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TEST
ACCELERATOR

NLCTA-Note #18

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Subject: Molecular-transport considerations in the design of the SLED-II vacuum system

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The purpose of this Note is to examine molecular-transport considerations in the SLED-II vacuum system in order to design a pumping scheme that will achieve our rough goals for maximum pressure without rf: 3×10^{-8} Torr in the SLED-II 3-dB coupler and rectangular-waveguide components, and 10^{-7} Torr in the circular waveguides. We use the "Vaktrak" computer program[1] to estimate the pressure profile in the presence of pumps, outgassing sources, and conductance limits in a numerical model of the SLED-II vacuum system. The molecular conductances of the rf and vacuum components, which the program requires, have been estimated analytically, as described below. Several cases of varying outgassing and pumping were simulated in order to draw conclusions about what is necessary to achieve the pressure goals.

Conductance Estimates of RF and Vacuum Components

The molecular transport conductances of the components in the vacuum system were estimated using the following approximate formulae,[2] which are fine for N_2, CO, and air (and only 20% low for H_2O) at 300°K:

For a rectangular duct of cross-section $W \times H$ and length L:

$$C_{duct}(W,H,L) = (200\ \mathrm{l/s \cdot in^2}) \frac{W^2 H^2}{(W+H)L}.$$

For a long tube of diameter D and length L:

$$C_{tube}(D,L) = (80\ \mathrm{l/s \cdot in^2}) D^3/L.$$

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[1] V. Ziemann, "Vacuum Tracking," SLAC-PUB-5962 (1992).

[2] R. W. Carlson, "Molecular Transport" in *Methods of Experimental Physics, Vol. 14 (Vacuum Physics and Technology), Section 1.3* (Academic Press, Inc., 1979).

For a conical taper from diameter D_1 to D_2, of length L:

$$C_{cone}(D_1,D_{2,},L)=(80\ \mathrm{l/s\cdot in^2})D_1^2D_2^2/\overline{D}L.$$

For a thin hole of area A:

$$C_{hole}(A)=(77\ \mathrm{l/s\cdot in^2})A.$$

For this calculation, the SLED-II vacuum system is modeled as the serial network of components sketched in Figure 1. The conductances of all components are modeled after their prototypes currently in use for SLED-II R&D in the Klystron Test Lab. The model vacuum system includes the following components in sequential order (from left to right in the sketch):

(1) **Pumped adjustable short.** Molecules that pass through the 0.050" annular gap between the shorting plunger and the wall of 4.75-inch diameter waveguide are removed by an ion pump appended to a 2-inch long tubulation of 1.4-inch inner diameter. The conductance of the annular gap (approximated by a rectangular duct) is $C_{duct}(4.75"\pi,0.05",0.3")=25\ \mathrm{l/s}$. The conductance of the tubulation is approximately $C_{tube}(1.4",2")=100\ \mathrm{l/s}$. A reasonable choice for the ion-pump speed is $S=20$ or 40 l/s. The effective pumping speed through the adjustable short will be $(C_{duct}^{-1}+C_{tube}^{-1}+S^{-1})^{-1}=10$ or 13 l/s, depending on whether S is 20 or 40 l/s.

(2) **WC475 waveguide.** The primary source of gas in each delay line is approximately 120 ft of 4.75-inch diameter waveguide. The rate of gassing per unit area, without baking, is expected to be approximately $10^{-9}\ \mathrm{Torr\text{-}l/s\text{-}cm^2}$. The corresponding rate per unit length is $3.8\times10^{-6}\ \mathrm{Torr\text{-}l/s\text{-}m}$. Baking at 150°C can reduce these gassing rates by at least two orders of magnitude. The conductance-length product is $C_{tube}(4.75",L)L=220\ \mathrm{l\text{-}m/s}$.

(3) **Conical taper.** The conical taper in each delay line is approximately 17 inches long and has conductance $C_{cone}(1.8",4.75",17")=100\ \mathrm{l/s}$.

(4) **Coupling iris.** The coupling iris in each delay line is a thin aperture of approximately 1.2-inch diameter. The conductance is $C_{hole}(\frac{1}{4}\pi(1.2")^2)=87\ \mathrm{l/s}$.

(5) **Circular waveguide pumping port.** A circular waveguide pumping port is a tube of 1.8-inch diameter, about 10 inches long, perforated by an azimuthal array of 48 holes of 0.125-inch diameter. The conductance of the 48-hole array is $48C_{hole}(\frac{1}{4}\pi(0.125")^2)=45\ \mathrm{l/s}$. The holes are connected to a pump by a 2-inch long, 1.4-inch diameter tubulation. The conductance of the tubulation is $C_{tube}(1.4",2")=100\ \mathrm{l/s}$.

A reasonable choice for the ion-pump speed is $S = 20\ \mathrm{l/s}$, or 40 l/s if two 20-l/s pumps are attached to the pump port. The effective pumping speed of the port will be $S^* = [(48C_{hole})^{-1} + C_{tube}^{-1} + S^{-1}]^{-1} = 12$ or 17 l/s, depending on whether S is 20 or 40 l/s. The conductance of the waveguide through the pumpout is $C_{tube}(1.8", 10") = 47\ \mathrm{l/s}$.

(6) Flower-petal mode transducer. A flower-petal mode transducer consists of two parallel ducts of WR90 waveguide, each approximately 10 inches long. Each duct is connected, through a pair of thin apertures (the flower petals), to a common 1.8-inch-diameter waveguide 6 inches long. The conductance of each of the two parallel WR90 ducts is $C_{duct}(0.4", 0.9", 10") = 2.0\ \mathrm{l/s}$. The conductance of each of the four parallel flower-petal apertures is approximately $C_{hole}(\frac{1}{4}\pi(0.3")^2) = 5.4\ \mathrm{l/s}$. The conductance of the common circular waveguide is $C_{tube}(1.8", 6") = 78\ \mathrm{l/s}$. Therefore, the net conductance through the mode transducer is $[(2C_{duct})^{-1} + (4C_{hole})^{-1} + C_{tube}^{-1}]^{-1} = 3.2\ \mathrm{l/s}$.

(7) Rectangular waveguide pumping port. A rectangular waveguide pumping port is a WR90 duct, 6 inches long, perforated by 105 holes of 0.052-inch diameter. The conductance of the 105-hole array is $105C_{hole}(\frac{1}{4}\pi(0.052")^2) = 17\ \mathrm{l/s}$. The holes are connected to a pump by a 2-inch long, 1.37-inch diameter tubulation. The conductance of the tubulation is $C_{tube}(1.37", 2") = 100\ \mathrm{l/s}$. A reasonable choice for the ion-pump speed is $S = 20\ \mathrm{l/s}$, or 40 l/s if two 20-l/s pumps are attached to the port. The effective pumping speed of the port will be $S^* = [(105C_{hole})^{-1} + C_{tube}^{-1} + S^{-1}]^{-1} = 8.4$ or 11 l/s, depending on whether S is 20 or 40 l/s. The conductance of the waveguide through the pumpout is $C_{duct}(0.4", 0.9", 6") = 3.3\ \mathrm{l/s}$.

(8) SLED-II 3-dB coupler. This will be a hybrid coupler (possibly a Magic Tee), which is a junction of four WR90 ducts. Because of the symmetry of the SLED-II vacuum network, we need only to consider two of the four ducts. (There will be no net molecular flow to the other half of the coupler.) We will model the entire coupler as a single 15-inch-long duct of WR90, with conductance $C_{duct}(0.4", 0.9", 15") = 1.3\ \mathrm{l/s}$.

(9) Rectangular waveguide pumping port. (Described above.)

(10) Flower-petal mode transducer. (Described above.)

(11) Circular waveguide pumping port. (Described above.)

(12) Conical taper, about 12 inches long, from 1.8-inch diameter to 2.93-inch diameter. $C_{cone}(1.8", 2.93", 12") = 81\ \mathrm{l/s}$.

(13) WC293 transmission-line waveguide. Another significant gas source is a transmission-line waveguide, 2.93 inches in diameter, in roughly 40-ft sections separated by circular waveguide pumping ports (described above). Here, in order to find an optimal distance between pumping ports, we model the transmission line as a semi-infinite chain of alternating WC293 tubes and pumping ports. The rate of gassing per unit area, without baking, is expected to be approximately 10^{-9} Torr - l / s - cm^2. The corresponding rate per unit length is 2.4×10^{-6} Torr - l / s - m. Baking at 150 °C can reduce these gassing rates by at least two orders of magnitude. The conductance-length product is $C_{tube}(2.93", L)L = 55$ l - m / s.

Simulations

Several design considerations become clear when varying some of the parameters in the model of the vacuum system. Several cases were simulated, as described below. The results are shown in Figure 2.

Case 1: All pumps speeds were 40 l/s, and the outgassing rate of all circular waveguides was 10^{-9} Torr - l / s - cm^2 (corresponding to chemically etched but unbaked surfaces). The rectangular waveguide components were assumed to be gas-free. The pressure in the SLED-II coupler was 4×10^{-7} Torr, and the pressure in the circular waveguide was 3–8$\times 10^{-6}$ Torr. These pressures are too high for operation of the SLED-II at high power.

Case 2: The outgassing rate in all circular waveguide was decreased by two orders of magnitude, to 10^{-11} Torr - l / s - cm^2, consistent with a bake-out at 150°C for several days. The pressure dropped by the same factor (100) everywhere, even in the gas-free rectangular waveguide components—the pressure in the SLED-II coupler became 4×10^{-9} Torr. This situation is acceptable for high-power operation, and provides a large safety margin.

Case 3: The greater outgassing rate (10^{-9} Torr - l / s - cm^2) was applied to the transmission line, but the lower outgassing rate (10^{-11} Torr - l / s - cm^2) was applied to the delay line. The result shows that the transmission-line and delay-line regions are isolated by the conductance-limited coupler region. However, the gas load from the delay line raised the pressure at the coupler to 10^{-7} Torr, which is too high.

Case 4: The lower outgassing rate (10^{-11} Torr - l / s - cm^2) was restored to all circular waveguide, and the circular-waveguide pumpout (5) near the SLED-II delay-line iris was replaced by a high-conductance spool-piece (effectively removing the pump port and its associated conductance limitation). While the pressure in the coupler

(7×10^{-9} Torr) may be acceptable, the pressure in the nearby flower-petal mode transducer (10^{-7} Torr) may be too high.

Case 5: The outgassing rate was kept low, and the rectangular-waveguide pumpout (7) nearer the delay-line was replaced by a high-conductance spool-piece. The pressure in the coupler is approximately 10^{-8} Torr, the flower petal is three times higher. This situation is acceptable, and has fewer pumps than Case 2.

Case 6: The pumping speed at all the pump ports was cut in half (from 40 l/s to 20 l/s). The pressure increased by about 70% (restrained by the conductance limitations of the pump ports) which is still acceptable.

Conclusions

The greatest gas load comes from outgassing in the large-diameter circular waveguides. The pressure in the 3-dB coupler (a rectangular-waveguide component) is proportional to the outgassing rate (per unit surface area) in the circular-waveguide delay lines and transmission lines. Consequently, the outgassing rate of the circular waveguides must be reduced to 10^{-11} Torr-l/s-cm^2, which will require some form of bake-out.

Pump speeds of 20 l/s at all pumping ports (Case 6) should be adequate. Speeds of 40 l/s at all ports (Case 5) will provide an extra margin of safety. Pump speeds greater than 40 l/s are unnecessary, given the conductance limitations of the pumping ports and the adjustable short.

Acceptable pressure was simulated in straight pump-to-pump runs of 120 ft for WC475 (delay lines) and 40 ft for WC293 (transmission lines).

The simulations show that the design goals—3×10^{-8} Torr in the SLED-II 3-dB coupler and rectangular-waveguide components, and 10^{-7} Torr in the circular waveguides—can be achieved using the same vacuum components and techniques that are currently used in the SLED-II R&D program in the Test Lab.

SCHEMATIC DIAGRAM OF SLED-II VACUUM SYSTEM

Not to scale.

Circ. Waveguide is cross-hatched.

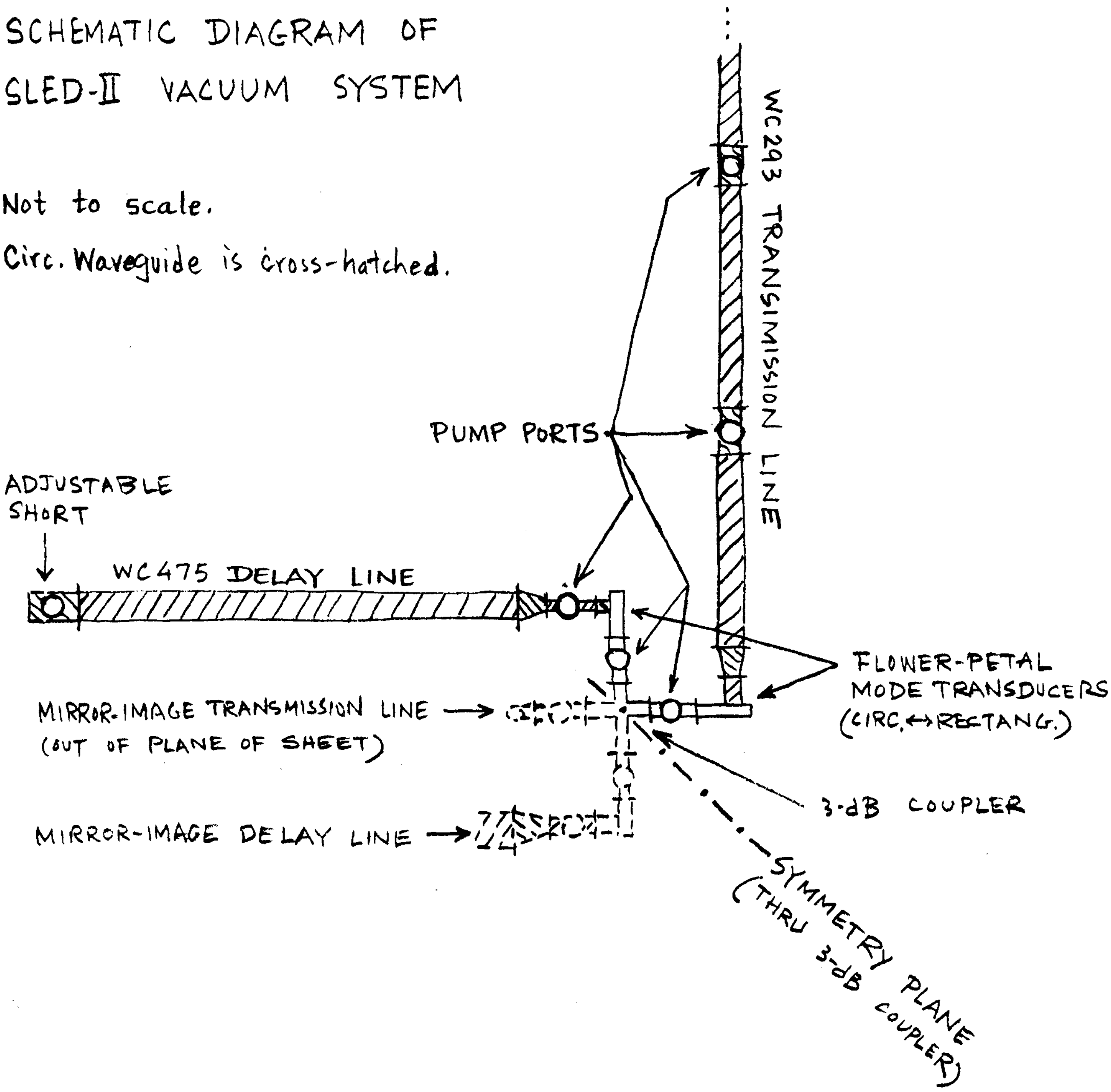
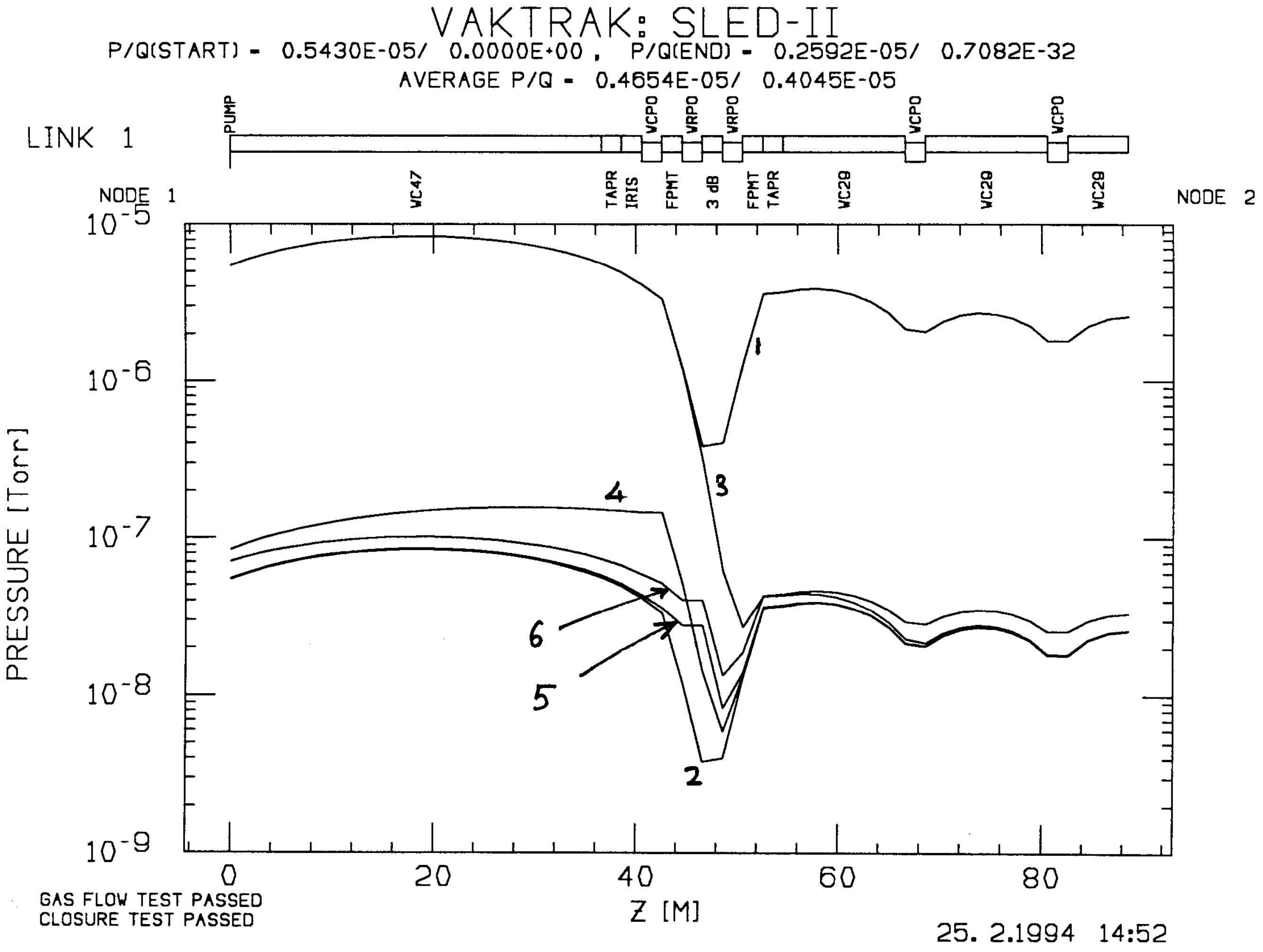


Fig. 1


VAKTRAK: SLED-II
P/Q(START) = 0.5430E-05/ 0.0000E+00 , P/Q(END) = 0.2592E-05/ 0.7082E-32
AVERAGE P/Q = 0.4654E-05/ 0.4045E-05
LINK 1
PUMP
VCPO
VRPO
VRPO
VCPO
VCPO
NODE 1
WC47
TAPR
IRIS
FPMT
3 dB
FPMT
TAPR
WC28
WC28
WC28
NODE 2
PRESSURE [Torr]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0
20
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60
80
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1
2
3
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6
GAS FLOW TEST PASSED
CLOSURE TEST PASSED
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Fig. 2