" in those locations.

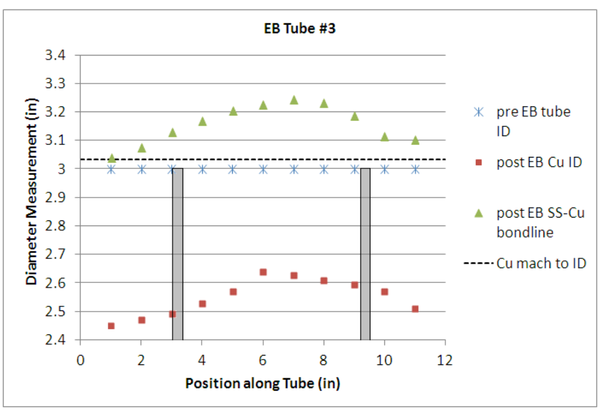

Figure 3: The relevant dimensions for the 3rd Explosion Bonded tube fabrication.

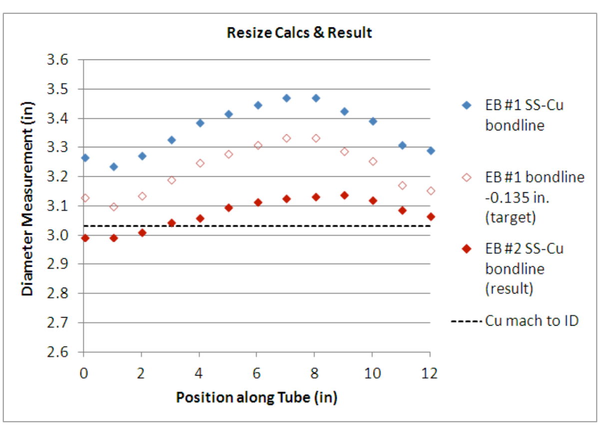

Figure 4: Determination of pre-EB tube ID.

As can be seen from Figure 3 and Figure 4, getting the exact thickness desired is still not exact. Figure 4 shows that there can be a bonding variation (for our size and geometry) of approximately 0.100 to 0.200 inches in diameter. This variation, along with the "bulging" issue requires careful planning and coordination with the EB supplier.

The earlier EB tubes were not wasted as portions of the explosion bonded tube were of suitable dimensions for braze tests to be made. Slices of the tube sufficiently long (~0.8") for two separate window braze tests were machined from the tube, and coaxial windows similar to those discussed in reference 1 were fabricated. In these windows the explosion bonded copper buffer layer surrounding the window ceramic was substantially thicker than in the windows discussed in reference 1, however, the window braze assembly was perfect (Figure 5) and the windows were vacuum tight, and survived a thermal cycle test down to cryogenic temperatures.

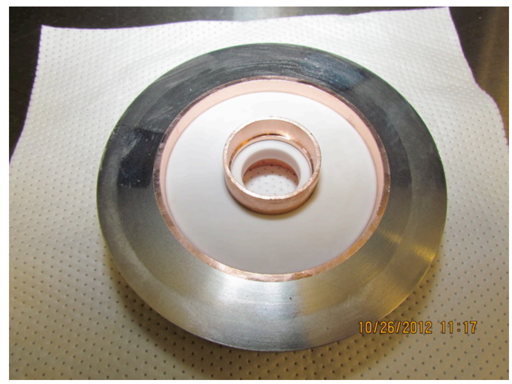

Figure 5: Coaxial window (~3" dia. ceramic) brazed into an Explosion Bonded copper / SS outer Compression Ring.

TECHNICAL APPROACH

Figure 6 shows the hot test assembly as a cut-away concept drawing. The brazed portion of the assembly will be made in two stages. First is the inner window assembly which consists of the inner conductor, the ceramic backing rings, and the two Alumina windows (Figure 7). The second braze bonds the inner conductor assembly to the explosion bonded (EB) assembly, such that the windows are aligned with the thick compression rings of the EB part. EIA adapter flanges and coax are connected for testing purposes.

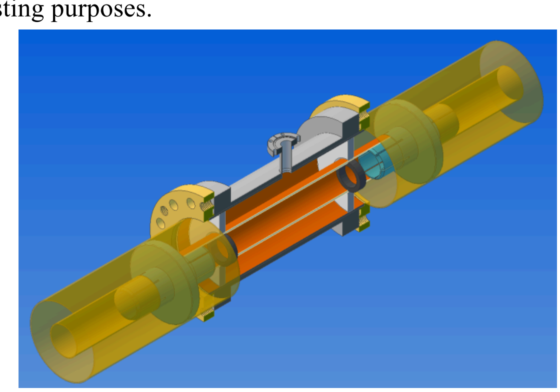

Figure 6: Dual-window Coupler hot test assembly drawing.

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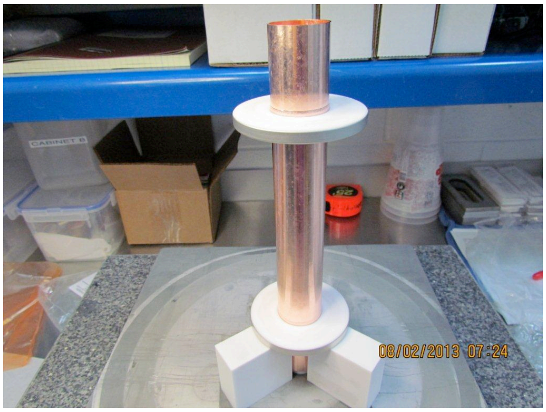

Figure 7: The dual coaxial window inner braze assembly.

Preliminary Testing / Measurements

Prior to the second braze, the inner conductor assembly was tested in a low power RF test (Figure 8). The RF test assembly could be easily made using a thin aluminum sheet rolled and hose-clamped around the metalized OD of the windows. The results are shown in Figure 9. Where the reflection has a -30 dB bandwidth of ~30 MHz, and the S21 transmission loss was measured at <0.01 dB.

Another single brazed window assembly was cycled to 4°K and back in JLab's vertical test dewar, then checked for leak tightness and dimensional changes.

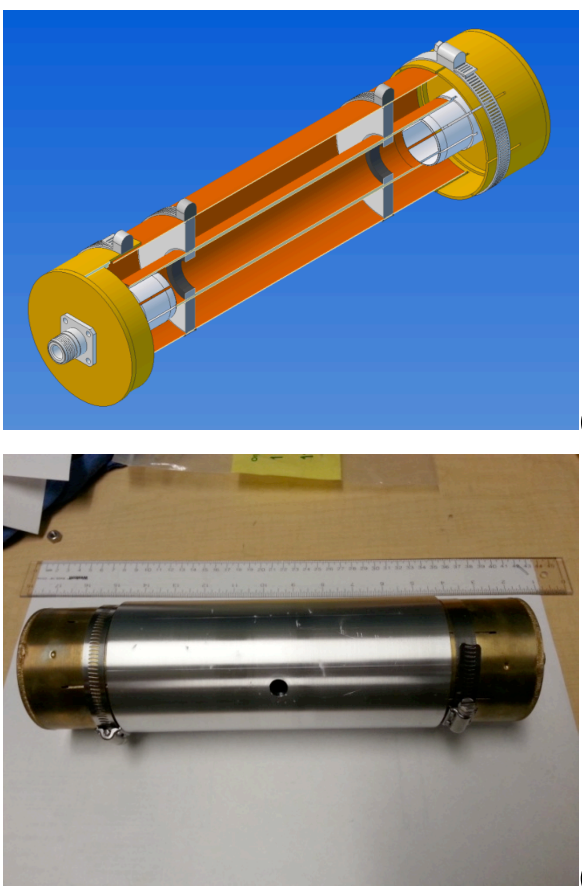

Figure 8: Low Power RF test set-up for testing window / inner conductor braze assembly (a – 3D drawing, b – as fabricated).

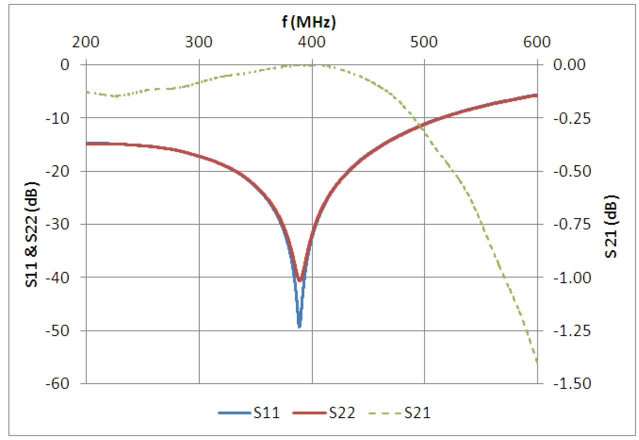

Figure 9: Plot of the S-parameters for the inner conductor low power RF test of Figure 8.

Final Assembly Braze

After measurements of the inner braze assembly, a final braze will be performed between the machined EB tube and the inner braze assembly. Figure 10 below shows the two parts before brazing.

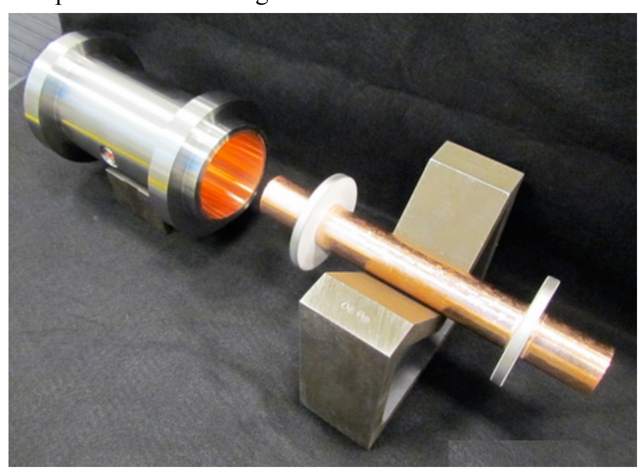

Figure 10: Shown are the inner braze assembly and the machined Explosion Bonded tube.

High Power RF Testing

The Coupler will be thermally cycle tested and vacuum checked to assure a leak tight assembly, then tested at high power using the set-up of Figure 6.

CONCLUSIONS

A dual coaxial window matched coupler has been designed and fabricated using compression ring technology for the windows and explosion bonding to combine the outer conductor to the vacuum wall.

REFERENCES

[1] Neubauer, M., et. al. "High Power Coax Window", PAC11.

[2] Neubauer, M., et. al. "High Power Co-Axial SRF Coupler", PAC12.

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