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A HIGH PEAK POWER S-BAND SWITCHING SYSTEM FOR THE ADVANCED PHOTON SOURCE (APS) LINEAR ACCELERATOR (LINAC)*

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Abstract

An S-band linear accelerator is the source of particles and front end of the Advanced Photon Source [1] injector. Additionally, it will be used to support a low-energy undulator test line (LEUTL) and to drive a free-electron laser (FEL). To provide maximum linac availability for all uses, an additional modulator-klystron subsystem has been built, and a waveguide-switching and distribution subsystem is now under construction. The combined subsystems provide a hot spare for any of the five S-band transmitters that power the linac and have been given the additional function of powering an rf gun test stand whenever they are not otherwise needed. Design considerations for the waveguide-switching subsystem, topology selection, timing, control, and system protection provisions are described.

1 DESIGN CONSIDERATIONS

The APS linac [2] uses five 35-MW peak power output, pulsed klystrons, numbered in order from L1 to L5. L1 drives the first 2856-MHz accelerating structure, located just downstream of the electron gun, and L3 drives the sixth 2856-MHz accelerating structure located immediately downstream of the positron conversion target. The L2, L4, and L5 klystrons each drive a SLED cavity assembly [3] that in turn drives four 2856-MHz accelerating structures. A sixth klystron-modulator system has been installed in the linac gallery. Design work is in progress on a waveguide distribution and switching system that will allow the sixth subsystem to serve as a hot spare for any of the others.

The most critical design issues for this system are waveguide switch reliability at 35 MW of peak power and reducing losses to an acceptable operational level.

1.1 Losses and Topology

The loss issue was addressed first because of its critical effect on system topology. A loss budget was established based on maintaining operational characteristics that should allow filling of the storage ring under almost all conditions without adding unnecessary complexity and cost. A basic requirement is to be able to provide good-quality beam at the 400-MeV positron accumulator ring (PAR)/booster-synchrotron injection energy in the event of failure of any one of the klystron-modulator systems. The loss-budget allocations are: 15% power loss at L4 and L5, 25% power loss at L1 and L2, and 25% to 40% power loss at L3. The higher loss at L3 was included specifically to allow consideration of a parallel extra-low-loss path feeding L1 and L2.

There is very little unused space in the linac gallery, restricting long waveguide runs to heights sufficient to clear most other equipment. A height of 15 feet, 4 inches, was chosen in order to allow the run to be placed in front of the klystrons while allowing adequate clearance for smooth replacement of a faulty klystron. The reference design uses WR284 waveguide, which drops down to a waveguide switch located approximately at penetration height near each klystron. This results in a total length of more than 250 feet between L6 and L1 and a predicted loss of just over half the incident power. A modified topology, using an additional waveguide switch located at the height of the main waveguide run, but above each intermediate klystron, reduces the total length to 200 feet. The predicted loss in the modified topology is reduced to 41% of the incident power. With the modified topology, the predicted loss is further reduced to 28% by changing the waveguide size to WR340. This exceeds the 25% loss-budget at L1. Losses at all other klystrons, including L4 which is critical for determining positron injection energy, are within budget. Parallel, more direct waveguide runs, especially using circular waveguide can produce lower losses at L1. However, it is hard to justify the considerable extra expense, since the loss at L4 would not be improved. To verify this reasoning, tests were made of linac operation at reduced L1 power. Reductions much greater than 28% were made without unacceptable performance degradation.

Numerous configurations were evaluated over the course of this effort. When compared to alternatives, the modified daisy-chain design in WR340 either had lower losses at all klystrons or had lower cost with equal or better loss at L4. Losses at L1, L2, and L3 have been determined to be acceptable with this design, although some higher cost designs produced lower losses at one or more of these klystrons. On the basis of the above design analysis process and supporting test results, the modified daisy-chain topology, using two waveguide switches per klystron in WR340 oxygen-free high-conductivity copper

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waveguide, was selected for the switching system.

The original design concept directed power from L6 to a full-power dummy load when L6 was not needed as a hot spare for one of the other linac transmitters. This load is still included in the current design and will be used to verify operational readiness of a transmitter that has been repaired. The addition of two more waveguide switches allows for extra flexibility in the system. Various thermionic rf guns and photocathode rf guns in the linac and in the rf gun test stand can be powered whenever the hot spare function is unused.

1.2 High-Power Reliability

Waveguide switch reliability has been the subject of an ongoing investigation. Thomson CSF indicated that they preferred not to supply 35-MW klystrons for use with SF6 pressurized waveguide because breakdown and conditioning are significant issues above 30 MW [4]. Tests conducted by ANL personnel at SLAC confirmed that breakdown occurred above that level in pressurized WR284. It was also determined that the switches can be severely damaged if breakdown occurs [5].

Two approaches have been considered to increase the power level at which breakdown occurs. The use of a circulator-dehydrator to keep the SF6 both moisture-free and moving has been successfully used at the Duke University Free-Electron Laser Laboratory for trouble-free operation at 34-MW peak power [6]. The decision to build much of the distribution waveguide in WR340 suggests a second approach for which no previous experience is known. Scaling suggests that the breakdown vulnerability threshold at 30 MW in WR284 would occur above 40 MW in WR340.

A test was performed at ANL, in which a WR340 switch was successfully operated at 35 MW using WR284 windows and pressurized tapered transitions.

Additional tests will be conducted at SLAC in the near future to quantify the difference in performance between the two waveguide sizes. In the upcoming tests, all pressurized components, including windows, will be implemented in the waveguide size under test. WR340 windows will be included in the WR340 test set-up. In-house construction of WR340 windows is now underway.

We are proceeding with a design that incorporates both of the above approaches, as shown in Figure 1. WR340 had already been selected for the major portion of the switching and distribution system. Using WR340 for essentially all of it has significant standardization advantages while incurring some additional space problems that have now been solved. Use of a circulator-dehydrator is the practical approach for a relatively large, spread out system in any event.

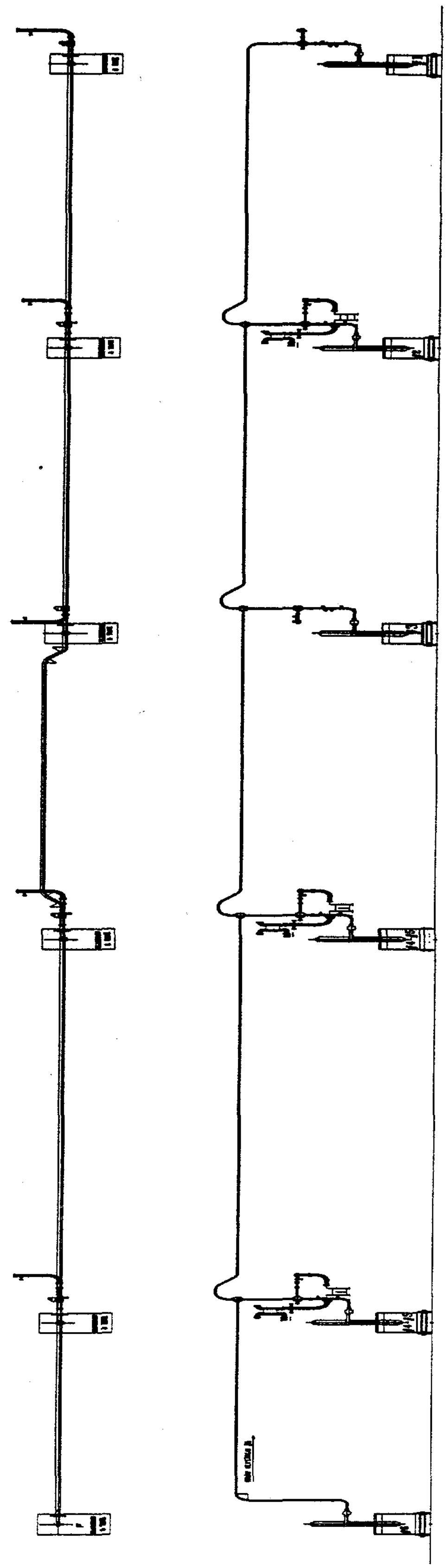

Figure 1: Mechanical layout of the klystron-switching system, by means of which the sixth klystron can be selected in place of any of the five others.

2 TIMING

Each modulator-klystron subsystem receives two modulator triggers, an rf drive gate and a SLED PSK trigger. Each trigger has unique timing requirements that are a function of trigger distribution delays, internal delays, and beam transmission time.

Therefore, a separate timing selection software window will be provided for each linac sector when driven by each allowable modulator-klystron subsystem. The switching control subsystem will provide confirmation of operational mode to EPICS [7], in order to ensure that the correct screens for the confirmed mode are active.

The linac uses two separate trigger repetition rates. The rf repetition rate is a uniform 60 Hz, or sub-multiples thereof, chosen to minimize load-regulation requirements on the modulators. The nominal rf rate is 30 Hz. The beam repetition rate and bunch pattern are completely flexible, up to a maximum of 60 Hz.

Ordinarily, each klystron is triggered synchronously at the rf repetition rate. If a klystron (L1 or L6; possibly L3 in the future) is driving an rf gun that provides beam to the linac, that klystron will be triggered at the beam rate. L6 can also drive the rf gun test stand with asynchronous, stand-alone timing.

3 CONTROL AND PROTECTION

Switching is performed under local control. The system is interlocked so that both the klystron drive and the modulator PFN voltage must be removed from all klystrons that are in the switching path. Klystron drive can be only reapplied following confirmation of successful switch transfer.

Interlocks and auxiliary reflected power protection are automatically switched in tandem with waveguide switching. SLED de-tuning needle position, water flow to the high-power rf components, and vacuum are among the categories included in the switched interlocks.

4 CURRENT STATUS

Our first priority has been the design and construction of items that support linac operation with a photocathode rf gun. Construction of a flexible rf gun test facility that can be operated without interruption, while the linac is injecting into the storage ring, is next on the priority list. Waveguide switches have been ordered. Detailed design is in progress for the main waveguide run and the L1/gun area switching. Our goal is to achieve both of these operating modes very early in 1999, and all activities are progressing well.

Switching between L1 and L6 will follow during the first half of 1999 when the initial part of the control and protection subsystem (or its prototype) can be completed and installed.

Implementation of redundancy-switching of the original five klystrons awaits detailed design and fabrication of the intermediate waveguide drops. Verification of the design and reliability of the control and protection subsystem is also a prerequisite.

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