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# SLAC LINEAR COLLIDER WAVEGUIDE VALVE*

N. R. DEAN, W. R. FOWKES, M. W. HOYT, H. D. SCHWARZ AND E. F. TILLMANN
*Stanford Linear Accelerator Center*
*Stanford University, Stanford, California 94305*

## Abstract

A waveguide valve with a peak RF power handling capability of 70 MW and a reliable vacuum seal was needed for changing the new SLC klystrons. The original SLAC indium seal valve experienced RF breakdown above 35 MW and did not make a reliable vacuum seal. A new design was developed which incorporates the old valve housing but employs a new concept. The indium-knife edge seal has been replaced by an O-ring seal mechanism, which is transported to an RF-free environment during high power operation. The O-ring "garage door" seal RF currents are reduced to a manageable level through the use of an RF choke plunger which has a rejection capability in excess of 20 dB. The isolation between the high power RF and the O-ring chamber exceeds 100 dB.

## 1. Background

High vacuum all-metal waveguide valves have been in use for more than twenty years at SLAC. There is one valve for each of the 244 linac klystrons for the purpose of isolating the accelerator vacuum from the klystron output flange disconnect region during klystron removal and/or replacement (Fig. 1).[1] These valves worked adequately on the linac below peak power levels of about 30 MW. This original SLAC waveguide valve employed a resonant iris coupling the broad walls of parallel waveguides. The reusable vacuum seal on the early waveguide valve was achieved by forcing a circular plunger with a stepped knife-edge into an indium filled groove which was concentric with the circular coupling iris. By periodically remelting the indium, many valve closures were possible.

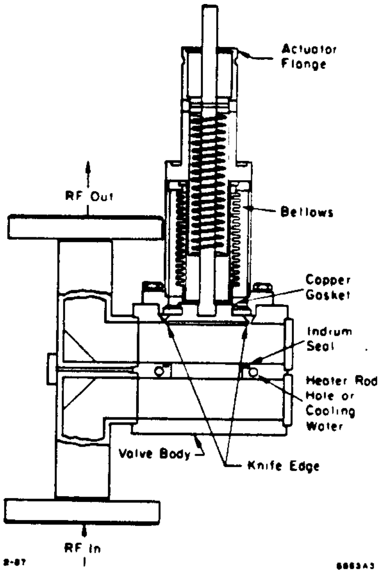

Fig. 1. Original SLAC indium seal waveguide valve.

When higher power klystrons were developed for the SLAC Linear Collider (SLC) it became apparent that this original knife-edge/indium design would be inadequate for the SLC klystron power. The indium had a tendency to adhere to the knife-edge and would tear upon opening, producing sharp jagged points in the upper waveguide chamber ultimately causing RF breakdown during higher power operation. Some indium bits would fall into the lower waveguide chamber.

The backside of the knife-edge plunger had to make good RF contact with the broad wall of the upper waveguide chamber during high power operation. This flexible RF seal also experienced problems on many valves above 30 MW.

It became clear, rather late in the SLC program, that either a new design, a modified design or the elimination of the valve altogether, would be necessary for fault-free 50-70 MW klystron operation. The elimination of the waveguide valve, however, would require venting an entire sector (320 feet of accelerator and eight klystron output waveguide feed sections) each time a klystron was to be replaced. The cost in lost running time to the experimental program of this alternative would be completely unacceptable.

## 2. Design Considerations

A completely new design was attractive because the component could be perfected, manufactured and tested while the old valve continued to serve at reduced power. It became apparent, however, that the original design had some features which might also be employed at high power levels if its major weaknesses (RF breakdown, leaks, etc.) could be eliminated. There would be significant cost savings in using part of the old valve body. The logistics problem of incorporating the new design using the old valve body while keeping the accelerator going was to be solved by temporarily replacing groups of old valves with straight waveguide sections (called "spool-pieces") while the new valve design was incorporated into the modified body. Of course, klystrons could not be changed where "spool pieces" were used without venting the sector.

There was some earlier consideration given to redesigning the indium seal with a deeper indium groove and a hemispherical sealing surface instead of a knife-edge.

The original SLAC design had three locations where either local RF electric field strengths or high current densities across contacts were likely to cause RF electrical breakdown. In the new SLC design the knife-edge and the sharp points having to do with the indium would be completely eliminated. The flexible contacts between the back side of the plunger and the top broad wall of the upper waveguide chamber would also be eliminated. It appeared that the best long-term reliability could be achieved with a design utilizing an elastomer to make the vacuum seal and then be transported to an RF-free environment during high power operation. This would include redesigning the resonant iris to provide a smooth vacuum sealing surface.

The entire piston/O-ring assembly is transported to an RF-free region during high power operation of the waveguide valve. The waveguide short in the upper valve chamber of the original design has been replaced by a choke short followed by a metal-to-metal RF seal backup. The latter provides the "garage door seal" for excluding the RF from the "garage" housing the O-ring assembly. The RF currents in the metal-to-metal seal have been reduced to a manageable level by the presence of the RF choke short which reflects more than 99% of the RF energy incidence upon the choke short face (see Fig. 2).

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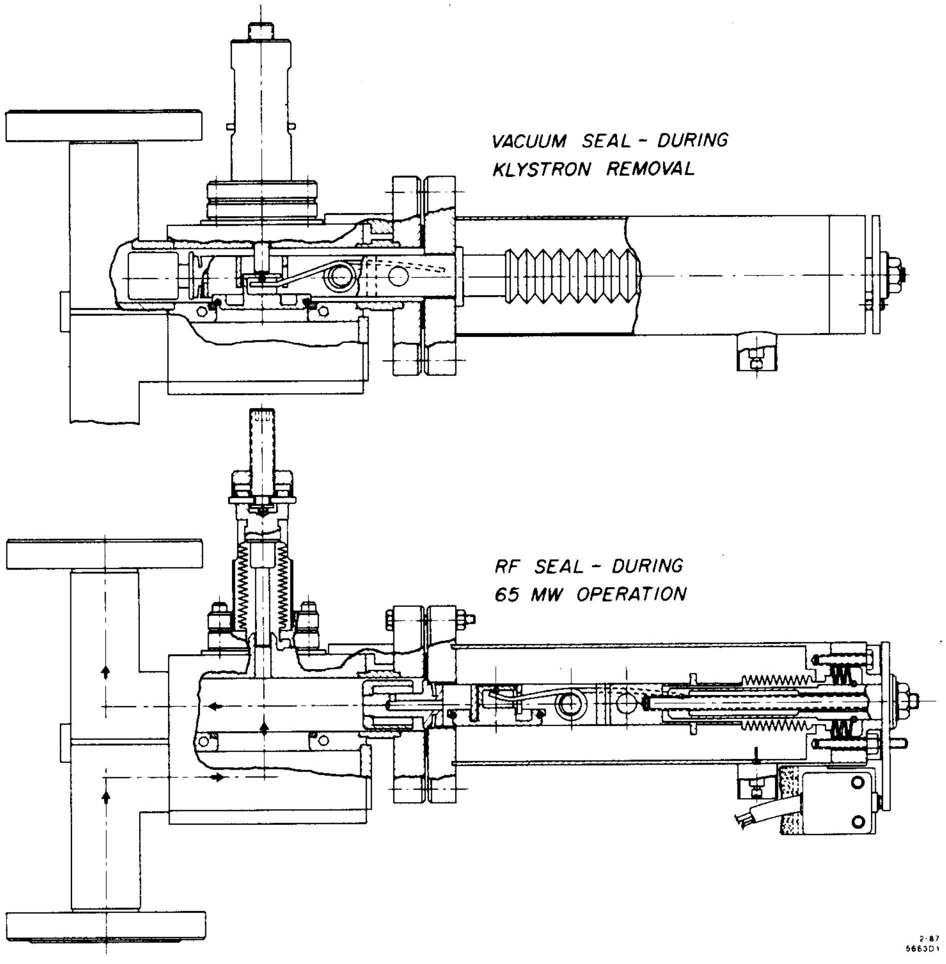

1. Resonant Iris
2. Choke Short
3. Metal-to-Metal Seal
4. O-ring Piston
5. Driver Mechanism
6. Microswitch
7. RF Pick-up Probe
8. Pushrod

Fig. 2. SLC waveguide valve.

The choke short is a rectangular shaped cup that is slightly smaller than the inside dimensions of the rectangular WR-284 waveguide. The cup is designed to provide good rejection for both the $TE_{10}$ waveguide mode and the $TE_{11}$ higher-order coaxial mode. The clearance between the cup's perimeter and the inside of the waveguide is 1.78 mm.

An obvious concern is that RF leakage into the O-ring chamber could damage the O-ring and introduce contaminants into the accelerator vacuum system. An RF pick-up probe was installed in the O-ring chamber in each valve to enable the monitoring of any RF leakage into the chamber. It is estimated that the coupling of this probe to any likely mode configuration in the O-ring chamber will be 15 dB or less. The maximum tolerable RF leakage into the O-ring chamber has been somewhat arbitrarily set at 2 W peak (1.3 mW average) power. The ratio of power transmitted through the waveguide valve to power measured by the probe into a 50 $\Omega$ load, should be greater than about 90 dB for operation at 65 MW.

Each SLC waveguide valve is RF cold-tested and tuned after fabrication but before final bake. The VSWR at the operating frequency is typically 1.15 before tuning. After tuning the VSWR is less than 1.02 at 2856 MHz and has a bandwidth of about 3.5% where the VSWR is less than 1.10 (see Fig. 3). A scaler network analyzer is used to generate return loss versus frequency plots and to aid in the tuning for each valve. The tuning consists of dimpling the lower waveguide mitre bend to bring the VSWR at the operating frequency to less than 1.02.

The effectiveness of the RF choke short and the "garage door seal" is measured by amplifying the signal from the pick-up probe by 30 dB into a calibrated crystal detector with 1 W cw into the waveguide portion of the valve. The detector sensitivity is 0.0013 mW/mV. This test arrangement is capable of measuring RF leakage into the O-ring chamber that is 108 dB below the waveguide power.

A few of the early SLC prototype waveguide valves were high-power tested to 65 MW. The first versions of the RF "garage door seal" did not provide the needed RF exclusion from the O-ring chamber without putting excessive stress on the driver mechanism. A "double-flex" version of the aluminum plug was developed which provided consistent RF seals with the required RF isolation with less than 14 N-m of torque on the driver mechanism.

## 3. Mechanical Features

Waveguide valve components are fabricated and tested in accordance with SLAC specification PF-202-631-14-R1 (UHV components). After RF testing and tuning all production valves are nitrogen purge baked at 140° C for a minimum of 24 hours.

Once installed on the accelerator, each valve remains in the RF operating position (Fig. 2b) until a klystron tube requires removal or replacement. A microswitch interlock provides protection to each valve so that in the event of attempted actuation of the O-ring/piston assembly while the tube is in operation, the station will shut off. This interlock is also linked in series to a vacuum gauge which prevents tube operation at pressures above $3.3 \times 10^{-4}\,Pa$ ($2 \times 10^{-6}$ Torr).

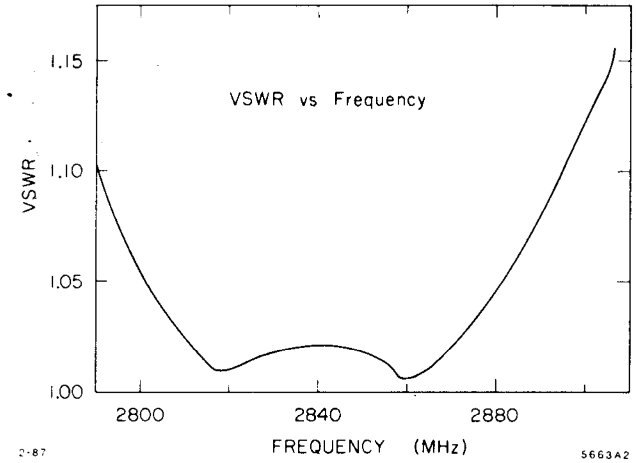

Fig. 3. Frequency response of typical SLC waveguide valve.

The force necessary to maintain the metal-to-metal "garage door seal" which excludes RF from the O-ring chamber is 38 N×linear $\mathrm{cm}^{-1}$. This sealing force is produced by compressing a series of five Belleville washers between the end cap of the O-ring chamber and the O-ring assembly driving spindle to 7.6 kN. Once compressing forces are reduced, rotation of the spindle will advance the thread driven O-ring/piston assembly to a position over the centerline of the iris. The vacuum seal is formed when the pushrod is advanced through its below cutoff guide in the broad wall of the upper waveguide chamber, moving the spring-loaded O-ring piston downward. The O-ring compresses ~10% against the seat portion of the iris, thus forming the vacuum seal. The force maintained on the O-ring seal is 50 N×linear $\mathrm{cm}^{-1}$. The spring-loading feature of the O-ring piston utilizes two stainless steel torsion springs supplying 4.7 N-m of return torque insuring the piston returns to its rest position when the pushrod is withdrawn and the O-ring/piston assembly is to be retracted into the O-ring chamber.

## 4. Valve Tests

During the pilot run of valve production, tests were conducted with two valves to determine the reliability and life expectancy of the new design. The testing consisted of complete closure cycles from the RF operation position (Fig. 2b) to the vacuum seal position (Fig. 2a). The tests were carried out at two levels of vacuum $\sim 10^{-3}$ and $2.7 \times 10^{-7}\,Pa$ ($\sim 10^{-5}$ and $2 \times 10^{-9}$ torr). During the test conducted at $\sim 10^{-3}\,Pa$ the internal moving parts were free-moving and 100 cycles were completed. When the test valves were operated at $2.7 \times 10^{-7}\,Pa$ however, the linear motion of the O-ring piston shaft within the bore of the plug became increasingly sticky, failing to travel the distance necessary to form a vacuum seal on the eleventh cycle.

It became apparent that at normal operating pressures ($10^{-7}\,Pa$), a means of reducing the friction coefficient would be necessary for reliable operation of the valve. The material selection had already been made (6061 aluminum for the plug and 304 stainless steel for the piston) and the tolerances of these mating parts allowed adequate interpart clearances: .127 to .177 mm per wall between the piston shaft and the plug bore. A dry lubricant was determined to be an acceptable solution. A tungsten disulfide coating of $\sim 1\,\mu m$ thickness was applied, by a diffusion bonding[2] process, to both the bore of the plug and the shaft of the O-ring piston. After completion of the WS2 coating process, the two test valves were reassembled and tested again at a pressure of $1.6 \times 10^{-7}\,Pa$. We were now able to complete 500 closure cycles on each valve without sticking problems. The test valves were then disassembled and inspected. Some of the WS2 coating had worn in spots; more WS2 had worn off the aluminum part. Following these tests, the WS2 coating was applied to all production valves.

Production of the valves was temporarily interrupted as a result of a quality control problem with the viton O-rings. A high percentage of O-rings had manufacturing defects which prevented forming a vacuum seal with an acceptable leak rate (less than $10^{-8}$ standard cc/sec).

Microscopic examination of these O-rings revealed voids in the O-ring flashing as a result of a worn O-ring mold, in addition to macroscopic inclusions within the viton. Microscopic examination of all O-rings became necessary to ensure only the highest quality O-rings were used on production valves.

## 5. Current Status

SLC waveguide valve installation began January 1986. As of February 1987, 233 of these valves have been installed on the linear accelerator. One valve was removed from operation shortly after being installed due to an electrical breakdown problem inside the valve. The remaining 232 waveguide valves have been functioning very well. In addition to meeting the requirements of 70 MW klystron operation that prompted conversion of the waveguide valves to the SLC-type, the greatly reduced manpower requirements to facilitate klystron tube changes has been an added benefit.

Prior to the waveguide valve conversion, many of the old valves had vacuum seal leaks large enough to necessitate venting an entire linac sector in order to change a klystron. Linac operations were interrupted and ~24 man-hours were required in connection with the venting and subsequent pumpdown of a linac sector.

The reliability of the SLC waveguide valve has eliminated this manpower requirement. Current manpower utilized for a klystron change is approximately two man-hours, and without interruption to linac operation.

## Acknowledgement

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