COOLING OF STANDARD S-BAND WAVEGUIDE

During accelerator operation it is important that the 60 feet of waveguide feeding each 10 feet of accelerator pipe be maintained at a temperature which does not vary with time. The temperature level as well as spacial temperature variations which are less than 2-3° F are relatively unimportant.

We are given in TW-61-26 that the standard S-band waveguides are 2.840" x 1.340" inside and that at 24 MW operation (Stage II) the waveguide skin heat generation rate, q", is 11.1×10^{-3} cal/cm² sec.

Let us assume that the ambient temperature may vary from 30° F to 110° F, that the waveguide operates at about 100° F, the waveguide wall thickness is 7/32 inch, that the allowable waveguide temperature variation (with time) is ± 1/4° F, and that the waveguide is cooled by two parallel water channels, one on either of its larger sides.

Our problem then is to design a system in which the waveguide and cooling water are closely coupled, and the waveguide and the ambient air are thermally isolated. We must, therefore, obtain a high convective heat transfer coefficient on the water side and a low effective coefficient on the air side.

To stay within the 2-3° F allowable spacial temperature variation, we need a water flow rate of 3070 - 2050 lb/hr. So, let us pick 5 gpm (2500 lb/hr) for 2-1/2° F temperature difference. There are two parallel channels so 1250 lb/hr flows through each.

To keep the convection heat transfer coefficent high we must demand that the flow be turbulent and to assure ourselves of the latter, let us require that Re ≥ 5000. Since $Re = w\, De/A_c\, \mu$ we find that we must choose a flow passage which satisfies the condition

$$De/A_c \geq 0.566 \ \ 1/\text{inch}.$$

For a rectangular tube with inside dimensions a x b

$$A_c = ab,\ D_e = 2\,ab/(a + b)$$

from which

$$a + b \leq 3.53 \text{ inch.}$$

This gives us an idea then of the maximum allowable size of cooling channel.

For convection heat transfer we have the dimensionless correlation

$$S_t\, P_r^{\,2/3} = 0.023\ R_e^{-0.2}$$

from which

$$h = \frac{.023\ C_p \mu^{\,0.2}}{P_r^{\,2/3}} \qquad \frac{w^{0.8}}{A_c^{\,0.8}\ D_e^{\,0.2}}$$

For water around 100° F and for our flow rate of 1250 lb/hr.

$$h = \frac{3.17}{A_c^{\,.8}\ D_e^{\,.2}} = 2.76\ \frac{(a + b)^{0.2}}{ab}$$

Now, the heat removal rate

$$q = hA\,(t_{wg} - t_{water})$$

therefore

$$t_{wg} - t_{water} = 18.5\ \frac{a}{(a + b)^{0.2}}$$

Since we can tolerate 1/4° F temperature variations in the waveguide, we can afford to lose $0.25/(t_{wg} - t_{water})$ of the total heat generated to the surrounding air when the waveguide to air temperature difference is a maximum (70°). The heat loss to the air through an insulation blanket is

$$q = kA\Delta t/x.$$

The average heat flow area through the insulation will be about 55 ft^2 (assuming about 1 inch insulation thickness). The Δt is 70° F and the lowest thermal conductivity we can expect is k = 0.025 Btu/hr - ft - °F. Then the thickness must be

$$x = \frac{9.60}{q} = \frac{9.60\ (t_{wg} - t_{water})}{0.25} = 1.16\ \frac{a}{(a + b)^{0.2}}$$

Thus, we have obtained the necessary insulation thickness as a function of the cooling channel dimensions. Note that the smaller the water channel dimensions, the smaller the necessary insulation thickness becomes. It must be remembered that since we have fixed the flow rate, the pressure drop and consequently the pumping power increases with decreasing channel size. Perry, Chemical Engineers Handbook, indicates that a pipe with a 1/2 square inch flow area is not far from the economic optimum. It must be remembered that we are not using commercial pipe, but something more expensive. The economic optimum would then tend toward somewhat smaller channel dimensions. To counterbalance this, we must remember that the rectangular channel has more surface area per unit flow area which results in a larger pressure loss. The 1/2 x 1 inch rectangular channel is therefore a reasonable size and one which will require that a reasonable amount of insulation (7/8 inch) be placed all around the waveguide. This size is also well below the $a + b = 3.53''$ upper limit we found earlier.

Assuming a 0.050" wall thickness the 120 feet of cooling channel associated with each 60 foot waveguide run will weigh about 75 lb/wg.

The maximum temperature difference around the periphery of the standard S-band waveguide (mid-point of small side to mid-point of large side) was calculated for the cooling configuration described. The maximum temperature difference expected is about 1° F.