REBUILDING WR-340 AND WR-284 WAVEGUIDE SWITCHES TO MEET HIGHER POWER AT THE ADVANCED PHOTON SOURCE*

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Abstract

The high-power S-band switching system for the Advanced Photon Source (APS) linear accelerator (linac) provides for a hot spare for two of the four S-band transmitters. The system utilizes four-port S-band switches of aluminum construction that are pressurized with sulfur hexafluoride during normal operation and are commercially available. A high-power S-band transmitter test stand at the APS linac has shown that processes that include the hand working and electropolishing of sharp edges internal to the aluminum construction of these switches have measurably improved power handling characteristics.

INTRODUCTION

The rf power for the APS linear accelerator is provided by Thales model TH2128 klystrons, rated at 35-MW peak power, and TH2128D klystrons, rated at 45-MW peak power. The ongoing process of upgrading new and rebuilt klystrons to model TH2128D continues as the lower-grade klystrons are retired or rebuilt with the power upgrade [1]. Of the six klystrons in the APS linac gallery, L1, L2, L4, and L5 are used for normal storage-ring injection. A sixth klystron, the TH2128D model, has been installed in the gallery and serves as a test stand for high-power testing and conditioning of components. This test stand is currently being redesigned to accommodate the high-power rf acceptance testing of S-band SLEDs (SLAC Energy Doublers). The switching system provides for uninterrupted rf power to the APS linac in the event that a klystron needs to be replaced [2].

TOPOLOGY

Figure 1 shows an overhead WR-340 waveguide run that supports the 2856-MHz signal from spare klystron L3. This run (labeled ‘From L3’) has been installed at an elevation of 14'6" to provide for clear passage of forklifts, thereby accommodating the removal of and replacement of klystrons. Figure 1 illustrates how the two WR-340 switches shown can lead to four scenarios. 1) The L3 rf signal can substitute for L1, providing rf power to the tunnel thermionic gun, which is used for normal storage-ring injection. 2) The L3 rf signal can be used to power the photocathode gun used for low-energy undulator test line (LEUTL) studies. 3) The L3 rf signal can, via a third switch in the linac tunnel, be directed to a test room [3]. 4) The L3 rf signal can be directed to a vertical water load termination for conditioning. The WR-340 waveguide was used for two reasons. First, it exhibits less return loss than does the WR-284 waveguide. Over the frequency range which the waveguide is designed to support, the WR-340 copper waveguide is 0.261 to 0.363 dB loss per 100 feet while the WR-284 copper waveguide is 0.508 to 0.742 dB loss per 100 feet. The second reason the WR-340 waveguide is used is to handle more power in the pressurized portion of the waveguide. Another switching arrangement has been installed at L2 whereby the spare klystron L3 can replace rf from klystron L2 if klystron L2 becomes temporarily disabled.

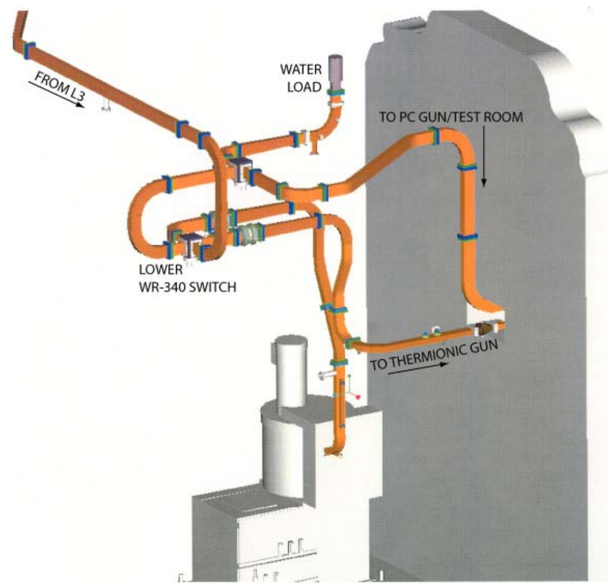

Figure 1: Switching at L1.

COMPONENTS

Measurements to date have determined that the loss from L3 to the photocathode rf gun over a distance of 150 feet is 0.84 dB. This overall loss is influenced by the number of flange joints, which is perhaps greater than ideal because the waveguide straights were limited to six feet due to the brazing furnace size. Windows and transition pieces, which make the size transition from WR-284 waveguide to WR-340 waveguide, contribute to the waveguide losses. The waveguide transitions are machined externally to a tapered shape prior to an internal wire EDM (electrical discharge machine) operation and have an overall length equal to 21.25". A goal of 40-dB return loss was chosen as one of the criteria for the WR-340 windows developed at the APS [4].

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The WR-340 flanges and gaskets are unique to the APS switching system, having been upgraded from the WR-284 merdinian male and female flanges developed at SLAC. Construction of the WR-340 waveguide is 0.25" wall OFHC copper. This makes for a heavy waveguide that demands significant attention to safety in installation and support. The heavy wall limits the elastic deflection of the broad wall from applied pressure or vacuum so that deflection is similar to that demonstrated by the proven 0.173" wall WR-284 waveguide. More costly brazed stiffeners to the WR-340 broad walls were thus not needed.

The nominal operating pressure of the SF_6 is 32 psig. Two pressure switches in parallel are installed at each zone to serve as rf interlocks, and they signal local cabinet displays if the pressure falls below 29 psig. An overpressure system for safety purposes incorporates a 35-psig burst disc and pressure relief valve built into the main manifold. There are no temperature stability water traces brazed to the WR-340 waveguide (excepting the WR-340 windows), since the entire WR-340 waveguide subsystem lies ahead of the sampling port, which is used for closed-loop phase regulation in each case.

Provisions have been made to monitor the moisture content of the SF_6, and a future SF_6 recovery system is planned to reclaim 97% of the SF_6 and provide for a scrub, clean, and dry process. Yet, the current SF_6 system is static with minimal moisture content monitoring. For the purposes of maintaining the waveguide and adding new components to the system, the SF_6 is vented completely from a zone. Although SF_6 recovery is not employed, during the SF_6 venting it is automatically tested for the presence of breakdown byproducts SO_2 (1 in 60 ppm) and HF (1 in 120 ppm). Following maintenance activities, the selected waveguide zone is evacuated to 10 mTorr and the zone is refilled from one of two cylinders holding fresh SF_6 pressurized at 400 psig. Automatic SF_6 switchover occurs when one cylinder pressure falls below 120 psig. The two larger zones (6 cubic feet each) have performed for a year without maintenance activity and therefore without SF_6 refreshment.

This describes the static SF_6 system that has performed well for five years. On one occasion, which involved the small zone at the L6 test stand using a 2856-MHz, 41-MW pulse with a 2-μs duration, severe arcing occurred causing SF_6 decomposition. This happened during testing of the prototype WR-340 window, which was afterward redesigned to handle higher power [5]. The arc residue on the SF_6 side of the ceramic contained neither of the more hazardous byproducts, SO_2 or HF. The residue deposited on the gas side of the window was found to be copper fluoride and copper fluoride hydroxide, indicating that the HF reacted with the copper. No other occurrence of SF_6 breakdown has been observed.

PRESSURIZED RF SWITCHES

Early testing at SLAC [6] was significant because WR-284 switches manufactured by Sector Microwave were seen to exhibit return loss characteristics at least commensurate with a more expensive brand of manufacturer. A decision was made to purchase fourteen Sector Microwave 340 size and four Sector Microwave 284 size switches. A more recent purchase order for additional switches has followed. The return loss of the WR-284 switch had been measured at SLAC to be 22 dB using the test setup described in [6]. More recent measurements at the APS using a network analyzer have indicated that WR-340 switches can be fine-tuned to 40 dB, whereas the acceptance criteria requires no return loss less than 36 dB. The network analyzer measurements indicate that the WR-284 switches can be expected in general to exhibit 31- to 35-dB return loss.

Fine-tuning the WR-340 switch in an attempt to reach 40 dB involves removing the electrical switch head to expose a round cover plate, as shown in Figure 2. For illustration purposes, the mitered rotor is raised. The round cover plate (labeled port 1) contains the index blind hole. This cover plate can be rotated slightly in reassembly to change indexing of the switch head and the position of the switch bearing (arrow in picture) relative to the aluminum channel piece (fixed to the rotor axis). This alters slightly the rotation of the rotor and the alignment of housing openings to rotor edges, thus influencing the return loss of the switch.

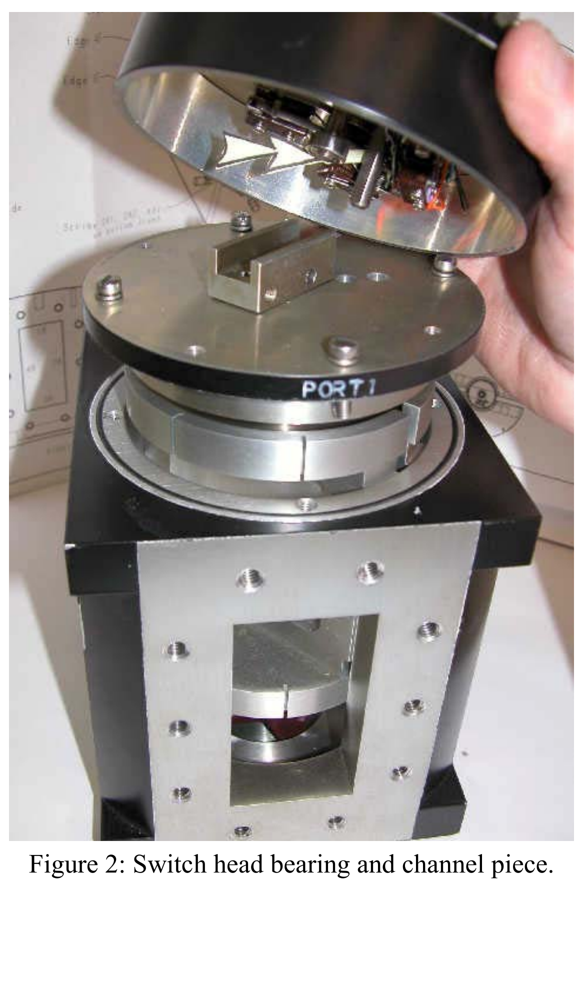

Figure 2: Switch head bearing and channel piece.

High-power testing of WR-284 switches to the extent that results are repeatable has not yet been performed. The great majority of testing has been with WR-340 switches. A factory WR-340 switch sometimes exhibits arcing at peak levels as low as 35 MW, such as the serial number 15 (SN 15) WR-340 switch at the APS. In order to improve this performance, the edges of the aluminum rotor and housing were hand-worked using extremely fine emery cloth backed by flexible lexan. Prior to this rework, the factory irridite finish (shown as silvery in Figure 2) and enamel are removed. Rotor edges that have been reworked are shown in Figure 3, though housing edges were also smoothed. Measurements using an optical comparator indicate that factory edge radii range from 0.002" to 0.008", while handworking increased these radii from 0.014" to 0.030". Following this handworking, the rotors and housing are electropolished to further smooth the edges. This process removes an additional 0.001" to 0.002" from the aluminum surface and thus opens the difference between rotor outer diameter and housing inner diameter 0.004" to 0.008".

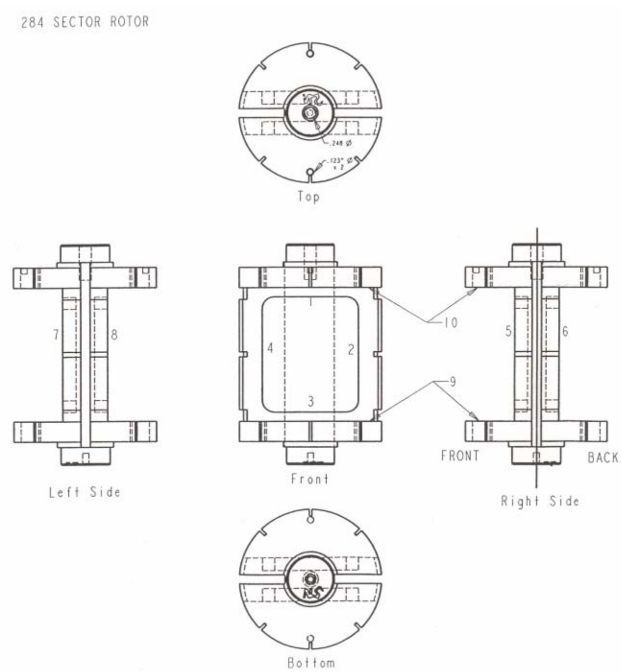

Figure 3: WR-284 rotor edges that are handworked.

Following this rework, the aluminum rotor and housing are irridited with a dark irridite process, and the rotor and housing are reassembled and optimized in alignment. The quality of the new irridite finish on the rotor and housing is more durable and more gold in color than the factory finish, because it follows an electropolish process. Eventually it was determined that the electropolishing and irridite finish alone allowed a WR-340 switch to reliably achieve 45-MW peak with 4-μs pulse, noting that not all factory-grade WR-340 switches are as poor in characteristics as was the SN 15 switch.

CONCLUSIONS

More extensive peak power testing of WR-284 switches is viewed to be necessary. Future purchase orders for WR-340 switches may be similar to the most recent, where the manufacturer supplied matched rotors and housings disassembled and unfinished. That arrangement allowed rework without disassembly of the factory unit. A more efficient option would be for the manufacturer to perform acceptable factory electropolishing and irridite finishing. The electropolish and irridite processes are believed to improve the peak power handling performance of the WR-340 switch by at least 10%. Data for WR-340 switches indicate that handworking offers only a few percent further improvement. At present, only the WR-284 switches receive the laborious handwork process (since operating them at 35 MW constitutes a greater field strength stress than is produced by 45 MW in WR-340).

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