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HEAT TRANSFER CALCULATIONS FOIL WIGGLER MASKS

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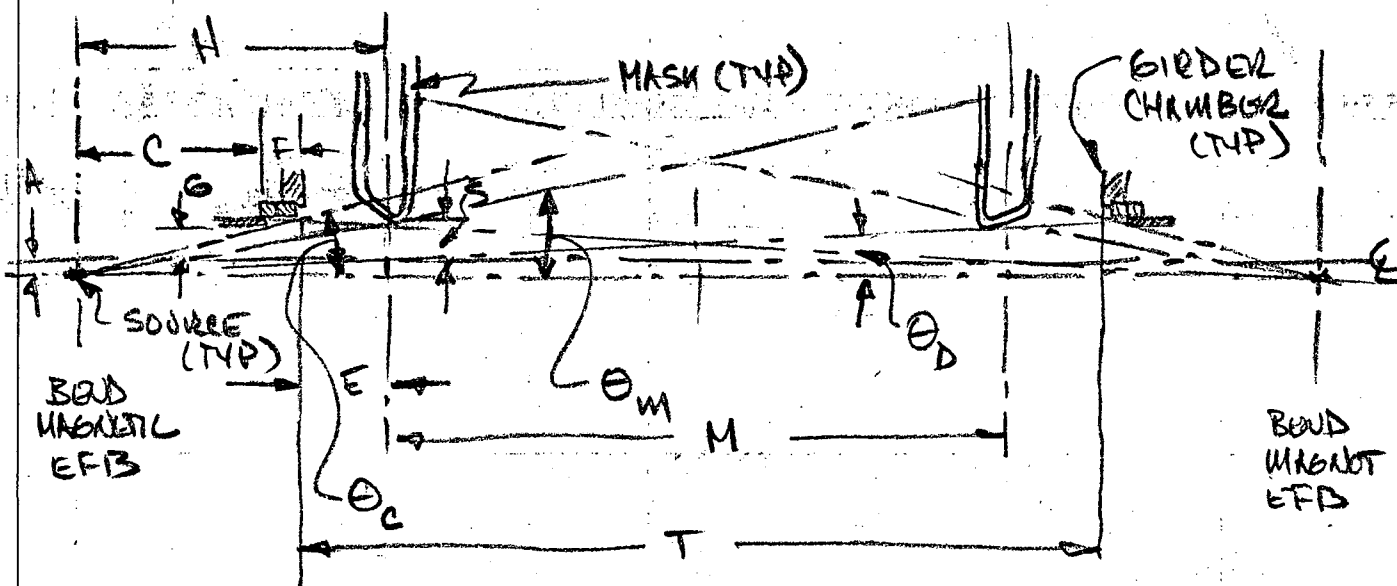
AUTHOR EGON HOYER	DEPARTMENT	LOCATION	DATE 6/25/82
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PROGRAM - PROJECT - JOB
SLF - WIGGLER / BEAM LINE II

MASKS - TWO MASK SYSTEM - DESIGN NO. 1

TITLE
HEAT TRANSFER CALCULATIONS FOR WIGGLER MASKS

LAYOUT:



MASK DESIGN PARAMETERS:

- BEAM POWER (DESIGN) = 200 kW / BEAM
(130 kW @ 3.76 eV, 100 mA)
- MAXIMUM TEMPERATURES = 250°C (SURFACE), 100°C (H₂O)
- VERTICAL MASKING = 2(9 mm) [Δ_y, θ_v, Δ_y] + 2(6 mm) [Δ_y] = 30 mm
- BEAM DIVERGENCE (± 1/γ) = ± .14 mRAD (3.76 eV)
- BEAM SPOT SIZE (± Δ_y) = ± .15 mm → USE 2Δ_y = (2)(.15 mm)

DIMENSIONS:

$$C = \frac{(DIFF)}{2} + \frac{(1/2 QUAD)}{2} + \frac{(EQUAD-QUAD)}{2} + (E) = .625m + .50m + .432m - .051m = 1.256m$$

$$G = 7.5cm \quad A = 10cm \quad (1cm \text{ OFFSET FROM } E)$$

$$\theta_c = \tan^{-1} \frac{G+A}{C} = \tan^{-1} \frac{7.5+1.0cm}{125cm} = 3.57^\circ$$

$$E = 2.5cm \text{ (FLANGE)} + 4.5cm \text{ (POSITION MONITOR)} + 12.5cm \text{ (BELLOWS)} + 0.2cm \text{ (CLEARANCE)} + \frac{60}{2}cm \text{ (1/2 MASK WIDTH)}$$

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$$E = \underline{0.227 \text{ m}}$$

$$F = \underline{0.051 \text{ m}}$$

$$H = C + F + E = 1.256 + 0.051 + 0.227 = \underline{1.534 \text{ m}}$$

$$M = \begin{matrix} 1.89 \text{ m} \\ (0.07 \text{ m})(27) \end{matrix} \text{ [27 PERIODS]} + \begin{matrix} 0.07 \text{ m} \\ (0.35 \text{ m})(2) \end{matrix} \text{ [2-1/2 PERIODS]} \\ + \begin{matrix} 1.64 \\ (0.82 \text{ m})(2) \end{matrix} \text{ [WIGGLER LENS]} + \begin{matrix} 0.06 \\ (0.06)(2) \end{matrix} \text{ [2-1/2 MASKS]} \\ = \underline{2.184 \text{ m}}$$

$$T = 2E + M$$

$$= (2)(0.227) + 2.184 = \underline{2.638 \text{ m}}$$

$$T_{\text{AUBIL}} = 103.795'' = \underline{2.636 \text{ m}} \quad \text{OK} \checkmark$$

$$\theta_D = \frac{-G + A}{C + F + T} = \frac{-7.5 \text{ cm} + 1.0 \text{ cm}}{125.6 \text{ cm} + 2(5.1 \text{ cm}) + 263.8 \text{ cm}} = \underline{1.22^\circ}$$

$$S = \tan \theta_D (H + M) - A$$

$$= (\tan^{1021} 1.22^\circ)(1.534 \text{ m} + 2.184 \text{ m}) - 1.0 \text{ m} = \underline{10.69 \text{ m}} \quad \text{⊕}$$

$$\theta_M = \tan^{-1} \frac{S + A}{H} = \frac{6.9 \text{ cm} + 1.0 \text{ cm}}{153.4 \text{ cm}} = \underline{2.95^\circ}$$

⊗ WIGGLER WILL HAVE A HORIZONTAL MOVEMENT CAPABILITY OF $\pm 6 \text{ mm}$. THEREFORE MASK WILL BE DESIGNED SUCH THAT $S_{\text{MAX}} = \underline{6.3 \text{ cm}}$.

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MASK HEATING:

$$0 \leq \varphi \leq \Theta_D:$$

SYNCHROTRON RADIATION IS ABSORBED BY
OPPOSITE GIRDLE CHAMBER

$$\Theta_D \leq \varphi \leq \Theta_M$$

SYNCHROTRON RADIATION IS ABSORBED BY
FAN MASK -

POWER:

$$P_{D-M} = \left(\frac{200 \text{ kW}}{360^\circ} \right) (2.95^\circ - 1.22^\circ) \frac{10^3 \text{ W}}{\text{KW}}$$

$$= 961 \text{ W}$$

HEAT FLUX

$$W_{D-M} = \frac{P_{D-M}}{A}$$

$$A_F = (H+M) (\Theta_M - \Theta_D) \left[\left(\frac{1}{\rho} \right) (H+M) + \delta \right] 2$$

$$= (153.4 \text{ cm} + 218.4 \text{ cm}) \left(\frac{371.8}{10^3} \text{ RAD} - 1.22^\circ \right) \left[\frac{180^\circ}{\pi \text{ RAD}} (371.8 \text{ cm}) + 0.15 \text{ cm} \right] 2$$

$$= 1.502 \text{ cm}^2 \quad (11.2 \text{ cm} \times 1.34 \text{ cm})$$

$$W_{D-M} = \frac{961 \text{ W}}{1.502} = 640 \text{ W/cm}^2$$

$$\Theta_M \leq \varphi \leq \Theta_C$$

SYNCHROTRON RADIATION IS ABSORBED
BY NEAR MASK -

POWER:

$$P_{M-C} = \frac{200 \text{ kW}}{360^\circ} (3.87 - 2.95^\circ) \frac{10^3 \text{ W}}{\text{KW}}$$

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$$= \underline{511 \text{ WATTS}}$$

HEAT FLOW

$$W_{m-c} = \frac{P_{m-c}}{A_N}$$

$$A_N = H^2 (\theta_c - \theta_m) \left[\frac{1}{2} H + \frac{1}{\pi} \right]^2$$

$$= (153.4 \text{ cm})^2 \left(\frac{3.87^\circ - 2.95^\circ}{\frac{180^\circ}{\pi}} \right) \left[153.4 \left(.14 \times 10^{-3} \text{ RAD} \right) + .015 \right]^2$$

$$= \underline{0.179 \text{ cm}^2} \quad (28 \text{ MILS})$$

(2.46 μm x .072 cm)

$$W_{m-c} = \frac{511 \text{ WATTS}}{0.179 \text{ cm}^2} = \underline{2847 \text{ W/cm}^2}$$

- REQUIRES TAKING AWAY HEAT
LOAD ON A SLOPING SURFACE

CONSIDER AN OTHC COPPER MASK

ABSORPTION COEFFICIENTS & LENGTHS:

FROM UCLRL 50174 (MC WASTON, ET AL.)

E (keV)	M/P (cm ² /gm)	l ₀ (mm)
117	11000	.0001
2	2315	.0005
3	778	.001
4.09	319	.004
5	192.5	.006
5.92	120.1	.009
7	73.6	.015
8	52.2	.021

$$l_0 = \frac{1}{M/P \rho}$$

$$\rho = 8.94 \text{ gm/cm}^3$$

$$l_0(\text{mm}) = \frac{1.119}{M/P (\text{cm}^2/\text{gm})}$$

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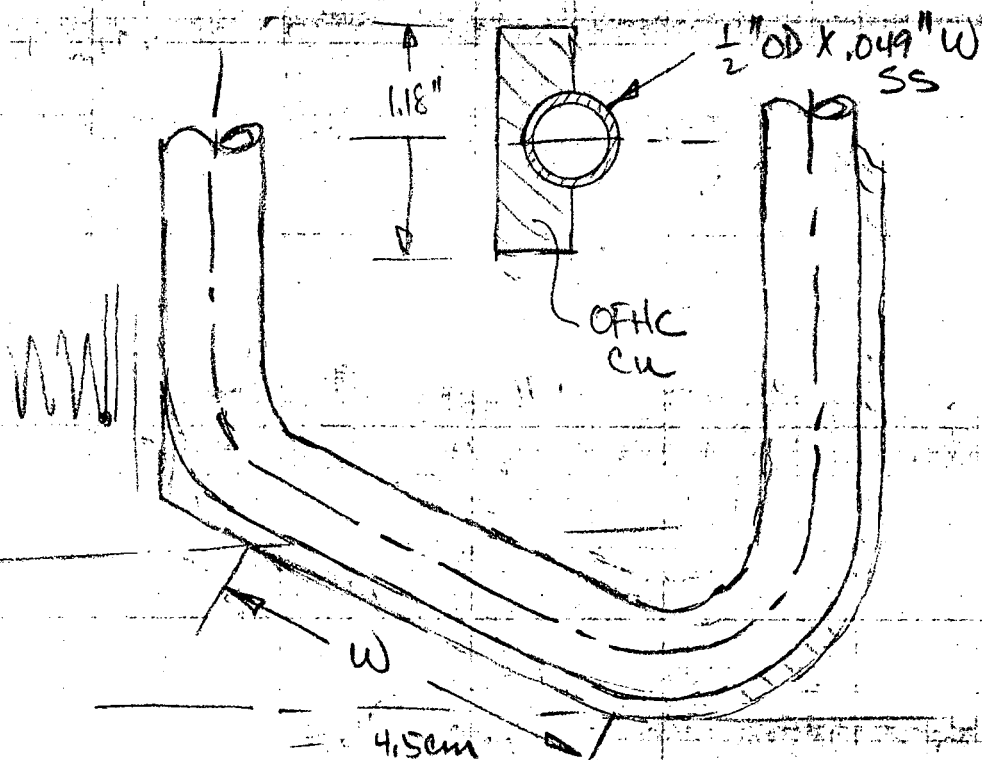
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E (KEV)	N/A (cm^2/gm)	l_0 (mm)
8.9	37.8	.030
9	290	.004
10	220	.005
15	74.4	.015
20	33.7	.033
25	18.3	.061
30	10.8	.104
40	4.86	.230
50	2.53	.442

@ 30eV $E_L = 4.7$ KEV FOL BONDING
WAGNET RADIATION

CONCLUSION — FOR PRACTICAL PURPOSES
X RAY DEPOSITION IS $\lesssim .1$ MM (.004")

CONSIDER THE FOLLOWING CONFIGURATION:



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HEAT FLUX ON SLOPED SURFACE:

$$W_{m-c} = (2847 \text{ W/cm}^2) \left(\frac{2.46 \text{ cm}}{4.5 \text{ cm}} \right)$$

$$= \underline{1556 \text{ W/cm}^2}$$

TEMPERATURE DROP ACROSS COPPER

SEE PAGE 7 FOR COPPER MASK

TEMPERATURE PROFILE AND SPACE

FACTOR COMPUTATION

$$q = h A \frac{\Delta T_{cu}}{\Delta x} = h W \Delta y M \frac{\Delta T_{cu}}{\Delta x \cdot N}$$

$$q = h W S \Delta T_{cu}; \Delta T_{cu} = T_M - T_S$$

$$S = \frac{\Delta y \cdot M}{\Delta x \cdot N} \quad \Delta y = \Delta x$$

$$S \text{ (SPACE FACTOR)} = \frac{W}{N}$$

$$\Delta T_{cu} = \frac{q}{h W S}$$

$$\text{@ } 200^\circ\text{C } h = 9.32 \text{ W/IN}^\circ\text{C FOR COPPER}$$

$$= \frac{511 \text{ W}}{}$$

$$\left(\frac{9.32 \text{ W}}{1^\circ\text{C}} \right) \left(\frac{4.5 \text{ cm}}{2.54 \text{ cm}} \right) (0.8)$$

$$= \underline{39.1^\circ\text{C}}$$

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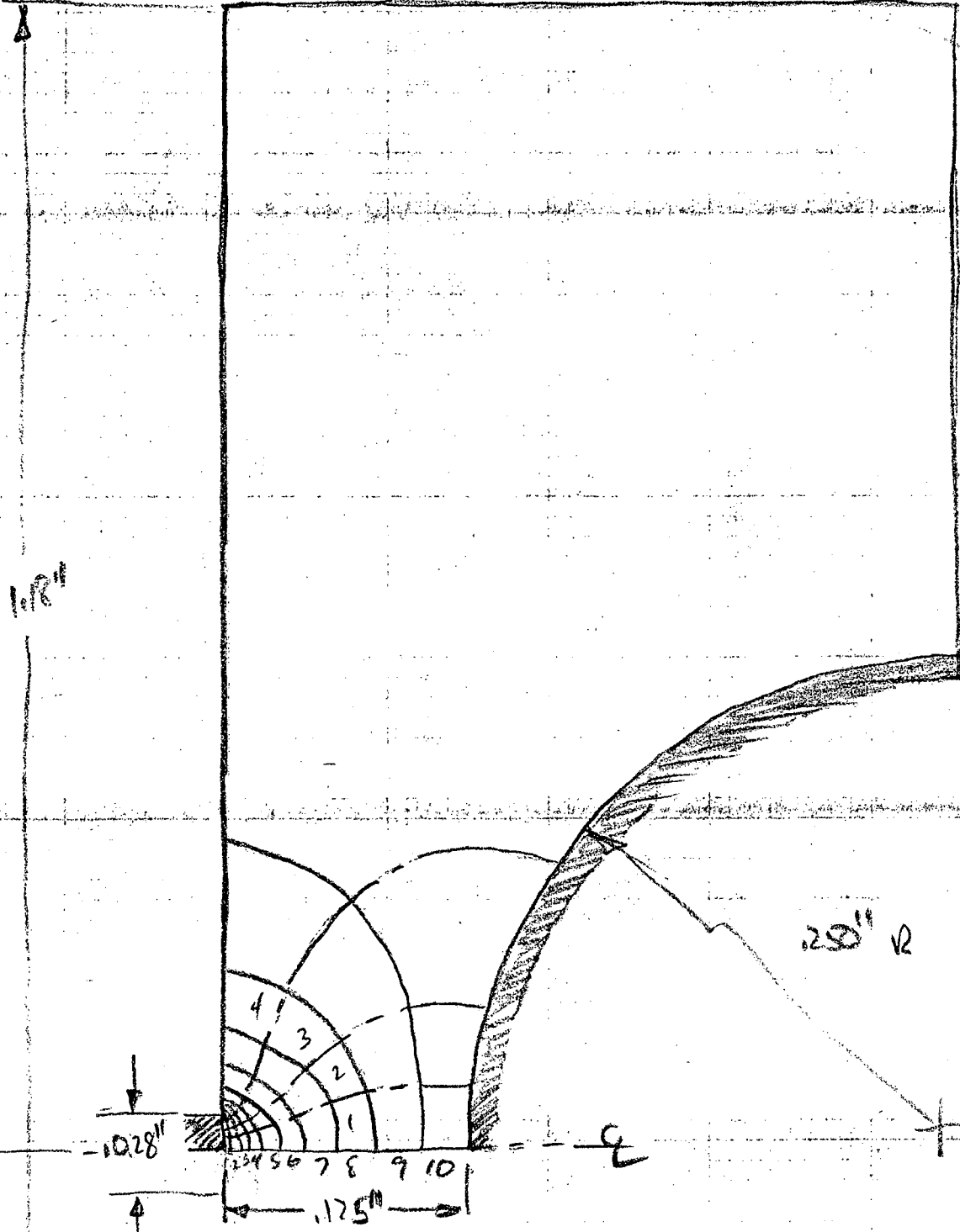
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TEMPERATURE PROFILE ACROSS MASK (COPPER):



$$S = \frac{M}{N} = \frac{2 \times 4}{10} = 0.80$$

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TEMPERATURE DROP ACROSS SS:

$$q = kA \frac{\Delta T}{\Delta x}$$

$$\Delta T_{SS} = \left(\frac{q}{k_{SS}} \right) \frac{\Delta x_{SS}}{A_{SS}}$$

$$\Delta T_{SS} = \frac{W_{SS}}{h_{SS}} \frac{\Delta x_{SS}}{A_{SS}}$$

$$W_{SS} = \frac{511 \text{ WATTS}}{(2 \times .125'' + .014'') (4.5 \text{ cm} + (.125'' (2) (\frac{2.54 \text{ cm}}{1''})) (\frac{2.54 \text{ cm}}{1''}))}$$

$$= 141 \text{ WATTS/cm}^2$$

FOR .1049" WALL SS TUBING:

$$\Delta T_{SS} = \frac{\left(\frac{141 \text{ W}}{\text{cm}^2} \right) \left(\frac{2.54 \text{ cm}}{1''} \right)^2 (.1049'')}{\left(\frac{9.4 \text{ BW}}{102 \text{ FT}^2} \right) \left(\frac{10.41 \text{ W}}{3.413 \text{ BW}} \right) \left(\frac{1 \text{ FT}}{12''} \right) \left(\frac{1.8 \text{ W}}{1 \text{ W}^\circ \text{C}} \right)}$$

$$= 108^\circ \text{C}$$

1413 W / IN² °C

FILM TEMPERATURE RISE:

$$\Delta T_f = \frac{W_{SS}}{h}$$

$$\frac{W_d}{h_d} = (Nu)_d = .023 (Nu)_d^{.8} (Pr)_d^{.4}$$

$$d = 4/12$$

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CONSIDER 20' / SEC WATER VELOCITY, BULK
WATER TEMPERATURE $\approx 65^\circ\text{C}$ (150°F)

$$N_r = \frac{V(4R)}{v}$$

$$R_{\text{int}} = \frac{\pi R^2}{2\pi R} = \frac{R}{2}$$

$$R_{\text{ext}} = \frac{(6R)(2R)}{2(2R+6R)} = \frac{3}{4} R$$

FOR $\frac{1}{2}$ " OD X .049" WALL

$$N_r = \frac{(20' / \text{SEC})(4) \left(\frac{.25'' - .049''}{2} \right) \frac{\text{FT}}{12''}}{1.477 \text{ FT}^2 / \text{SEC} \times 10^{-5}} = \frac{1.40 \times 10^5}{1.477 \text{ FT}^2 / \text{SEC} \times 10^{-5}}$$

$$P_r = \frac{2.74}{\text{HR FT}^2 \text{ OF}}$$

$$h = \frac{.394 \text{ BTU}}{\text{HR FT}^2 \text{ OF}}$$

$$h = \frac{.023 (N_r)^{.8} (P_r)^4 h}{4 R}$$

$$= \frac{(1.40 \times 10^5)^{.8} (2.74)^4 h}{(4) \left(\frac{.201''}{2} \right)}$$

$$= \frac{19.4 \frac{\text{W}}{\text{IN}^2 \text{ } ^\circ\text{C}}}{3 \text{ W/cm}^2 \text{ } ^\circ\text{C}}$$

$$\left(\frac{.394 \text{ BTU}}{\text{HR FT}^2 \text{ OF}} \right) \left(\frac{\text{W-HR}}{3.413 \text{ BTU}} \right)$$

$$\left(\frac{1.80 \text{ } ^\circ\text{C}}{\text{ } ^\circ\text{C}} \right) \left(\frac{\text{FT}}{12 \text{ IN}} \right)$$

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$$M_{SS} = \left(\frac{141 \text{ W}}{\text{cm}^2} \right) \left(\frac{6.145 \text{ cm}^2}{1 \text{ in}^2} \right)$$

$$\underline{909 \text{ W/in}^2}$$

$$\Delta T_f = \frac{909 \text{ W/in}^2}{19.4 \text{ W/in}^2 \text{ } ^\circ\text{C}} = \underline{47 \text{ } ^\circ\text{C}}$$

BULK H₂O FLOW RATE + ΔT:

$$Q = VA = V \pi r^2$$

$$= (20' / \text{sec}) (\pi) (.201' \text{ in})^2 \left(\frac{\text{ft}^2}{144 \text{ in}^2} \right) \left(\frac{7.48 \text{ gal}}{\text{ft}^3} \right) \frac{\text{min}}{60 \text{ sec}}$$

$$= \underline{7.9 \text{ GPM}}$$

$$\Delta T_w = \left(\frac{3.80 \text{ GPM } ^\circ\text{C}}{\text{KW}} \right) \left(\frac{(1511 + 961) \text{ KW}}{7.9 \text{ GPM}} \right)$$

$$= \underline{0.7 \text{ } ^\circ\text{C}}$$

MAX. WATER TEMPERATURE: (2 MASKS IN SERIES)

$$T_{\text{max H}_2\text{O}} = T_{\text{in}} + \Delta T_w + \Delta T_f$$

$$= 40^\circ\text{C} + (0.7)/(2) + 47^\circ\text{C} = \underline{89^\circ\text{C}}$$

MAX. SURFACE TEMP. OF MASK:

$$T_s = T_{\text{max H}_2\text{O}} + \Delta T_{SS} + \Delta T_{\text{C/W}}$$

$$= 89^\circ\text{C} + 108^\circ\text{C} + 39^\circ\text{C} = \underline{236 \text{ } ^\circ\text{C}}$$

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