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Design and Testing of a High Power, Ultra-High Vacuum, Dual-Directional Coupler for the Advanced Photon Source (APS) Linear Accelerator*

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Abstract

Leaks and cracks have developed in the vacuum windows of the linac WR 284 waveguide directional couplers. In the existing coupler design the vacuum window is brazed to the waveguide. Replacement of a cracked window requires the removal of the component from the waveguide system resulting in a loss of vacuum in the waveguide. A new design has been developed and a prototype tested that utilizes bolted-in vacuum windows and allows for easier replacement of the windows in the system, while still providing suitable radio frequency (rf) specifications.

I. INTRODUCTION

The rf operating frequency of the APS linac is 2.856 GHz. Rf power is provided by five 35-MW pulsed klystrons with a pulse width of 5.0 µS, and a repetition rate up to 60 Hz [1]. Three of the five klystrons supply power to SLED (the SLAC energy doubler) cavity assemblies [2]; therefore, the electrical specification of peak power for the waveguide is >200 MW.

This paper describes the mechanical and rf design of a high power, ultra-high vacuum, WR 284 waveguide dual directional coupler for the APS linac rf system. Section II describes mechanical aspects of the coupler, and sections III and IV describe the rf measurement setup and the results.

II. COUPLER MOUNTING ARRANGEMENT

The coupler mounting arrangement is shown in Figure 1. The internal geometry of the insert, the CF (Conflat)-style flange and the flange-mounted viewport closely replicates that of the original brazed window design. This allows reuse of the directional couplers from the original waveguide system. In the new design, the insert is furnace brazed to the broad wall of the waveguide. Subsequent to brazing, a step-bored flange with tapped bolt holes is gas-tungsten arc welded to the insert from the inside (vacuum side). The viewport is sealed to the mating flange using a conventional oxygen free high conductivity (OFHC) copper gasket. The mounting bolts also secure the coupler mount housing, that is piloted into a slight recess in the viewport to maintain concentricity with the insert.

The directional coupler fits snugly (0.001-0.003" diametral clearance) within the coupler-mount housing to maintain concentricity with the insert opening. A shim is used between the directional coupler and the coupler mount housing to tune the coupling sensitivity of the assembly. The body of the directional coupler is rotated to adjust coupling directivity. An annular coupler retainer secures the directional coupler to the coupler mount housing (via a shoulder on the directional coupler and tapped holes in the coupler mount housing) to maintain directivity and solid electrical contact.

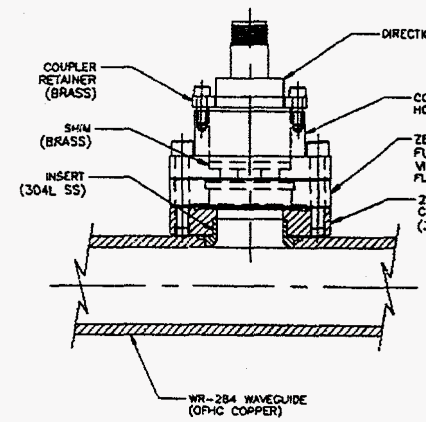

Figure 1: Coupler mounting arrangement.

This arrangement allows simplified replacement of a damaged window and immediate reinstallation of the directional coupler. Fused silica was used for the window. Fused silica windows and CF flanges are adequate for ultra-high vacuum use. The previous design required removal of the waveguide section and rework, including furnace brazing, of a new window. The distance between the two directional couplers is 4.518 inches. This corresponds to 3 $\lambda_g/4$, where λ_g is the wavelength of the rf wave in the waveguide. This distance allows the best directivity between the two couplers [3].

III. MEASUREMENT SETUP AND PROCEDURES

The rf measurements were made using a prototype of the dual-directional coupler. The test setup included a waveguide mount for each directional coupler and several coupling loops.The measurements were used to determine the optimum orientation and depth for the directional coupler loop in the WR 284 waveguide. The loop provides a coupling coefficient 57 ± 2 dB and directivity between the forward and reverse power measurement >32 dB at the operating frequency and over a test band of ±10 MHz.

The experimental setup consisted of a Hewlett Packard Model 8510 network analyzer, two WR 284 waveguide-to-coax transitions, two 6" pieces of plain waveguide, and the prototype shown in Figure 2. The 6" pieces of waveguide were inserted between the transitions and the directional coupler to

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ensure that any fields due to evanescent modes created in the coax-to-waveguide transition would not be included in the measurements.

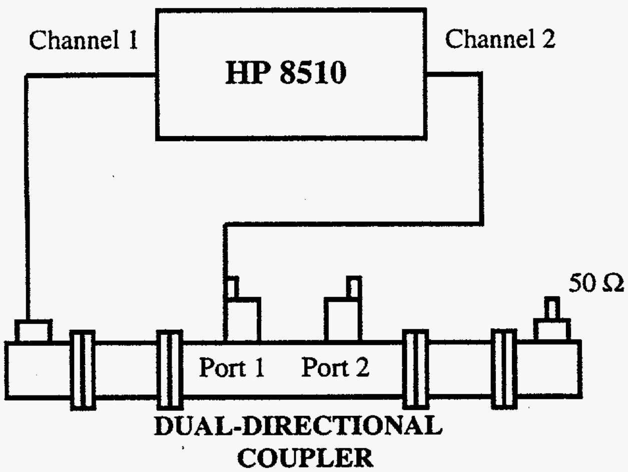

Figure 2: Measurement setup.

The center frequency of the analyzer was set at the APS linac rf frequency of 2.856 GHz with a span of 10 MHz. A waveguide calibration was performed using a WR 284 calibration kit to eliminate errors caused by the two transitions and attached 6" pieces, and to ensure that the measurements reflected only the device under test. Six different directional coupler inserts, numbered 1 through 6, were used and all but coupler 1 had a measured matched resistance that was 50.5 ± 0.1 Ω; the value of coupler 1 was 51.3 Ω. This small deviation did not seem to negatively affect the performance of the coupler.

The measurement procedure consisted of five steps. The setup for the first step was as shown in Figure 2. Channel 1 of the 8510 was connected to the coax-to-waveguide transition and channel 2 was connected to the directional coupler located in port 1 of the prototype. A 50-Ω broadband matched load was placed on the end of the second coax-to-waveguide transition. Shims were inserted into the directional coupler mounting to change the depth of the loop in the guide. The shims varied in size from 0.12" to 0.18". A transmission (S_{21}) measurement was done and a shim size was chosen that resulted in a forward power for port 1 of approximately -57 dB. The same shim size was then put into the coupler mounting of port 2 in the prototype.

In step two, the cable from channel 2 on the 8510 was removed from the coupler in port 1 of the prototype and attached to the coupler located in port 2. The S_{21} measurement was done while the directional coupler was rotated, in order to rotate the loop until the power reading was as low as possible. This measurement was the reverse power of port 2.

For step three the coax from channel 1 of the 8510 was switched with the 50-Ω load on the transition. The resulting transmission measurement was the forward power for port 2 (see Tables 1-3). If the forward power was not approximately -57 dB, then next size shim was used and steps one and two were repeated.

In step four the coax from channel 2 of the 8510 was moved to the directional coupler located in port 1 and the coupler was rotated until the power reading was as low as possible. The transmission measurement was the reverse power at port 1.

In step five the original setup as described in step one was used and the measured forward power at port 1 was compared to the value recorded in step one. Again, if the second power measurement was not approximately -57 dB then the next size shim was used and the steps were repeated again until the correct shim size and corresponding loop position for the specifications were found.

IV. RESULTS

Six shim sizes were initially used: 0.12", 0.14", 0.15", 0.16", 0.17", and 0.18". Preliminary measurements determined that shim thicknesses of 0.14" to 0.16" corresponded to a forward power measurement between 54.8 and 59.2 dB for the couplers. A shim thickness of 0.14" was chosen in order to decrease the number of measurements. As shown in Table 1, forward power measurements with this shim size were fairly close to 57 dB and it was decided that as improvements were made in the prototype design this shim would provide the coupling that was required. Directional couplers 1 and 2 were paired together and met the specifications when inserted into the mounting using the 0.14" shim with no modifications to the prototype. It was decided to eliminate these couplers from the testing and use only the remaining couplers for which modifications to the prototype mounting had to be performed in order for the couplers to meet the specifications.

Based on the measurements taken and shown in Table 1, couplers 4 and 5 have the worst directivity, ranging from 20 to 25 dB. An inspection of the prototype revealed that changes could be made in the design to improve the directivity and the coupling. Two areas for improvement were found inside the coupler mountings. The first was that concentricity was not maintained between the inner diameter (I.D.) of the original rotatable flange and the I.D. of the insert, and the second was that the weld between the flange and the insert on the waveguide was not smooth enough (see Figure 1).

Table 1 Redesigned Coupler - Original.

Coupler Insert Port1 Port2	Fwd Pwr Port 1 (dB)	Rev Pwr Port 1 (dB)	Fwd Pwr Port 2 (dB)	Rev Pwr Port 2 (dB)
3 and 4	-56.445	-88.527	-54.758	-76.641
4 and 3	-55.584	-75.629	-56.525	-87.891
5 and 6	-55.641	-81.113	-55.588	-85.297
6 and 5	-56.24	-97.668	-55.936	-83.047
4 and 5	-56.055	-77.363	-56.195	-79.305

The roughness of the weld was smoothed out without changing the rotatable flange. This approach made relatively minor differences in the measurements, as shown in Table 2. The I.D. of the rotatable flange allowed approximately 0.015" clearance between its I.D. and that of the insert. Therefore, the next step was to replace the rotatable flange with a nonrotatable one which allowed approximately 0.003" to 0.005" clearance between its I.D. and the insert's I.D. This change resulted in a much simpler welding process, and the resulting weld was smooth. Table 3 shows data taken after changing the flange type. The measurements show improvement in directivity compared to the data shown in Table 2.

Table 2 Smoothed welding between flange and insert.

Coupler Insert Port 1 Port 2	Fwd Pwr Port 1 (dB)	Rev Pwr Port 1 (dB)	Fwd Pwr Port 2 (dB)	Rev Pwr Port 2 (dB)
3 and 4	-56.672	-85.781	-55.221	-79.363
4 and 3	-55.496	-79.906	-56.59	-89.737
5 and 6	-57.146	-83.398	-56.5	-90.758
6 and 5	-55.723	-91.293	-56.832	-81.668
4 and 5	-55.109	-77.656	-55.799	-82.582

V. CONCLUSION

As shown by the data presented in Tables 1-3, the conclusion can be made that it is possible to create a directional coupler that meets the electrical specification. The coupler will be able to operate at high peak power, and simplified window replacement without rebrazing the part is possible. Tight tolerances for the clearance between the CF flange and the insert in the waveguide I.D. must be closely adhered to and all welds exposed to rf must be smooth.

Table 3 Changed flange type.

Coupler Insert Port 1 Port 2	Fwd Pwr Port 1 (dB)	Rev Pwr Port 1 (dB)	Fwd Pwr Port 2 (dB)	Rev Pwr Port 2 (dB)
3 and 4	-58.453	-95.371	-57.391	-85.508
4 and 3	-57.932	-87.535	-57.023	-95.312
5 and 6	-58.605	-87.734	-58.395	-88.562
6 and 5	-58.895	-98.848	-58.059	-92.176
4 and 5	-57.969	-86.805	-56.152	-85.637

VI. REFERENCES

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