Waveguide Chase Temperature
Between the SNS Klystron Building and Linac Tunnel

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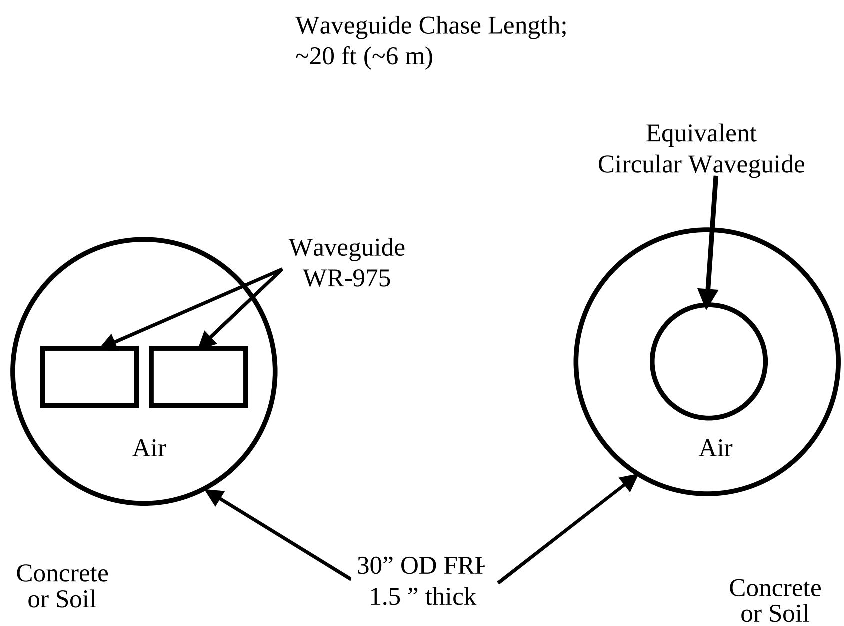
Abstract

The waveguide chases between the klystron building and the linac tunnel will be heated due to rf-dissipation on the waveguide walls. The present layout of the waveguide chase has no active cooling and is thermally well-insulated system. This study is for estimation of the temperature rise of the waveguide and the chase during operation.

Introduction

A waveguide chase for the 805 MHz, 500 kW klystron will have two waveguides, several power/signal lines, and the outer FRP pipe which is surrounded by concrete/soil. Each waveguide will generate 11.8 W/ft that corresponds to 38.7 W/m or 52.1 W/m^2. The length of the waveguide chase is about 6 m. So the total power generation in the waveguide chase is ~460 W.

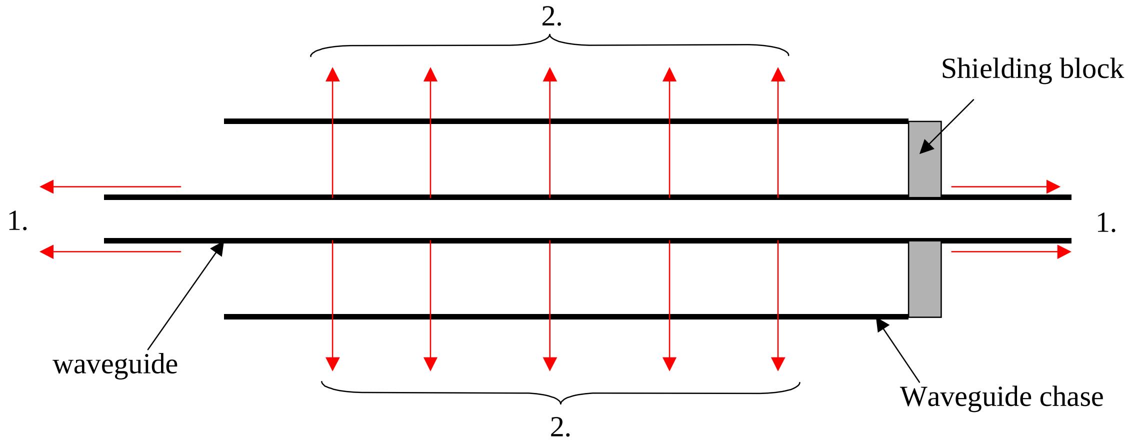


(a) actual waveguide chase cross section (b) simplified waveguide cross section

Figure 1. Cross-sections of (a) the waveguide chase and (b) the one simplified for 2-D FEM analysis. (805 MHz, 500 kW power transfer example)

In order to make the problem simple, these two rectangular waveguides are replaced with a circular waveguide whose surface area is equal to those of two rectangular waveguides combined. The equivalent 2-D cylindrically symmetry model is explained in Figure 1.

Two paths of heat transfer are considered here. One is simple heat conduction through the waveguide wall which corresponds to “1” in Figure 2, and the other is heat transfer to the concrete/soil via air in the waveguide chase, which is “2” in Figure 2. The linac tunnel end of the chase is blocked for the radiation shielding, so confined air is assumed inside the chase.



1. : heat transfer through the waveguide wall
2. : heat transfer through the surrounding concrete

Figure 2. Heat transfer model for waveguide chase.

For a reasonable concrete/soil thickness, which is actually semi-infinite, temperature profiles were analyzed by increasing this thickness. The temperature profile changes are negligible when the thickness is more than 10 ft (3 m). Hereafter 10 ft (3 m) is used for thickness of concrete/soil. The material properties used here are summarized in Table 1.

Table 1. Material properties

	Concrete (or Soil)	Aluminum	Air
Density (kg/m^3)	~2500	2707	~1.1
Specific Heat (J/kg/K)	880	896	~1000
Heat conduction coeff. (W/m/K)	~1	204	~0.027
Viscosity (kg/m/s)			~2x10^{-5}
Emissivity	~0.8	~0.2	

Waveguide Temperature in Steady State

In steady state, following simple relation is satisfied.

Pgen (=460 W) = P1 +P2
P1: heat transfer through the waveguide wall (simple conduction)
P2: heat transfer to the concrete/soil

P2 is the power that the surrounding concrete receives, can be divided into the radiation heat transfer and the heat transfer via air. For the radiation heat transfer between real waveguides and the surrounding wall, 0.75 is used as a shape factor. By changing P2, temperature profiles and P1 are found to satisfy the above relation. The waveguide temperature at about 3 m away from the chase is set at 300 K as a boundary condition for the calculation of P1. The maximum temperature rise of waveguide is about 55 K. The conduction heat transfer through the waveguide wall is about 30 W, the radiation heat transfer is about 390 W. The waveguide will reach its maximum temperature in a few tens of minutes.

Temperature of Concrete around Waveguide Chase

The above analysis indicates that about 430 W (~72 W/m) from the two 500 kW, 805 MHz waveguides will be transferred to the surrounding concrete/soil which will be heated up. In order to estimate the temperature of the surrounding concrete/soil during the operation and after rf turn off, a 2-D transient analysis has been done. Figure 3 shows the temperature behavior of the maximum temperature point of the surrounding concrete/soil. The concrete temperature will reach about 320 K at about 10^7 sec after rf turn-on. And after turn-off, the temperature will decrease as shown in Figure 3. It will take about 200 hours for the maximum concrete temperature to have 310 K (dT=10 K), and will take about 1900 hours to have 301 K (dT=1 K). In this analysis the heat capacity of air inside chase is neglected.
Figure 4 shows the temperature profile of concrete/soil at the time of 200 hours after rf turn-off.

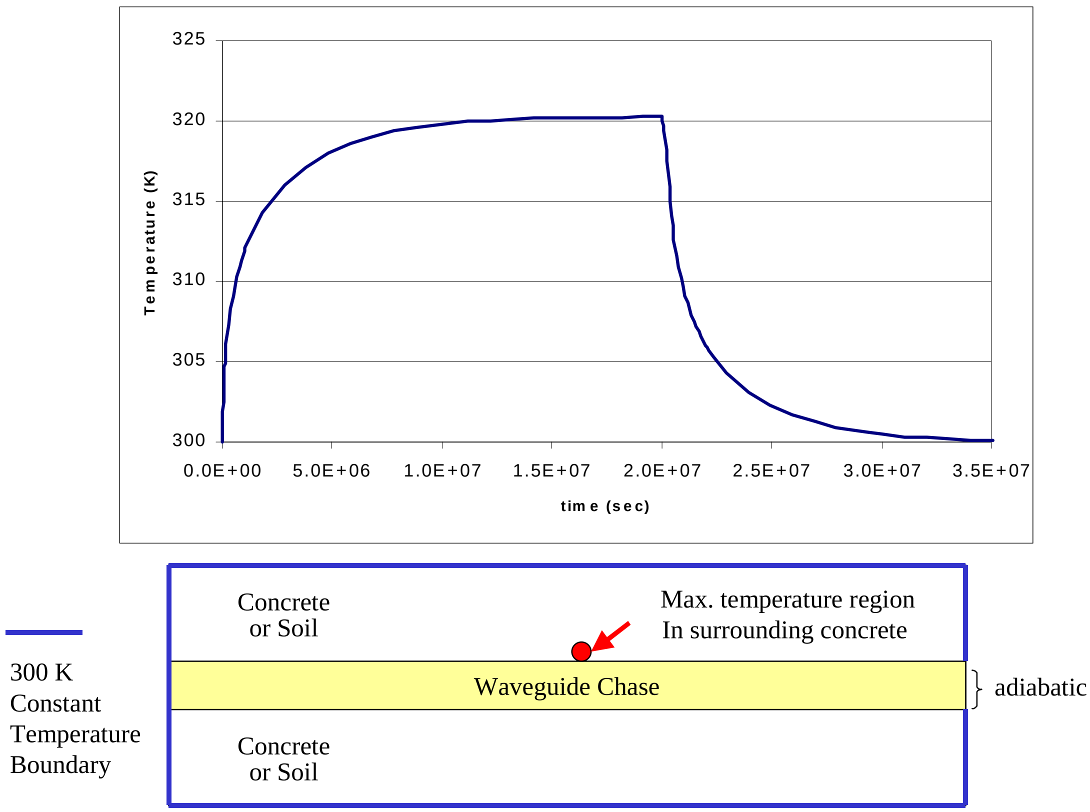


Figure 3. Time history of concrete temperature. At t=0, full power rf is turned on, and at t=2e7sec rf power is turned off.

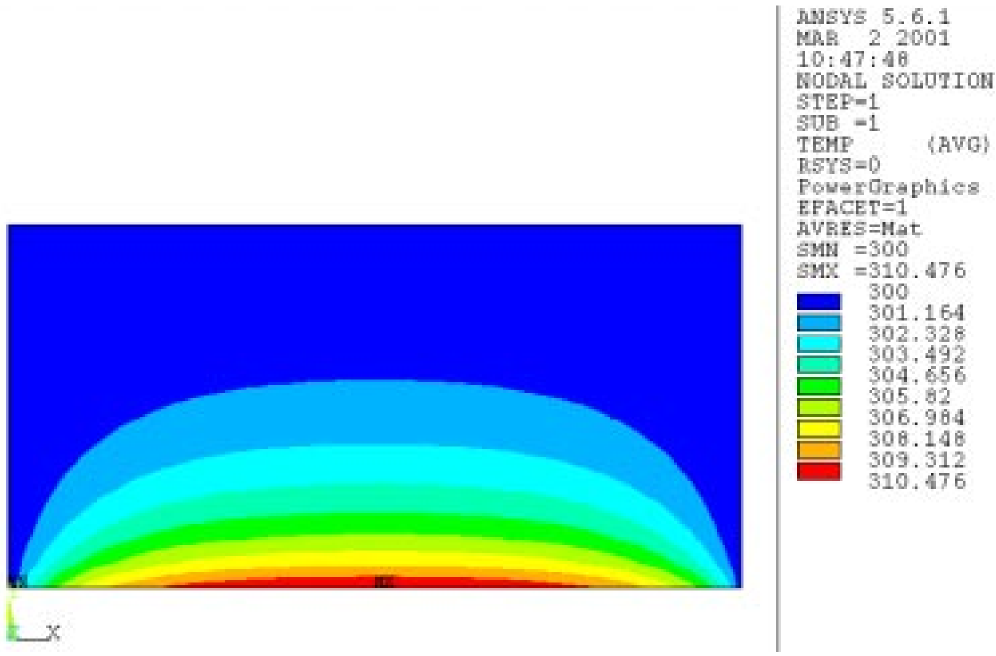


Figure 4. Concrete temperature at 200 hours after rf turn off. (concrete region only)

Summary and Recommendation

Thermal analysis has been done to estimate the temperature behavior of the waveguide chase for 805 MHz, 500 kW, 7% duty cycle rf power transfer from the klystron building to the linac tunnel. Results are summarized as follows:

- the maximum temperature rise of the waveguide: ΔT~55 K
- the maximum temperature rise of the surrounding concrete: ΔT~20 K
- the length of time for the surrounding concrete to reach ΔT=10 K after rf turn-off: ~ 200 hours
- the length of time for the surrounding concrete to reach ΔT=1 K after rf turn-off: ~ 1900 hours

Other analysis such as forced flow air convection cooling has been done, which shows that about 40 l/s forced air flow is enough to maintain the waveguide temperature rise to less than 20 K, but there will be an activated air treatment problem, so this concept is excluded from consideration.

- water cooling of waveguide, that can extract about 400 W (200 Wx2) is preferable.
- in this case, the air temperature rise at the reference signal cable location: ΔT < 3 K (Figure 5)

The surface heat flux of 402.5 MHz, 5MW waveguide chase is about 30% higher than that of 805 MHz, 500 kW case. But the conduction area of the waveguide wall is larger by 60%. The temperature increase will be very close to each other. So the water cooling is also necessary for this waveguide.

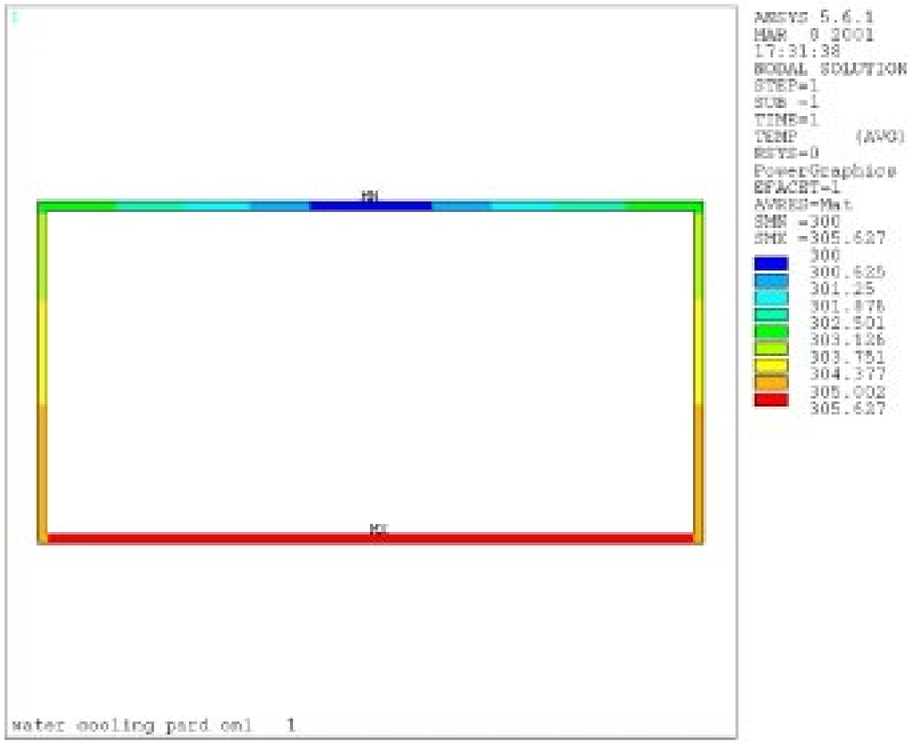


Figure 5. Waveguide temperature profile with water cooling (half inch constant temperature line on the top is assumed).