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TOLERANCES AND THERMAL EFFECTS OF GRATINGS

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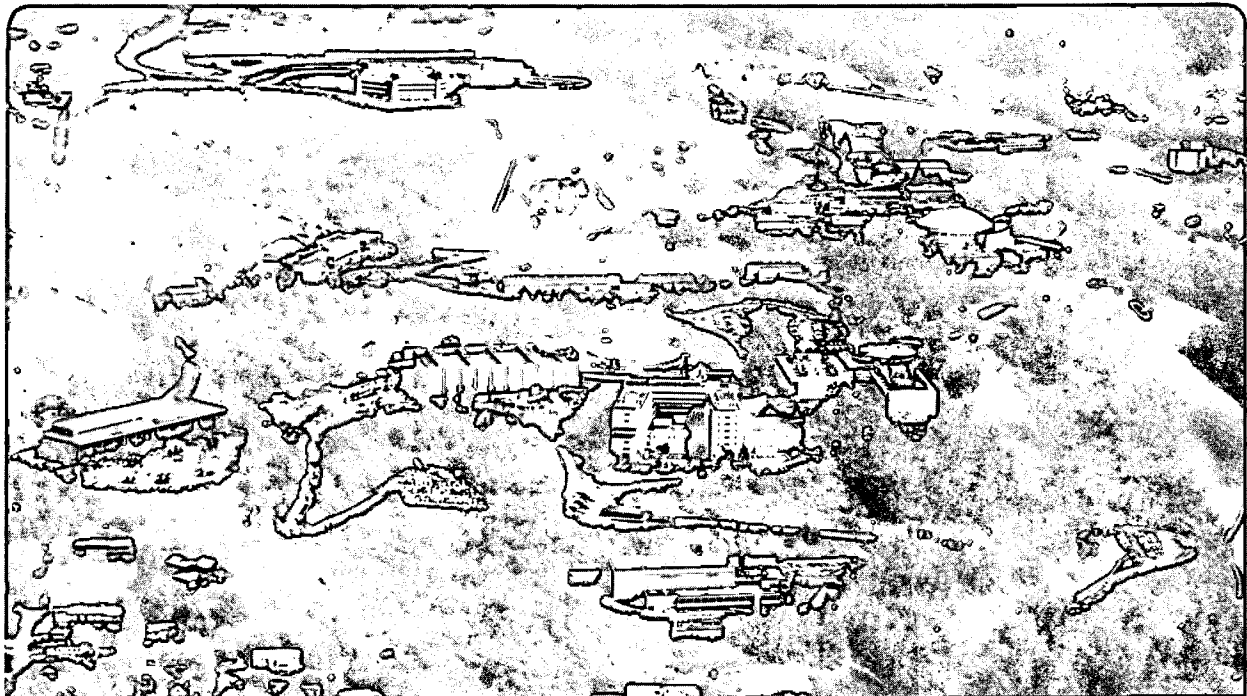
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M 5908A

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DEPARTMENT

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DATE

5/20/82

PROGRAM - PROJECT - JOB

SLF - BERM LINE II

NOV WOOD CHROMATON - GRATINGS

TITLE

TOLERANCES AND THERMAL EFFECTS OF GRATINGS

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GRATING PITCH TOLERANCE:

$$E(\text{eV}) = \frac{12398}{\lambda(\text{\AA})}$$

$$dE(\text{eV}) = -12398 \frac{d\lambda(\text{\AA})}{\lambda^2(\text{\AA}^2)} \quad (1)$$

PER HUTTON:

$$m\lambda = 2d \sin \theta_B \sin \alpha$$

$$m\lambda = 2d \sin \theta_B \cos(\alpha - \theta_B)$$

$$m \frac{d\lambda}{d\alpha} = -2d \sin \theta_B \sin(\alpha - \theta_B)$$

$$\text{FOR } m=1, \sin \theta_B = \theta_B$$

$$\frac{d\lambda}{d\alpha} = -2d \theta_B \sin(\alpha - \theta_B) \quad (2)$$

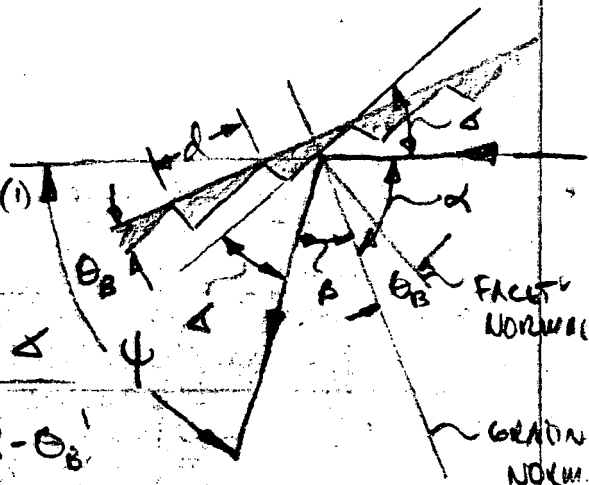
COMBINING (1) & (2)

$$d\alpha = \left(\frac{dE \lambda^2}{12398} \right) \frac{1}{2d \theta_B \sin(\alpha - \theta_B)}$$

$$\text{FOR } \frac{dE}{\theta_B} = \frac{13 \text{ eV (STAIN)}}{0.7}, \quad d = 16666 \text{ \AA} (6002/\text{mm})$$

$$d\alpha = \frac{13 \lambda^2(\text{\AA})}{(12398)(2)(16666)(.7) \left(\frac{\pi}{180} \right) \sin(\alpha - .70)} \quad \frac{10^6 \text{ M/RAD}}{\text{RAD}}$$

$$d\alpha(\text{M/RAD}) = \frac{0.0594 \lambda^2(\text{\AA})}{\sin(\alpha - .70)}$$



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ANGULAR RELATIONS :

$$\alpha - \beta = 2\theta_B$$

$$\alpha + \beta = 180^\circ - 2\Delta$$

Hence:

$$\alpha = 90^\circ + \theta_B - \Delta$$

$$|\alpha| = |\Delta|$$

$$\sin \Delta = \frac{m\lambda}{2d \sin \theta_B}$$

$$\Delta = \sin^{-1} \frac{\lambda}{2d \sin \theta_B}$$

THUS:

$$\alpha = 90^\circ + \theta_B - \sin^{-1} \frac{\lambda}{2d \sin \theta_B}$$

$$\alpha = 90.7^\circ - \sin^{-1} \frac{\lambda (A^\circ)}{(2)(16666 A^\circ)(.7^\circ) \pi}$$

$$\alpha = 90.7^\circ - \sin^{-1} (2.4556 \times 10^{-3} \lambda (A^\circ))$$

$$\psi = 180^\circ - (\alpha + \beta) = 2\Delta$$

THUS:

$$\psi = 2 \sin^{-1} \frac{\lambda}{2d \sin \theta_B}$$

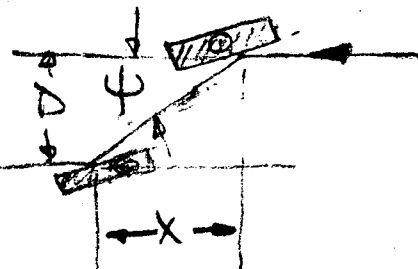
$$\psi = 2 \sin^{-1} (2.4556 \times 10^{-3} \lambda (A^\circ))$$

GRATING HORIZONTAL SPACING:

$$X = \frac{D}{\tan \psi}$$

$$\text{FOR } D = 3.0 \text{ cm}$$

$$X = \frac{3.0 \text{ cm}}{\tan \psi}$$



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MINIMUM GRATING THICKNESS

NOMINAL RULED AREA WILL BE 10cm X 4cm. THICKNESS WILL BE DETERMINED BY RIGIDITY CONSIDERATIONS.

FOR HOWER'S & RHEN, LENGTH TO THICKNESS RATIO FOR FUSED QUARTZ OPTICAL COMPOUNDS SHOULD BE 6:1. WITH THIS INFO, SEC GRATING THICKNESS IS:

$$EI \propto Et^3$$

$$E_1 t_1^3 = E_2 t_2^3$$

$$t_1 = t_2 \left(\frac{E_2}{E_1} \right)^{1/3}$$

IF $t_2 = 10\text{cm}/6 = 1.67\text{cm}$, $E_2 = 10.6 \times 10^6 \text{ PSI}$,
 $E_1 = 55 \times 10^6 \text{ PSI}$

$$t_1 = 1.67 \left(\frac{10.6}{55} \right)^{1/3} =$$

$$= .96\text{cm}$$

→ USE 1.0cm (MINIMUM)

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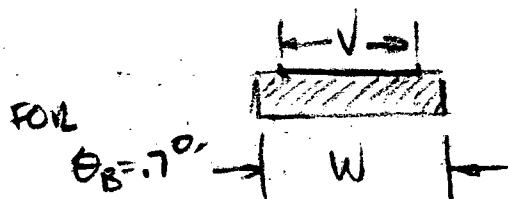
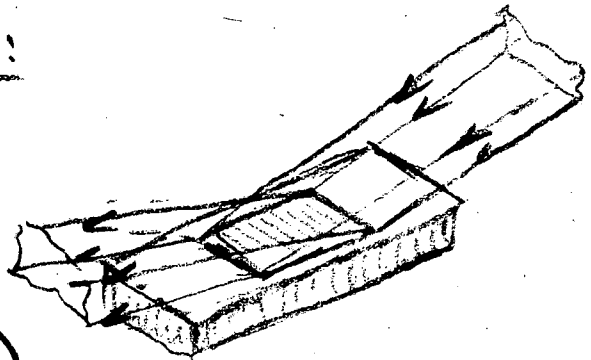
GRATING ILLUMINATION:

WIDTH (V) = 3cm MAX.

LENGTH (u): SEE TABLE

A

$$u = \frac{z}{(\sin \delta - \cos \delta \theta_B)}$$

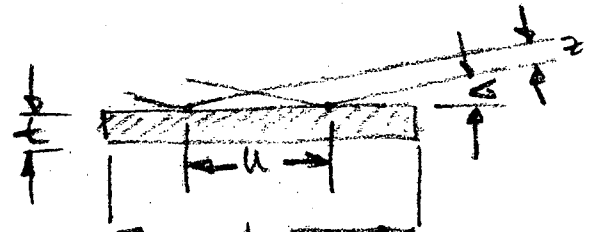


FOIL

 $\theta_B = 70^\circ$ $z = 1.0 \text{ mm}$ TRANSVERSE
PLANE

$$u = \frac{1.00 \text{ mm}}{(\sin \delta - 0.01222 \cos \delta)}$$

$$\bar{m} = (1 - \frac{\theta_B}{\tan \delta}) \bar{m}^*$$



LONGITUDINAL PLANE

 $L = 10 \text{ cm}$ $W = 4 \text{ cm}$ $t = 1 \text{ cm}$

$\lambda (^\circ)$	$\bar{m}^*$	$\psi (^\circ)$	$\delta (^\circ)$	$90 - \delta (^\circ)$	$u (\text{mm})$	$\bar{m} (\text{mm}^2)$	$u \bar{m} W$
8	1.731	2.2513	1.1257	88.87	134.57 ($L=10 \text{ cm}$)	1.276	3.72
15	2.59	4.228	2.1109	87.89	40.61	1.73	7.03
20	4.69	5.6301	2.815°	87.18	27.09	3.52	9.55
35.5	9.99	10.0°	5.00°	85.0°	13.34	8.59	11.46
40		11.2738	5.637°	84.363°	11.62		
70.7	20.8	20.0°	10.00°	80.0°	6.19	19.4	11.98
75		21.2251	10.613	79.387	5.81		
200	62.8	50.8284	29.4142	60.58	2.08	61.6	12.81

BASED ON K.J. KIM'S RUN KJK 0004,
4/30/82 FOIL $B_0 = 1.75 \text{ TES}$, $E = 3.7 \text{ keV}$, $I = 100 \text{ mA}$
 $\bar{m}$ VALUES (FOIL $B_0 = 5$) AND AVERAGE SLIT HEIGHT AT 13.88 eV
 (COLLIMATING WILKINSON) AFTER BEAM HAS GONE THRU

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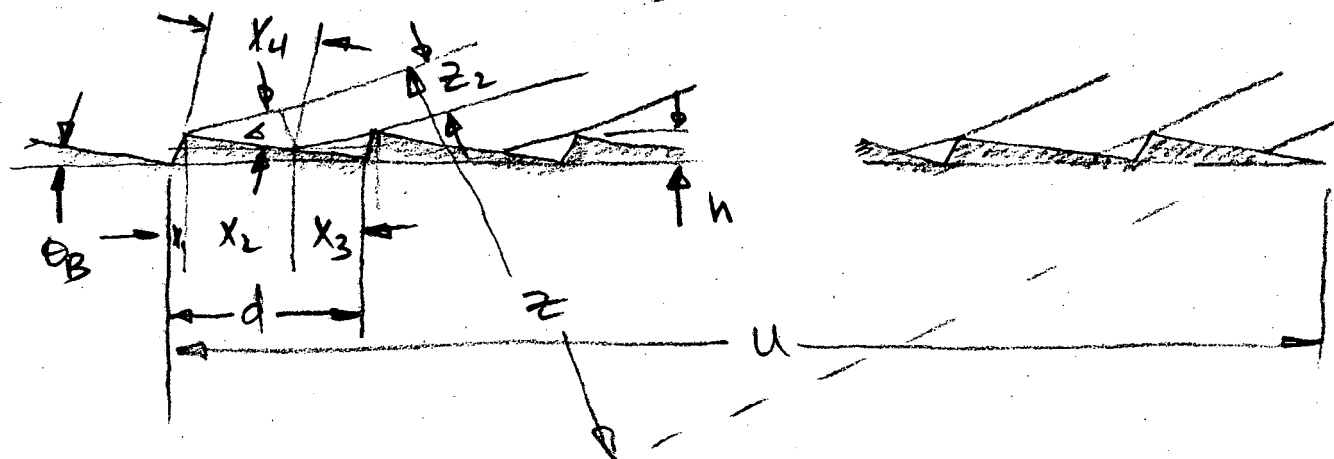
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ILLUMINATED LENGTH (u) :



$$z = n z_2 \quad (15)$$

$$u = nd \quad (2)$$

$$z_2 = x_4 \sin \delta \quad (3)$$

$$x_4 = \frac{x_2}{\cos \theta_B} \quad (4)$$

$$d = x_1 + x_2 + x_3 \quad (5)$$

$$h = \tan \theta_B (x_2 + x_3) \quad (b)$$

$$h = x_3 \tan \Delta \quad (7)$$

$$\lambda_1 = h \sin \theta_B \quad (8)$$

$$h = d \cos \theta_B \tan \theta_B (a)$$

FOUL SMALL OR

$$x_4 = x_2 \quad (4)$$

$$u = \Theta_B(x_2 + y_3) \quad (b)$$

$$K_1 = 10 \theta_B \quad (8)$$

$$\rightarrow h = e_B d \quad (9)$$

SOLVE FOR X_2

$$x_2 = d - x_3$$

$$x_2 = d - \frac{0.8d}{\tan \Delta}$$

$$\frac{x_2}{d} = \left(1 - \frac{\theta_B}{\tan \Delta}\right)$$

$$u = \frac{z}{z_2} d$$

$$u = \frac{z}{x_2} d$$

$$u = \frac{z}{(1 - \epsilon_B) \sin \delta}$$

$$u = \frac{z}{(\sin \delta - \cos \delta \sin \theta_B)}$$

For $\sigma = \psi/2$

$$u = \frac{z}{(\sin \psi)_2 - \cos \psi_2 \theta_B}$$

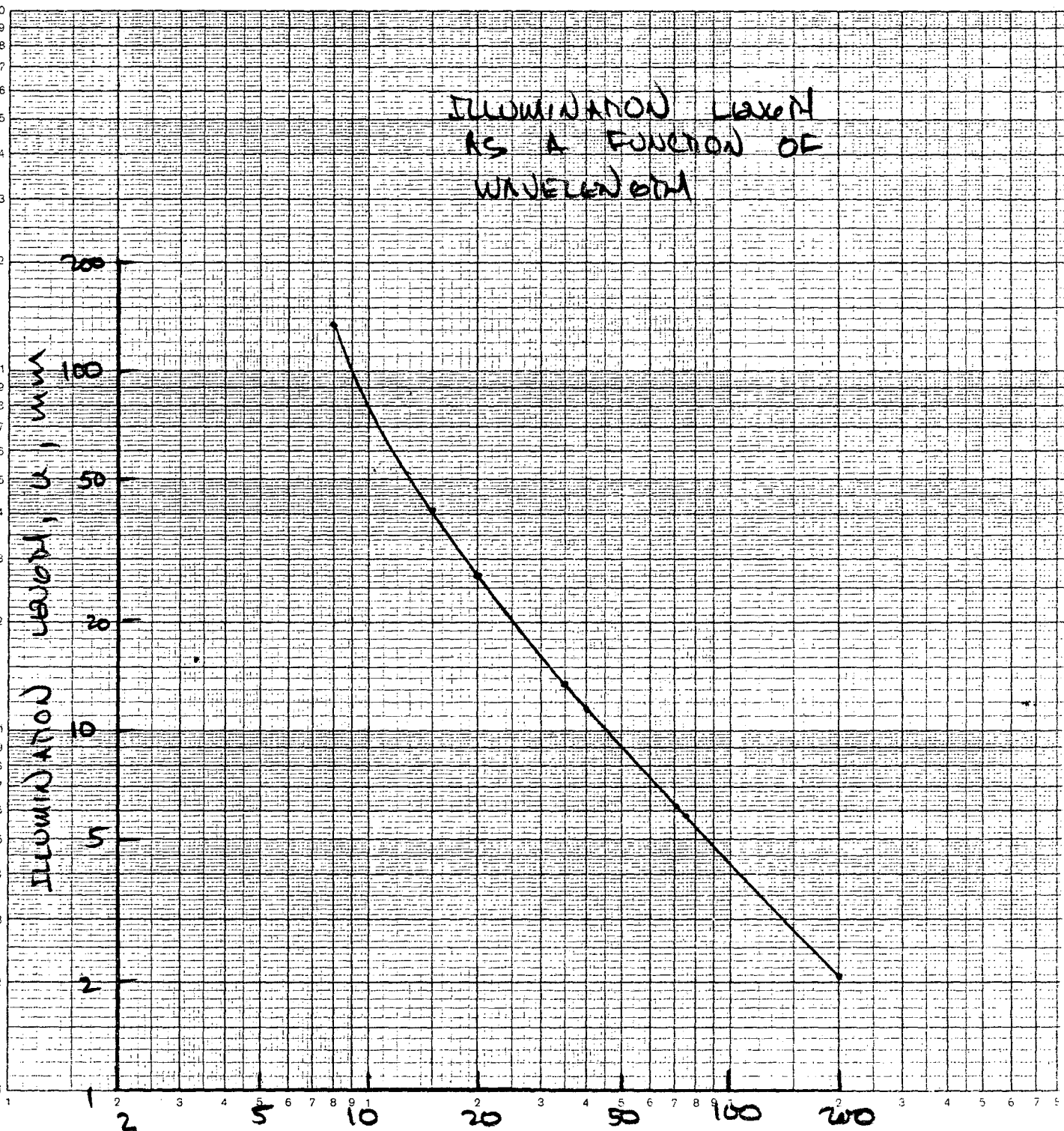
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ILLUMINATION LUXES
AS A FUNCTION OF
WAVELENGTH

ILLUMINATION
LUXES, λ , nm



WAVELENGTH, λ , Å

cell output

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GRATING THERMAL DISTORTION:

THE THERMAL DISTORTION OF A GRATING CAN BE EVALUATED BY CONSIDERING BOTH:

- ① A MACRO DISTORTION DUE TO A BULK TEMPERATURE DIFFERENCE BETWEEN THE ILLUMINATED SURFACE AND COOLED SURFACE
- ② A MICRO DISTORTION DUE TO A DIFFERENCE BETWEEN THE ACTUAL TEMPERATURE DISTRIBUTION AND THE BULK TEMPERATURE DISTRIBUTION

MACRO DISTORTION:

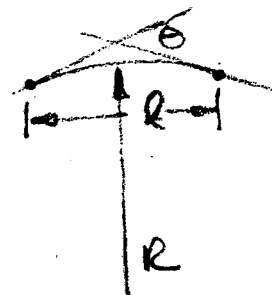
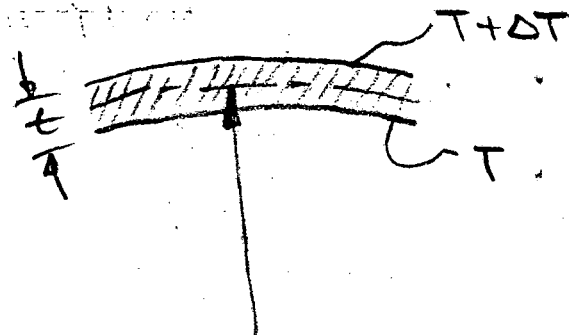
PERZ BOOK, 3RD EDITION, PG 335, CASE 5

CURVATURE DUE TO A TEMPERATURE DIFFERENTIAL THRU GRATING:

$$R = \frac{t}{\alpha \Delta T}$$

CHANGE IN SLOPE OVER DISTANCES:

$$\theta = \frac{l}{R} = \frac{l \cdot \alpha \Delta T}{t}$$



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HEAT TRANSFER:

$$q = k A \frac{\Delta T}{\Delta x} \quad \frac{A}{\Delta x} = \frac{V \Delta x M}{\Delta x N \Delta x}$$

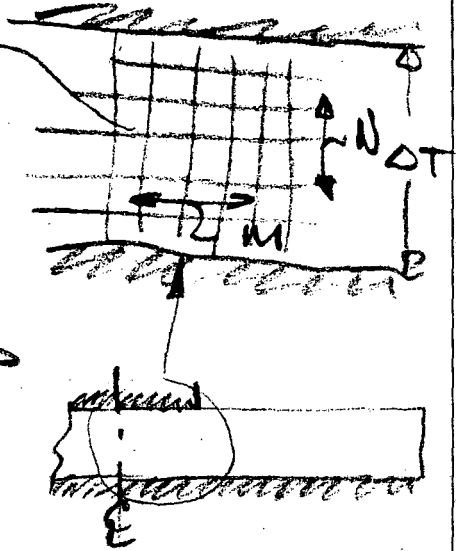
$$= k S \Delta T V \quad (\text{GRAPHICAL SOLUTION})$$

$$S = \frac{M}{N} = \frac{\# \text{ OF HEAT FLOW LINES}}{\# \text{ OF TEMP. INCREMENTS}}$$

$$\Delta T (^\circ\text{C}) = \frac{q [\text{W}]}{k [\text{W/m}^\circ\text{C}] S \sqrt{.} [\text{m}]}$$

$$q = (\bar{m} \sqrt{.} [\text{W}]) \sqrt{.} [\text{m}] (1 \text{ u}) [\text{m}]$$

$$\Delta T = \frac{\bar{m} u}{k S}$$



A BACK COOLING:

ON THE FOLLOWING PAGES, TEMPERATURE PROFILES AND S FACTORS ARE GIVEN FOR BACK COOLING + $t = 1.0 \text{ cm}$

- ① TRANSVERSE PLANE - TEMP. PROFILES FOR $V = 30 \text{ cm}$ WIDE ILLUMINATION

A

- ② LONGITUDINAL PLANE - TEMPERATURE PROFILE FOR $u = 50.8 \text{ mm}$ ($\lambda = 12.5 \text{ \AA}$)

- ③ LONGITUDINAL PLANE - TEMPERATURE PROFILE FOR $u = 20.4 \text{ mm}$ ($\lambda = 24.4 \text{ \AA}$)

- ④ LONGITUDINAL PLANE - TEMPERATURE PROFILE FOR $u = 2.0 \text{ mm}$ ($\lambda = 205 \text{ \AA}$)

- ⑤ S AS A FUNCTION OF U IS GIVEN.

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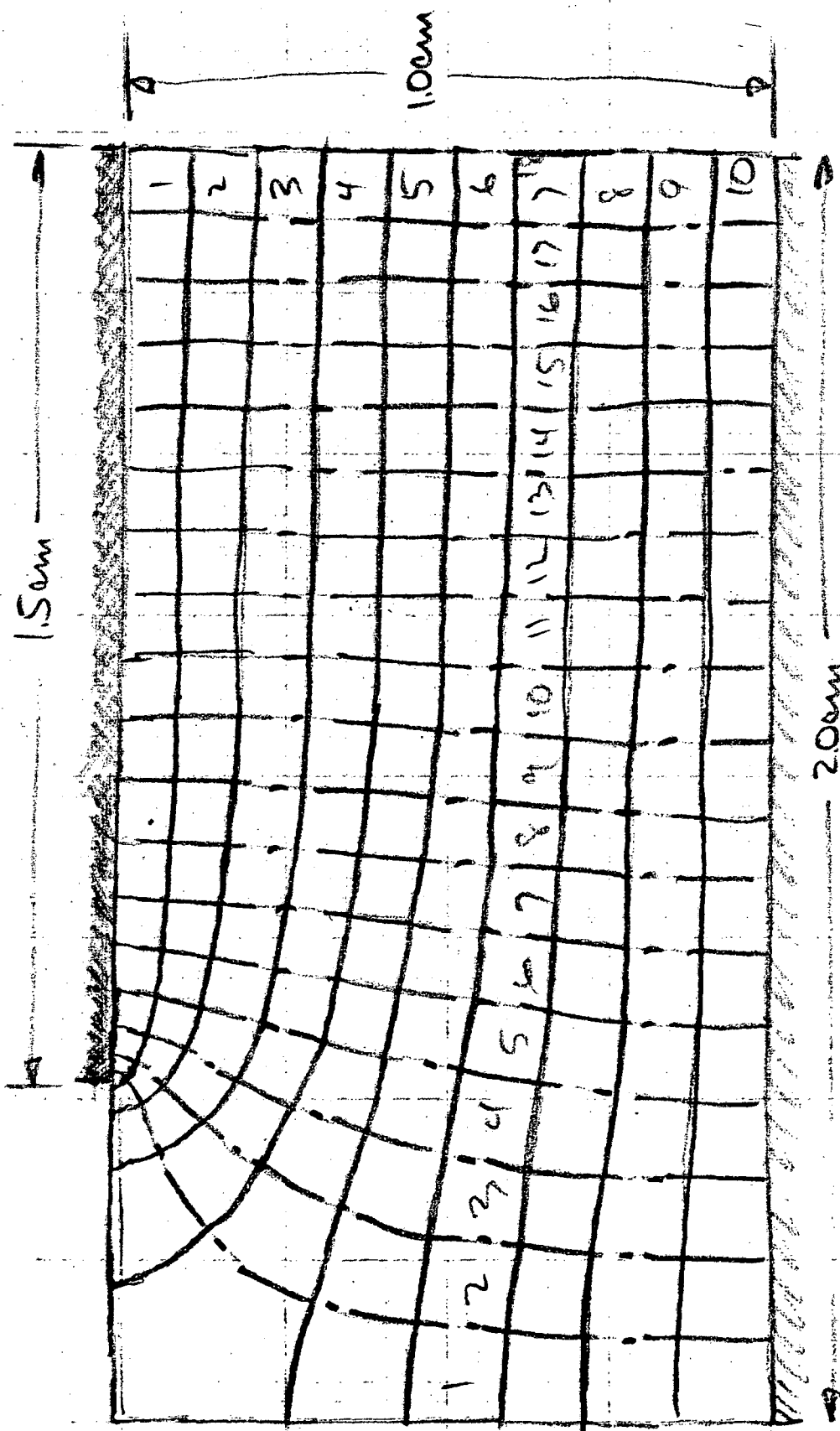
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① TRANSDUCER PLANE - TEMPERATURE PROFILE FOR 3.0cm WIDTH HEATING:



$$S = \frac{18 \times 2}{10} = 3.60$$

$$V = 3.0 \text{ cm}$$

$$W = 4.0 \text{ cm}$$

$$t = 1.0 \text{ cm}$$

BACK COOLING

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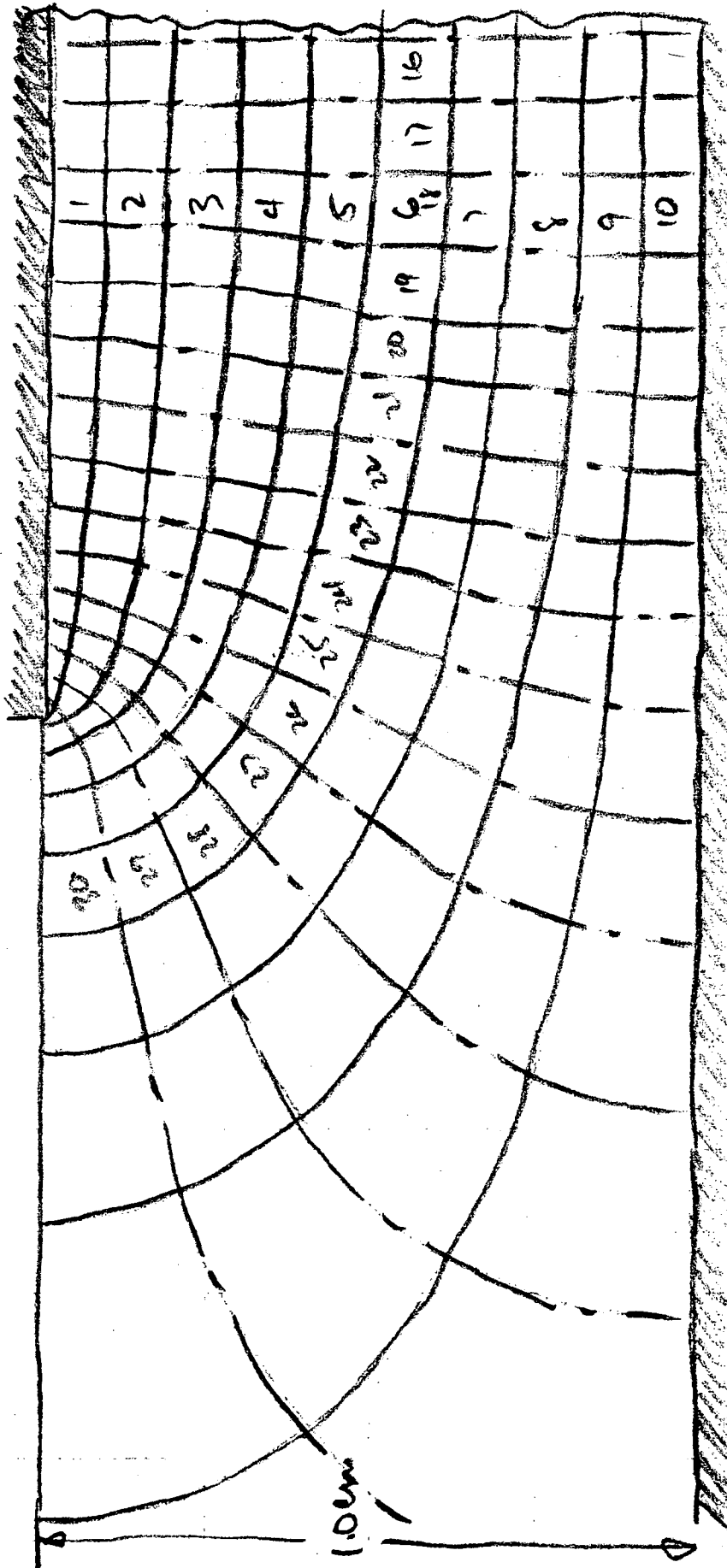
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LONGITUDINAL PLANE -
TEMPERATURE PROFILE FOR 12.5 Å CASE:

A

2.54 cm



5.0 cm

W = 5.08 cm

t = 1.0 cm

L = 10 cm

BACK COVER

$$S = \frac{W}{N} = \frac{2 \times 30}{10} = 6.00$$

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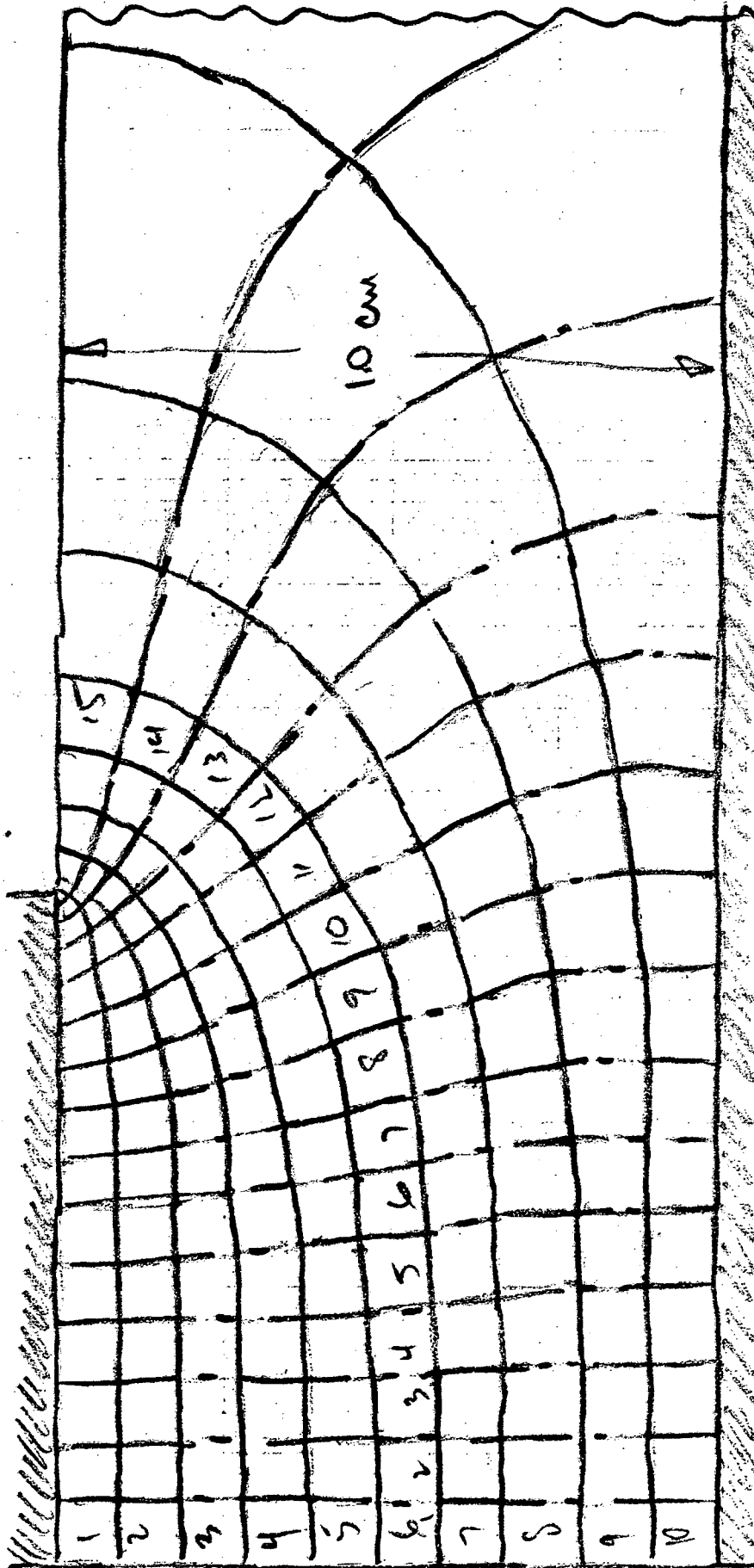
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LONGITUDINAL PLANE -

③ TEMPERATURE PROFILE FOR 24.5A

A

1.02 cm



5.0 cm

$u = 204 \text{ cm}$
 $t = 1.0 \text{ cm}$
 $L = 10 \text{ cm}$

$$S = \frac{(2)(15)}{10} = 3.00$$

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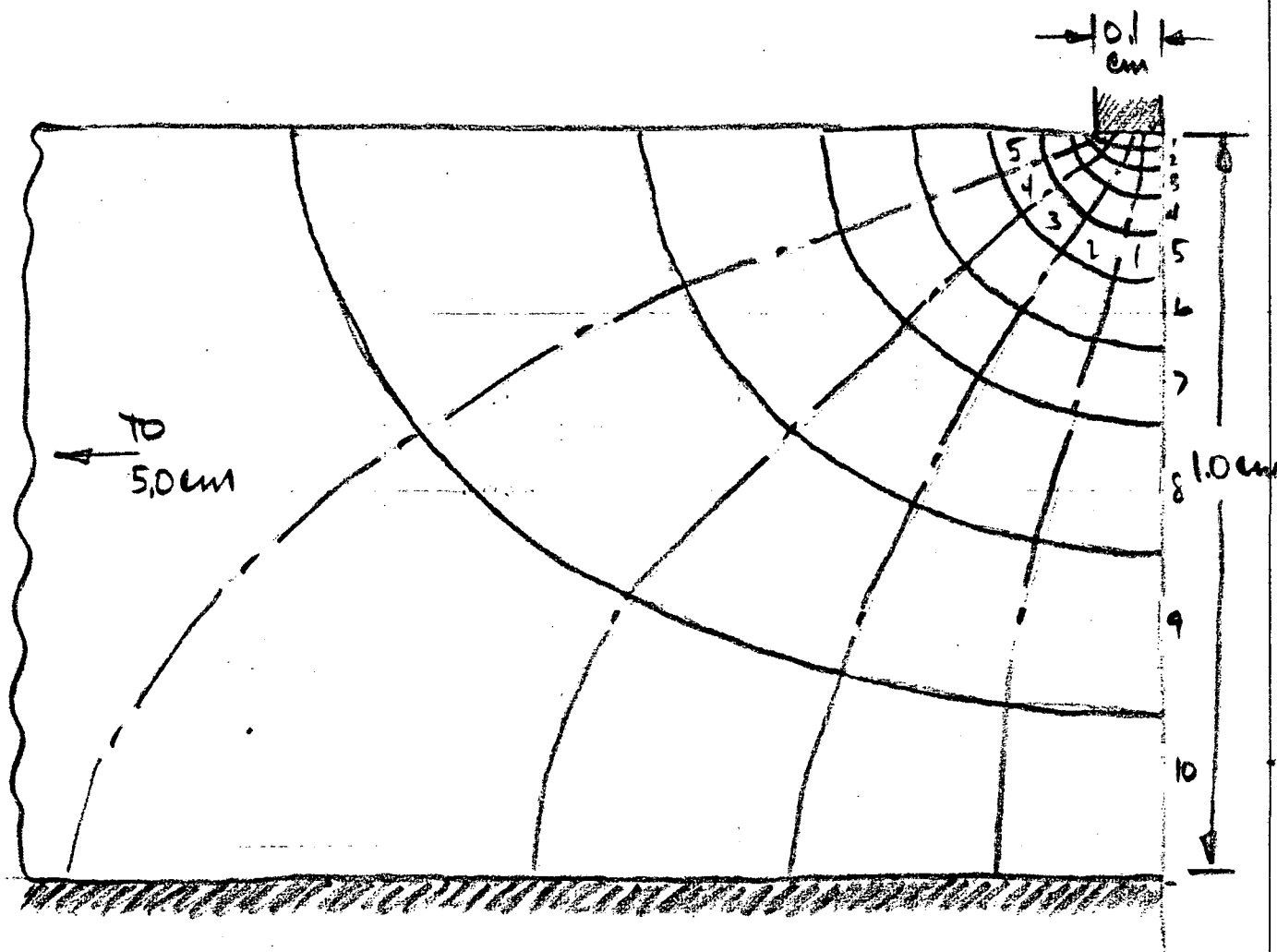
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- ④ LONGITUDINAL PLANE -
TEMPORAL PROFILE FOR 205 Å CASE:

A



$$S = \frac{M}{N} = \frac{25}{10} = 1.00$$

$$u = 0.2 \text{ cm}$$

$$t = 1.0 \text{ cm}$$

$$L = 10 \text{ cm}$$

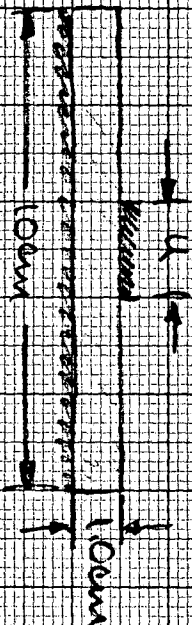
BLACK COOLING

SEED HOVER

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⑤ SPACE FACTOR, S , AS
A FUNCTION OF u ,
FOR GIVEN GEOMETRY



SPACE FACTOR, S

1.0 2.0 3.0 4.0 5.0 6.0 7.0

u (cm)

1.0

2.0

3.0

4.0

5.0

6.0

$S = u \cdot 1.0$

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COMBINING EQUATIONS:

LETTING $l = u$

$$\theta_E = \frac{u \alpha \Delta T}{t}$$

$$= \frac{u \alpha}{t} \frac{q}{K S V} = \frac{u \alpha}{t} \frac{\bar{u} \cdot u}{K S V}$$

$$= \left(\frac{\alpha}{K} \right) \left(\frac{u}{t} \right) \left(\frac{1}{S} \right) (\bar{u} u) = \left(\frac{\alpha}{K} \right) \left(\frac{u}{t} \right) \left(\frac{1}{S} \right) (\bar{u} u)$$

FOR $l = 1 \text{ cm}$, $\alpha = 3.5 \times 10^{-6} / ^\circ \text{C}$; $K = 71 \frac{\text{W}}{\text{m}^\circ \text{C}}$; α/K FOR SiC = $4.92 \times 10^{-8} \frac{\text{W}}{\text{m}}$

$$\theta_E = \left(4.92 \times 10^{-8} \frac{\text{W}}{\text{m}} \right) \left(\frac{u \bar{u}}{10} \right) \left(\frac{1}{S} \right) \left(\frac{u \text{ cm}}{1.0 \text{ cm}} \right) \frac{10^6 \mu \text{RAD}}{\text{RAD}} \frac{10^2 \text{ cm}}{\text{m}}$$

$$\theta_E (\mu \text{RAD}) = 4.92 \left(u \bar{u} \left(\frac{\text{W}}{\text{m}} \right) \left(\frac{u \text{ cm}}{1.0} \right) \frac{1}{S} \right)$$

$$\Delta T = \frac{\bar{u} u}{(71)(S)} \frac{10^2 \text{ cm}}{\text{m}} = 1.408 \frac{\bar{u} u}{S}$$

$\lambda (\text{\AA})$	$u \bar{u} (\frac{\text{W}}{\text{m}})$	$u (\text{cm})$	S	$\theta_E (\mu \text{RAD})$	$\bar{u} (\text{mV/m})$	$\Delta T (^\circ \text{C})$
8	3.72	13.46	14.46	17.0	11.2	.36
15	7.03	4.06	5.06	27.8	21.1	1.96
20	9.55	2.71	3.71	34.3	28.7	3.62
35.5	11.46	1.33	2.33	32.2	34.4	6.93
70.7	11.98	0.61	1.61	22.3	35.9	10.48
200	12.91	0.20	1.00	10.5	38.4	15.03

L = 15 cm (A)

θ_E IS PLOTTED AS A FUNCTION OF λ ON THE PAGE 32 (ACTUALLY PLOTTED ON THE dS PLOT OF PAGE 5). CLEARLY $\theta_E > dS$ FOR A MAJOR PORTION OF THE SPECTRUM. THUS

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THE SIMPLE GRATING COOLED FROM THE REAR IS NOT ACCEPTABLE. ADDITIONALLY, THE MICRODISTORTION ADDS TO THE CURVING, MAKING THE TOTAL CHANGE OF CURVING GREATER.

(B) SIDE COOLING:

ILLUMINATION:

$\lambda (\text{\AA})$	$\bar{m} (\text{W/Km})$
8	.276
15	1.73
20	3.52
35.5	8.59
70.7	19.4
200	61.6

HEAT TRANSFER:

$$\Delta T = \frac{q [W]}{K [W/m^{\circ}C] S u [m]}$$

$$q = \bar{m} v u$$

$$\Delta T = \frac{\bar{m} v}{K S}$$

S FACTORS FOR TRANSVERSE COOLING ARE GIVEN ON PAGES 17-20 FOR DIFFERENT THICKNESS GRATINGS.

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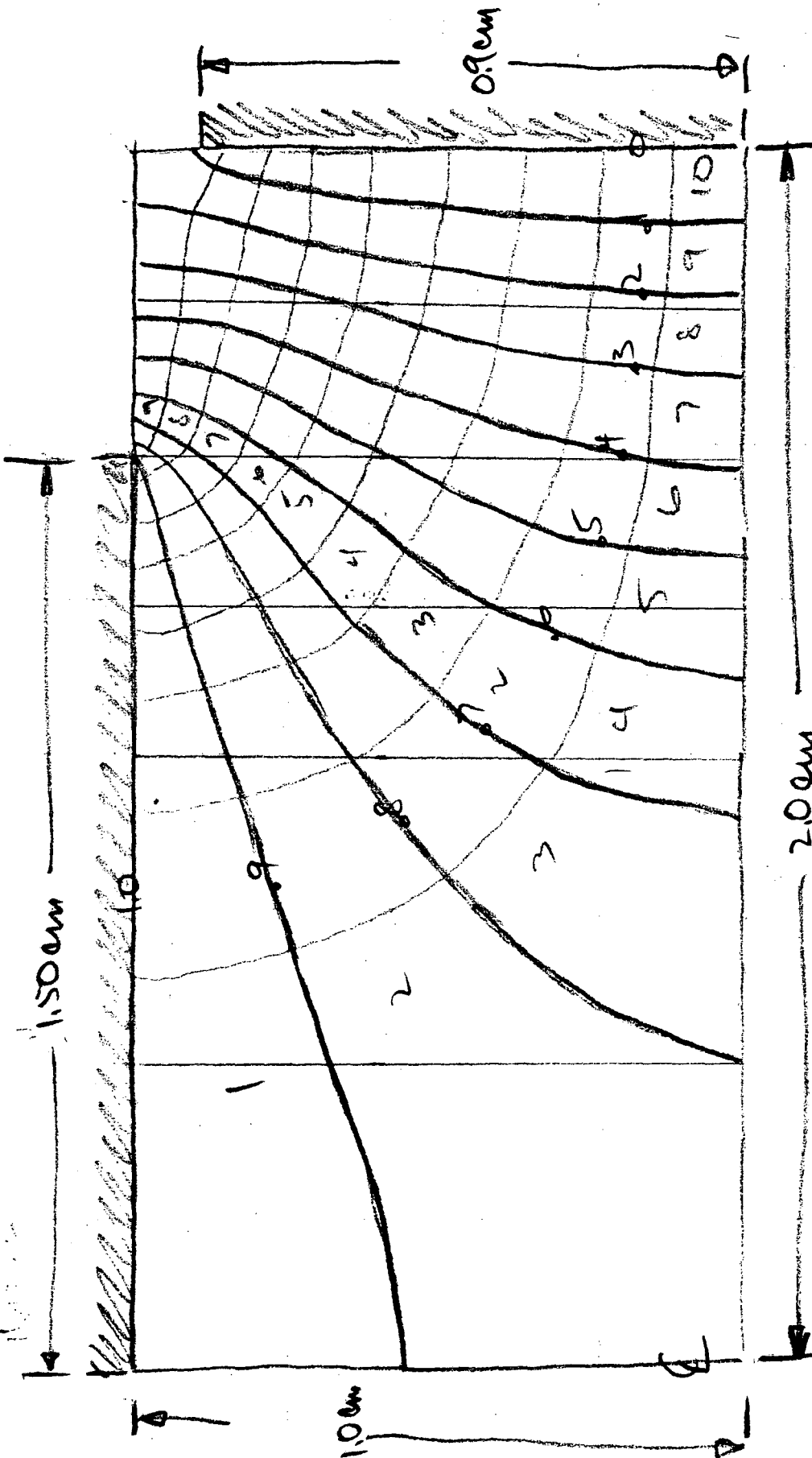
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TRANSVERSE PLANES - TEMPERATURE PROFILES FOR 1.0cm THICK COATINGS



$$S = \frac{(2 \times 9)}{10} = 1.80$$

$$V = 3.0 \text{ cm}$$

$$t = 1.0 \text{ cm}$$

$$W = 4.0 \text{ cm}$$

SIDE COATINGS

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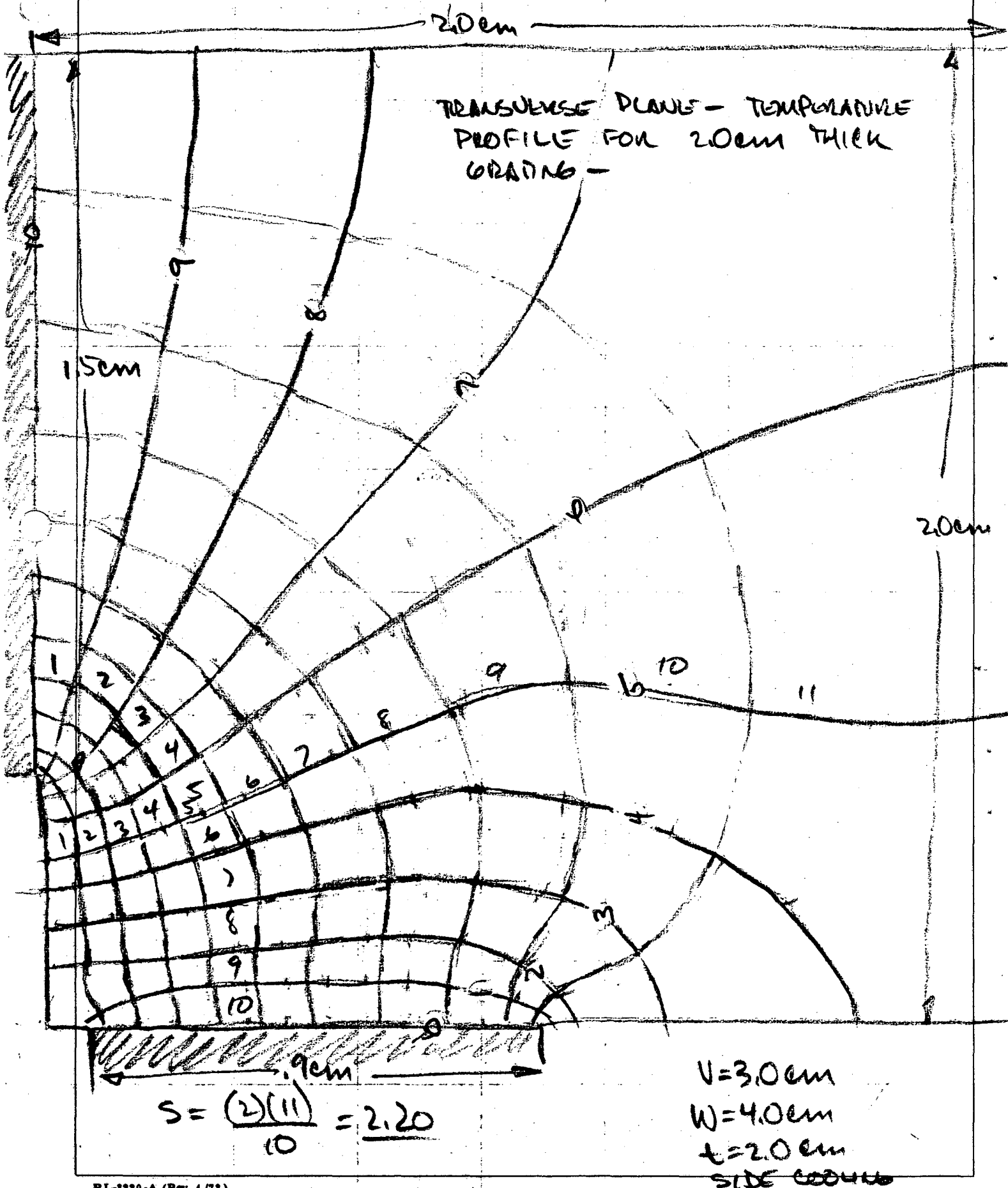
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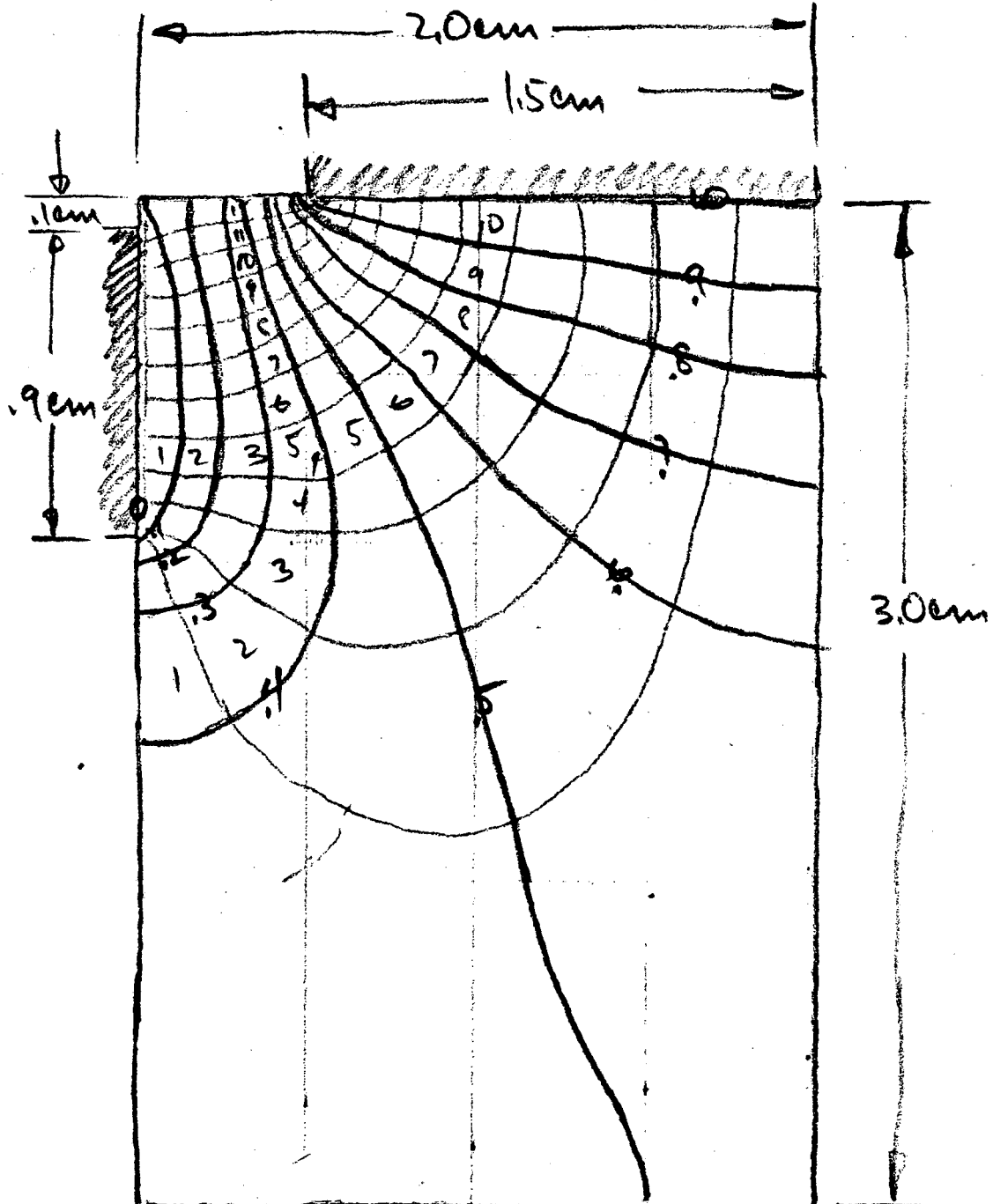
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TRANSVERSE PLANS - TEMPERATURE PROFILE FOR
3.0cm THICK GRATING.



$$S = \frac{(2 \times 12)}{10} = 2.4$$

$$V = 3.0 \text{ cm}$$

$$W = 4.0 \text{ cm}$$

$$t = 3.0 \text{ cm}$$

SIDE COOLING

ENGINEERING NOTE

SLO833

M5908

20.43
OF

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DEPARTMENT

LOCATION

DATE

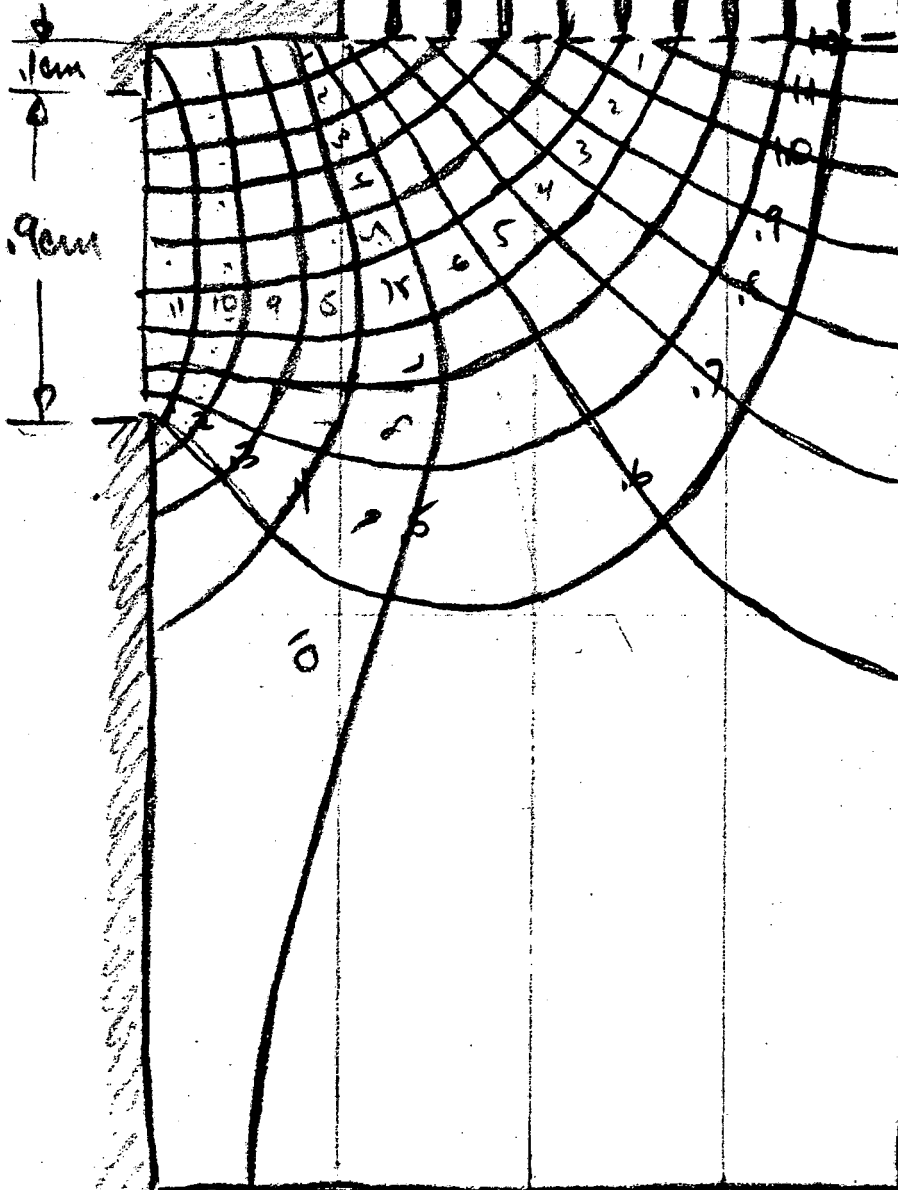
Egon Hoyer

5/6/82

TRANSVERSE PLANE - TEMPERATURE PROFILE FOR 3.0cm
THICK GRATING WITH UNIFORM FLUX
HEATING.

0.0 1.26 2.46 3.50 4.59 5.59 6.49 7.31 8.17 8.98 10.00

APPROXIMATELY
UNIFORM
FLUX
HEATING
GRATING



V = 3.0cm
W = 4.0cm
t = 3.0cm

$$S = \frac{(2)(10)}{11} = 1.82$$

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$$\text{USE } t = 3.0 \text{ cm} \quad S = 2.4 \quad (\text{PAGE 19})$$

$$\Delta T = \frac{\bar{m} \cdot 3.0 \text{ cm}}{(71 \text{ W/m} \cdot \text{K})(2.4)} \cdot \frac{10^2 \text{ cm}}{\bar{m}}$$

$$\Delta T = 1.761 \cdot \bar{m}$$

ΔT REPRESENTS TEMPERATURE DIFFERENCES BETWEEN HEATED SURFACE & COOLING SURFACE, THE TEMPERATURE DIFFERENCES BETWEEN THE TOP AND BOTTOM CAN BE APPROXIMATED USING THE TEMPERATURE PROFILE - ASSIGNING "10" TO HEATED SURFACE AND "0" TO COOLED SURFACE AND DETERMINING AN AVERAGE ΔT_{TB}

$$\Delta T_{TB} = \frac{\Delta T}{2.0} \left(\frac{(10 \times 1.5) + (0 \times 1.5)}{2.0} - 4.8 \right) = 0.35 \Delta T$$

$$\Delta T_{TB} = 0.616 \bar{m}$$

$$\theta_{ES} = \frac{k \alpha \Delta T_{TB}}{t}$$

FOR $l = u$

$$\theta_{ES} = \frac{u \text{ (cm)} (3.5 \times 10^{-6} / \text{cm}) (.616) \bar{m} \left(\frac{\text{W}}{\text{cm}^2 \cdot \text{C}} \right)}{3.0 \text{ cm}}$$

$$\theta_{ES} (\mu\text{RAD}) = 0.719 \bar{m} u$$

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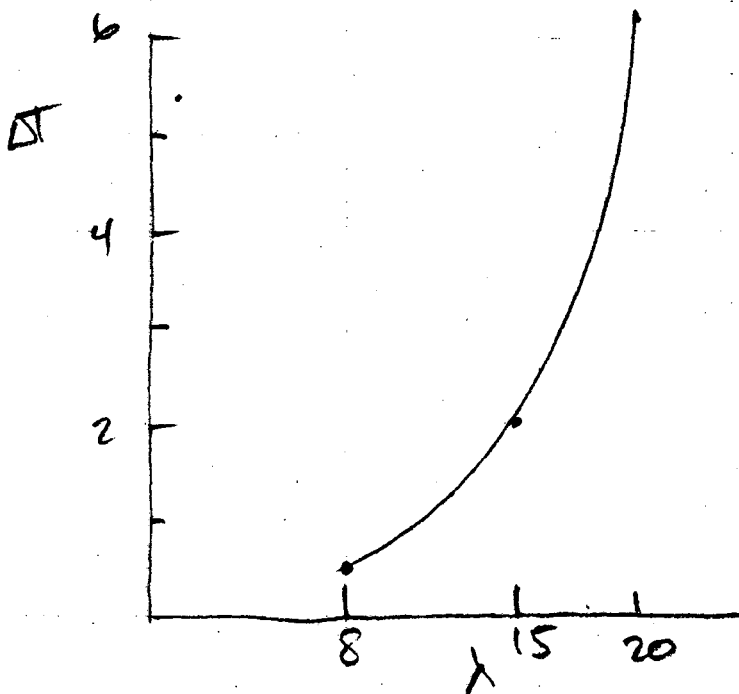
A

λ (Å)	$\bar{m}\alpha$ (W/cm)	$\bar{m}$ (W/cm ²)	θ_{ES} (mrad)	ΔT (°C)	ΔT_{TB} (°C)
8	3.72	.276	2.67	.49	.17
15	7.03	1.13	5.05	4.99	.70
20	9.55	3.52	6.87	6.20	2.77
35.5	11.46	8.59	8.24	15.1	5.59
70.7	11.98	19.4	8.61	34.2	12.8
200	12.81	61.6	9.21	108	38.0

LEISER
1 DIMENSIONAL
HEAT
TRANSFER



LOOKS BETTER

 θ_{ES} IS PLOTTED ON PAGE 32

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② RADIATION COOLING OF GRATING WITHOUT
RADIATING SURFACES ATTACHED TO GRATING:

CONSIDER:

$$Q_{IW} = 40 \text{ WATTS MAX.}$$

$$\epsilon_s = 0$$

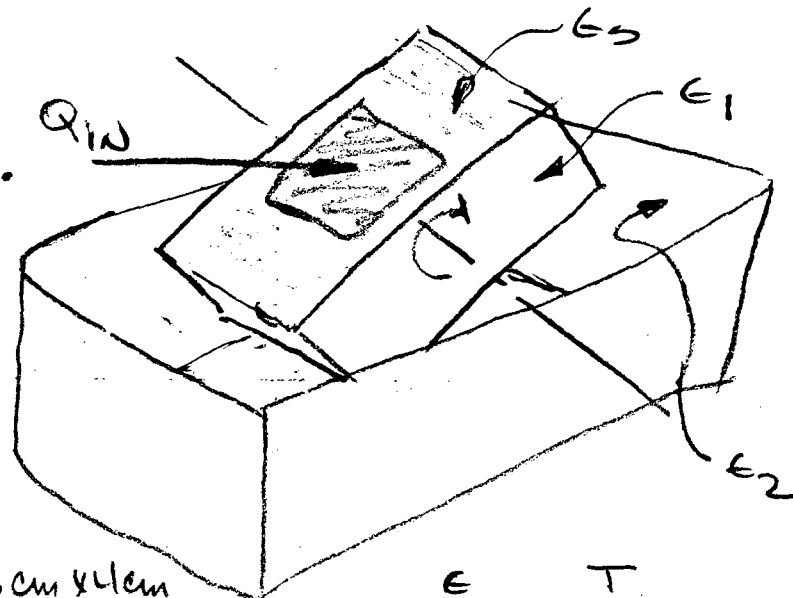
$$\epsilon_1 = .9$$

$$\epsilon_2 = .4 \text{ (TIN)}$$

$$T_2 = 40^\circ \text{C}$$

GRATING SIZE: 3cm x 4cm
x 10cm

(THICK X WIDTH X LENGTH)



ϵ S/C	T °C
.83	150°C
.96	650°C

SURFACE TEMPERATURES

$$Q_{IW} = A_1 F_{12} \sigma (T_1^4 - T_2^4)$$

$$T_1^4 = \frac{Q_{IW}}{A_1 F_{12} \sigma} + T_2^4$$

$$T_1 = \left(\frac{Q_{IW}}{A_1 F_{12} \sigma} + T_2^4 \right)^{1/4}$$

$$A_1 = (4 \text{ cm})(10 \text{ cm}) + (2)(3)(10 \text{ cm}) + (2)(4 \text{ cm})(5 \text{ cm})$$

$$= 124 \text{ cm}^2 = .0124 \text{ m}^2$$

$$F_{12} = \frac{1}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} = \frac{1}{\frac{1}{.9} + \frac{1}{.4} - 1} = .38$$

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$$T_1 = \left(\frac{40}{(1.24 \times 10^{-2} \text{ m}^2)(.38) \left(\frac{3.66 \times 10^{-4} \text{ W}}{10^2 \text{ } ^\circ\text{K}^4} \right) \left(\frac{39.37 \text{ W}}{\text{m}} \right)^2} \right)^{1/4} + (273.15)$$

$$5.673 \times 10^{-8} \text{ W}$$

$$T_1 = 632^\circ \text{K} = \underline{358^\circ \text{C}} \quad \text{MAXIMUM}$$

T_1 IS A FUNCTION OF Q_{IN} IS GIVEN ON THE FOLLOWING PAGE.

WAKING DISTORTION WITHIN GRATING:
FROM PG'S 14 & 16

$$\Theta = \frac{\alpha \Delta T}{t}$$

$$\Delta T = \frac{Q}{KS \alpha}$$

$$Q = \bar{m} V \alpha$$

$$\Delta T = \frac{\bar{m} V}{KS}$$

$$\Theta = \frac{\alpha \bar{m} V}{t KS}$$

$$\Theta = \frac{\alpha}{K} \frac{Q}{t S}$$

CONSIDERING SiC; $\frac{\alpha}{K} = 4.92 \times 10^{-8} \frac{\text{W}}{\text{W}}$
FOR:
 $t = 3.0 \text{ cm}$, $V = 3.0 \text{ cm}$
 $S = 2.80$ (SEE PG 26)

3/

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GRATING COOLING SURFACE

TEMPERATURE, T , °C

500

400

300

200

1

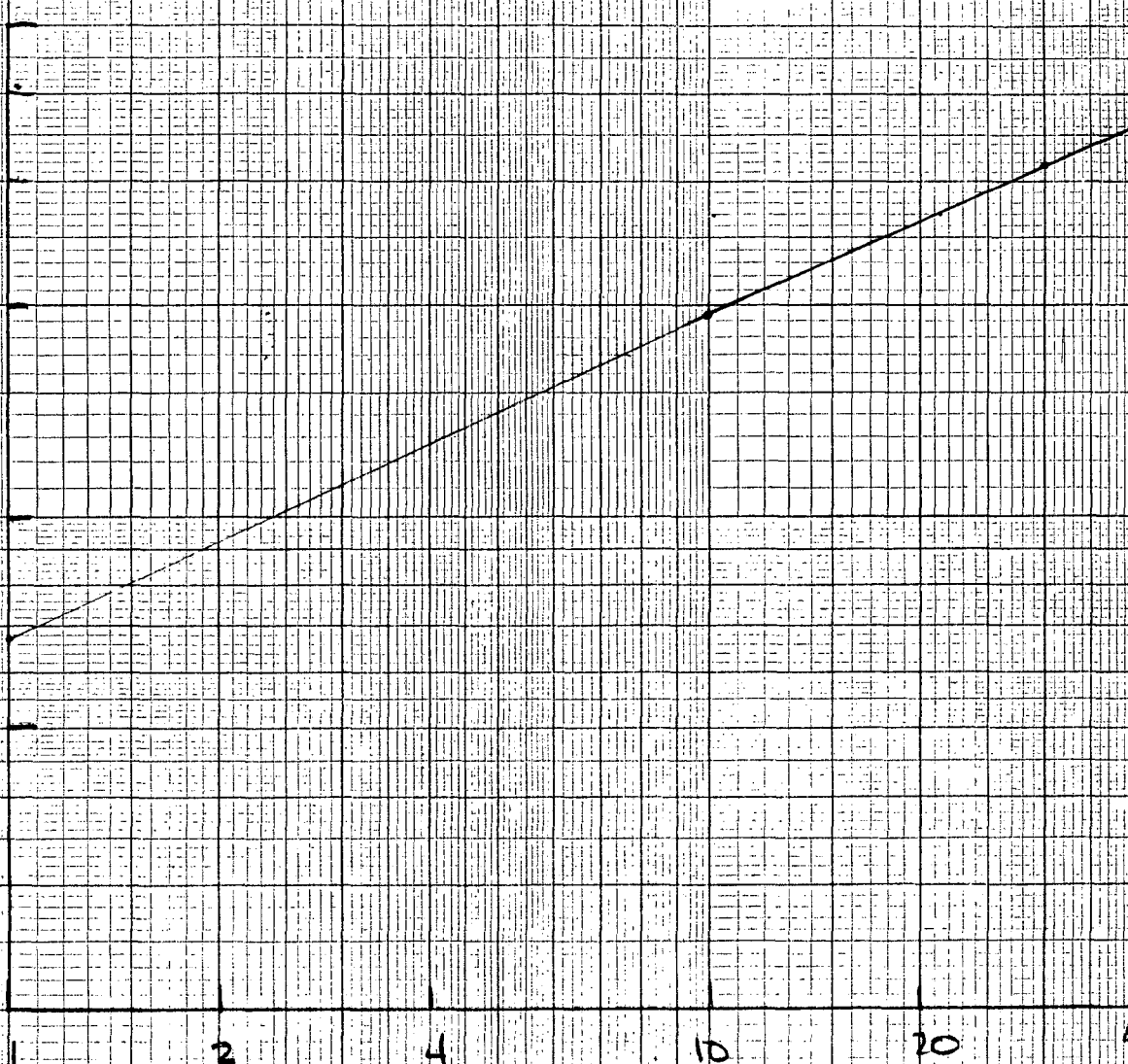
2

4

10

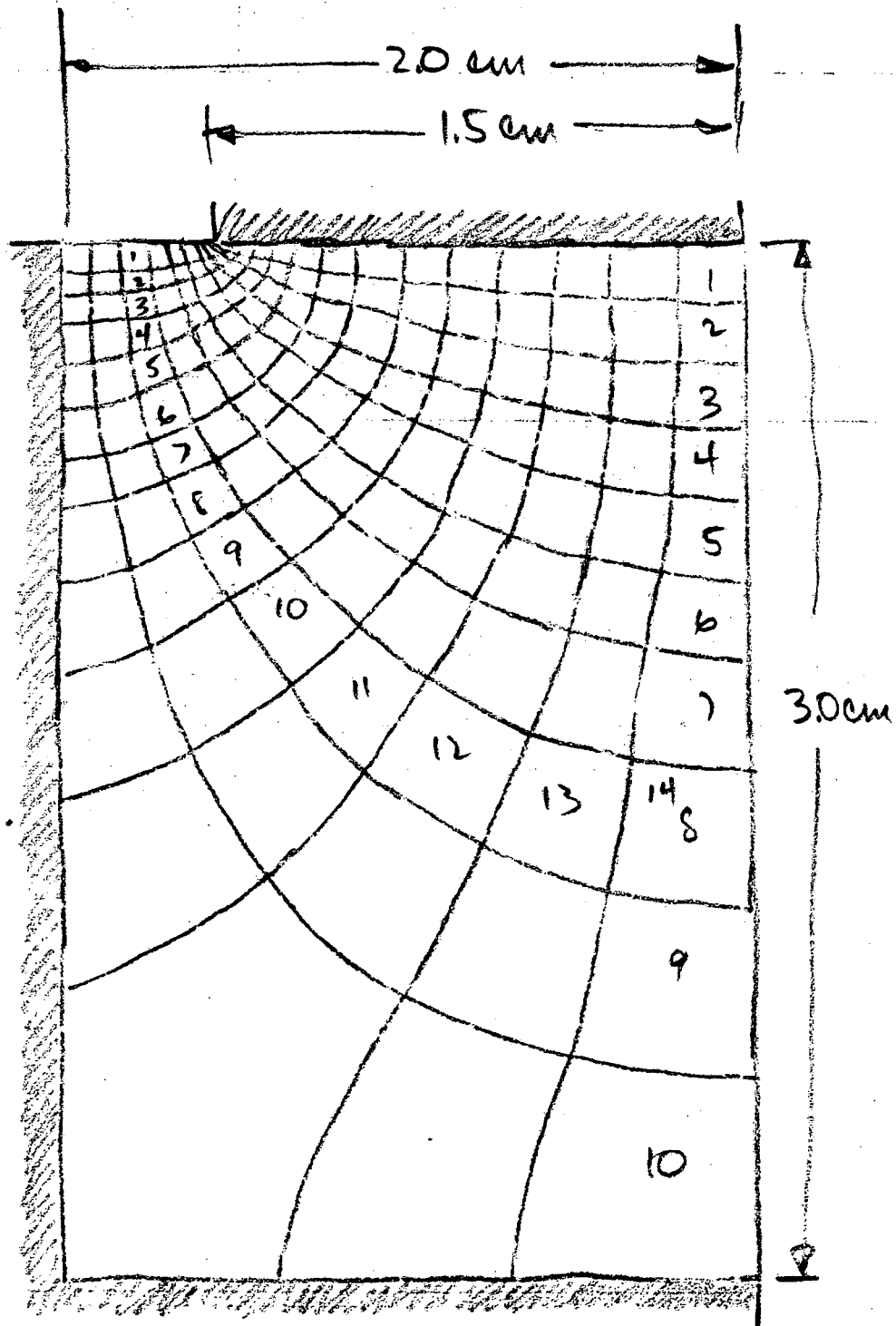
20

GRATING HEATING, Q_w , WATTS



4/

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$$S = \frac{(2 \times 14)}{10} = \underline{2.8}$$

$$\begin{aligned} V &= 3.0 \text{ cm} \\ t &= 3.0 \text{ cm} \\ W &= 4.0 \text{ cm} \end{aligned}$$

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$$\theta_e = \left(\frac{4.92 \times 10^{-8} \text{ W}}{\text{W}} \right) \frac{1}{(1.03 \text{ m})} \frac{1}{2.80} Q$$

$$\theta_e (\text{MEAD}) = 0.585 Q (\text{WATTS})$$

$$\Delta T_e = \frac{Q}{K S u}$$

$$= \frac{Q}{\left(\frac{71 \text{ W}}{\text{W/MK}} \right) (2.8) \text{ M}}$$

$$\Delta T_e (^\circ\text{C}) = \frac{.00503 Q (\text{W})}{\text{M (M)}}$$

A

λ A	$\bar{m}$ W/cm ²	u cm	Q W	θ_e MEAD	ΔT_e ($^\circ\text{C}$)	T_{MAX} ($^\circ\text{C}$)
8	.276	13.46	11.2	6.6	0.42	206
15	6.13	4.06	21.1	12.3	2.62	274
20	3.52	2.71	28.7	16.8	5.32	317
35.5	8.59	1.35	34.4	20.1	12.8	350
70.7	19.9	0.67	35.9	21.0	29.6	370
200	61.6	.20	38.4	22.5	96.6	455

L-15cm

θ_e IS PLOTTED ON DRAW 32

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① SIDE COOLING WITH WIDER GRATING:

CONSIDER 5.0cm WIDTH INSTEAD OF 4.0cm WIDTH:

THE TRANSVERSE TEMPERATURE DISTRIBUTION IS SHOWN ON THE FOLLOWING PAGE

MACRO DISTORTION:

ΔT INCREASES BY:

$$\Delta T_W = \frac{S}{S_W} = \frac{2.4}{1.8} = 1.333$$

ΔT_{TB_W} :

$$\Delta T_{TB_W} = \Delta T \left(\frac{(1.0)(1.5)^{1.74} + (.35)(1.0)}{2.5} - .58 \right) = .16 \Delta T$$

THUS, ΔT_{TB_W} DECREASES BY:

$$\Delta T_{TB_W} = (1.333) \left(\frac{.16}{1.35} \right) \Delta T_{TB} = .161 \Delta T_{TB}$$

THUS FOR ΔT : (FROM PAGE 21)

$$\Delta T = (1.761)(1.333) \bar{m}$$

$$\Delta T = 2.347 \bar{m}$$

$$\dot{Q}_{ESW} = (1.719 \bar{m}^2)(.161)$$

$$\dot{Q}_{ESW} = .438 \bar{m}^2$$

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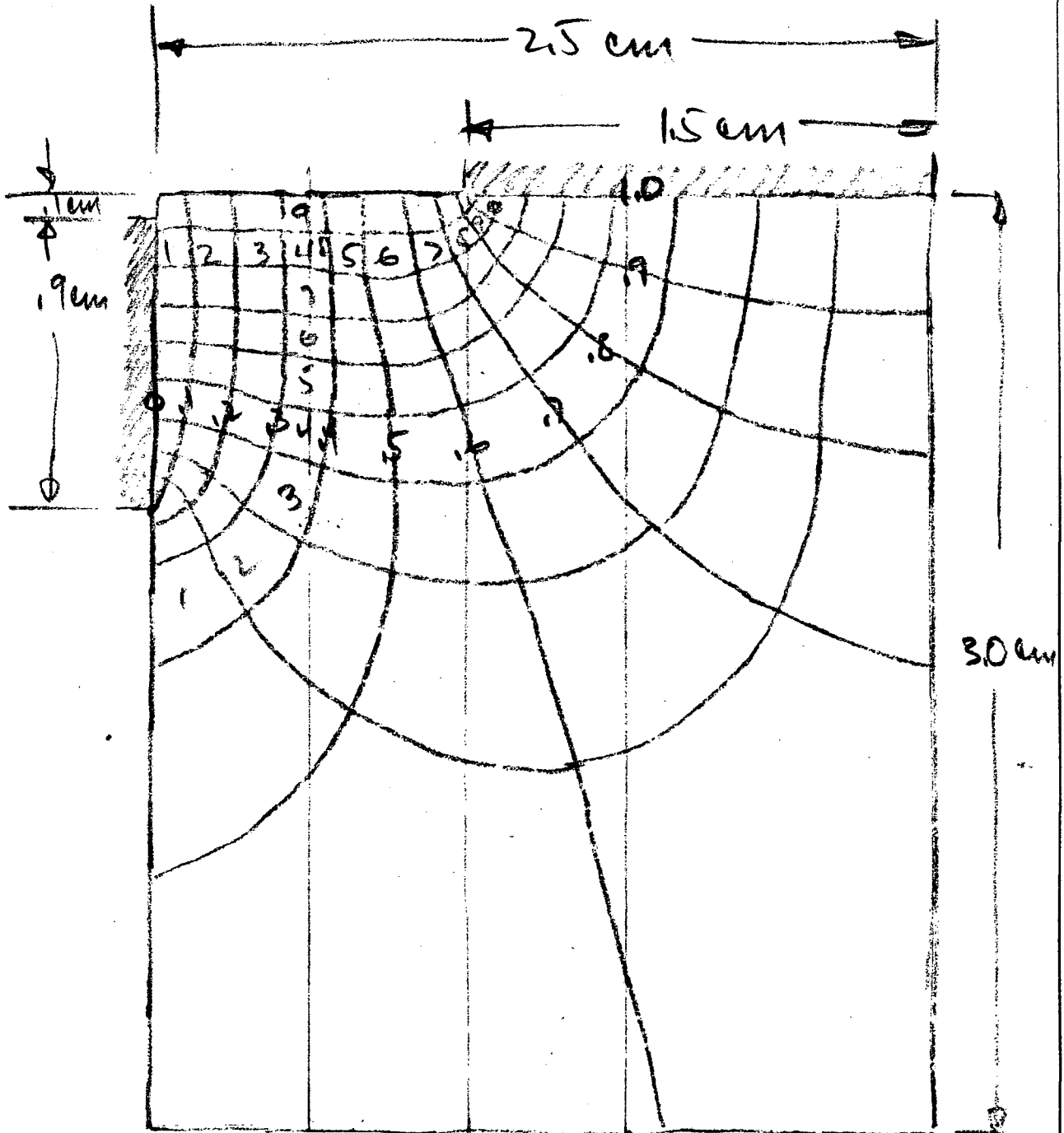
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$$S = \frac{(2 \times 9)}{10} = 1.8$$

$$V = 3.0 \text{ cm}$$

$$W = 5.0 \text{ cm}$$

$$t = 3.0 \text{ cm}$$

SIDE COOLING

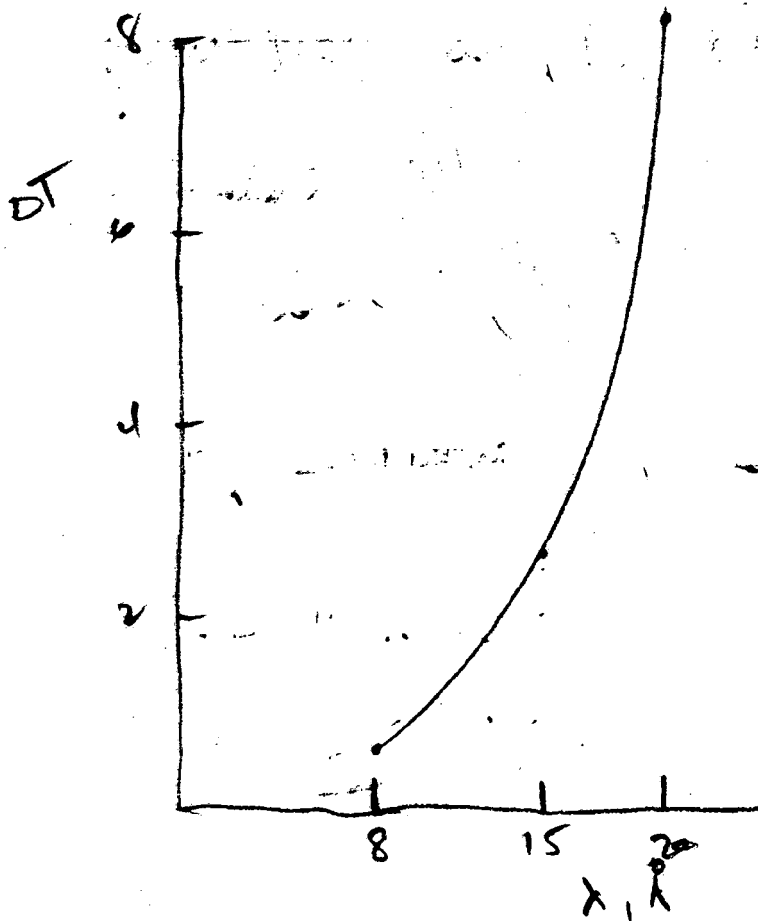
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λ (Å)	$\bar{m}$ (W/cm)	$\bar{m}$ (W/cm)	θ_{eq} (deg)	ΔT (°C)	ΔT_{TB} (°C)
8	3.72	.276	1.63	0.65	0.10
15	7.03	1.13	3.08	2.65	0.42
20	9.55	3.52	4.18	8.26	1.32
35.5	11.46	8.39	5.02	20.2	3.23
70.7	11.98	19.4	5.25	45.5	7.28
200	12.81	61.6	5.61	144	23.0

LEISUM
1 DIMENSIONAL
HEAT
TRANSFON

↑ LOOKS
BETTER

SEE PAGE 32 FOR θ_{eq}



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GRATING TIME-TEMPERATURE RISE:

$$P t = (P \gamma V) \Delta T$$

$$\frac{t}{\Delta T} = \frac{P \gamma V}{P}$$

$$= \left(\frac{1.42 \times 10^3 \text{ J}}{40 \text{ W}} \right) \left(\frac{\text{W-sec}}{\text{J}} \right) \left(\frac{3.1 \times 10^3 \text{ kg}}{\text{m}^3} \right) (.1 \text{ m}) (.04 \text{ m}) (.03 \text{ m})$$

$$\frac{t}{\Delta T} = 13.2 \frac{\text{sec}}{\text{OK}} \quad \text{FAST!}$$

GRATING COOLING SURFACE AREA:

WITH RADIATIVE SURFACES EXTENDING FROM THE GRATING SIDES:

FOR:

$$T_{\text{MAX}} = 250^\circ \text{C}$$

$$T_{\text{SUN}} = 30^\circ \text{C}$$

$$\epsilon_1 = 0.4 \quad (\text{TIN})$$

$$Q = 40 \text{ WATTS}$$

$$Q = \epsilon A \epsilon (T_{\text{MAX}}^4 - T_{\text{SUN}}^4)$$

$$A = \frac{Q}{\epsilon \epsilon (T_{\text{MAX}}^4 - T_{\text{SUN}}^4)}$$

$$= \frac{40}{\epsilon \epsilon (T_{\text{MAX}}^4 - T_{\text{SUN}}^4)}$$

$$\left(\frac{3.66 \times 10^{-11}}{\text{W}^2 \text{ K}^4} \right) (.4) [(250+273)^4 - (30+273)^4]$$

$$\textcircled{A} \text{ FOR } \epsilon = .9 \text{ (S)} \quad \text{OR } 2 \times 58.7 \text{ cm}$$

$$= 41 \text{ IN}^2$$

$$A = 18.22 \text{ IN}^2$$

WITH 2 SIDED FINS

$$A_{\text{FIN}} = 20.5 \text{ IN}^2 \rightarrow 132 \text{ cm}^2 \rightarrow 2 \times 66 \text{ cm}^2$$

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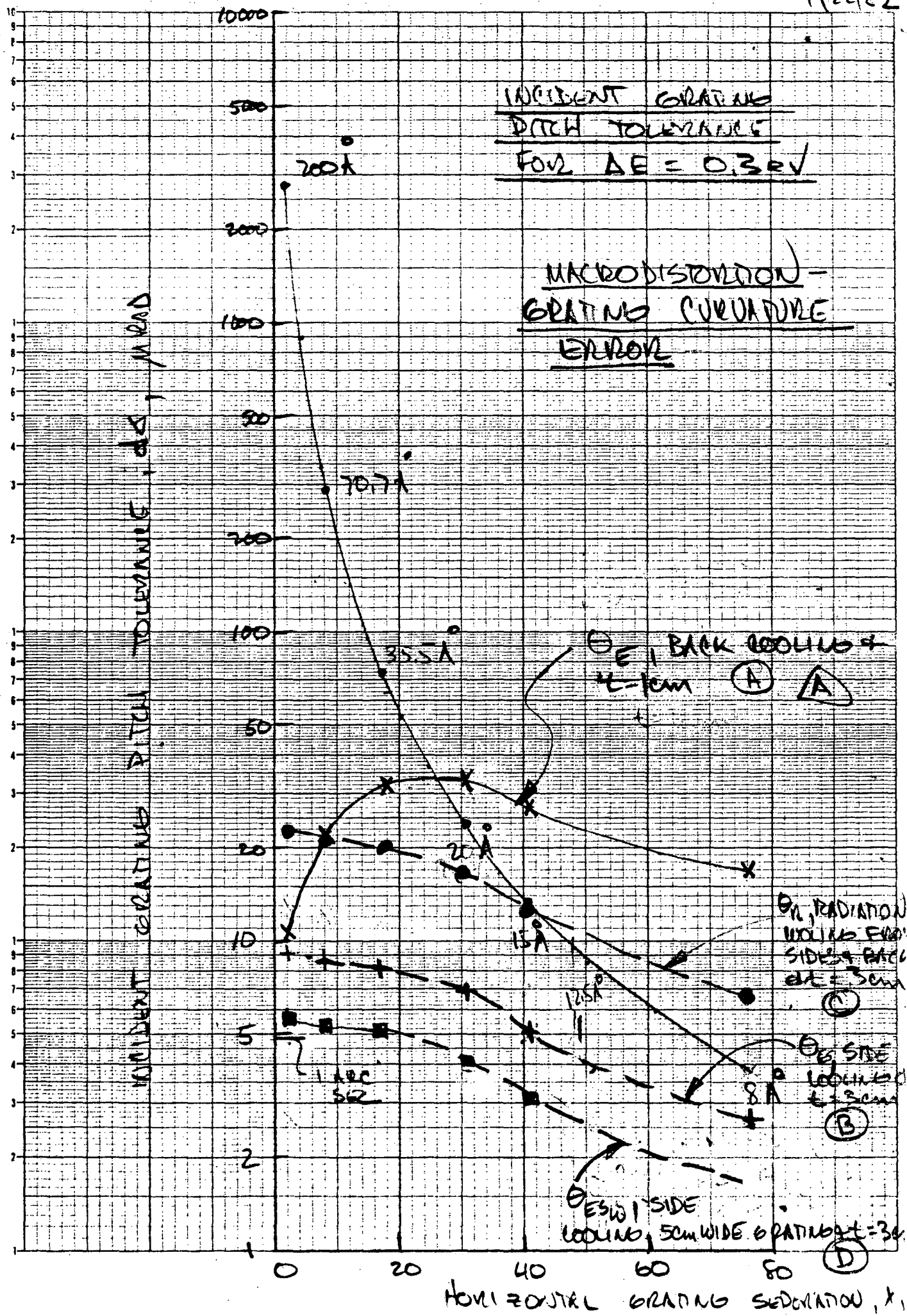
4 CYCLES X 70 DIVISIONS

SEMI-LOGARITHMIC

Buffalo, New York

GRAPHIC CONTROLS CORPORATION

Model 1000



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MICRO DISTORTION:

UTILIZING THE GRATING TEMPERATURE DISTRIBUTION MODELS AND EMPLOYING THE CONCEPT OF 1 DIMENSIONAL STRAIN (I.E. THE GRATINGS ARE MADE UP OF COLUMNS IN THE THICKNESS DIMENSION) SURFACE TOPOLOGIES CAN BE ESTIMATED.

THICKNESS GROWTH:

$$\begin{aligned}
 dh &= h \alpha \Delta T \\
 &= \alpha \sum_{i=1}^n \Delta h_i (f_i \Delta T) \\
 &= \alpha \Delta T \sum_{i=1}^n (\Delta h f)_i
 \end{aligned}$$

GROWTH FROM NEUTRAL AXIS:

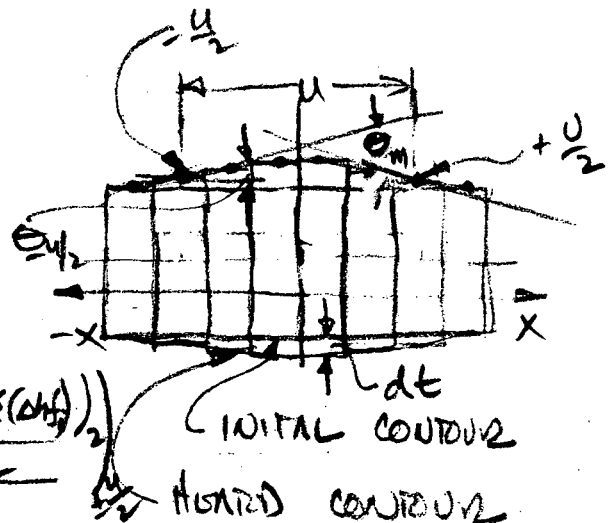
$$dt = \frac{dh}{2}$$

ANGULAR ERROR DUE TO TOPOLOGY:

$$\theta_m = 2 \theta_{u/2}$$

$$\theta_{u/2} = \frac{dt_1 - dt_2}{x_1 - x_2}$$

$$\theta_m = \frac{\alpha \Delta T \left(\sum (\Delta h f)_i - \sum (\Delta h f)_j \right)}{x_1 - x_2}$$



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③ SIDE COOLING:

- THIS TRANSVERSE PLANE TEMPERATURE PROFILE IS SHOWN ON PAGE 19

- LONGITUDINAL PLANE TEMPERATURE

△ PROFILES ARE SHOWN ON PAGES 34 (8 Å), 35 (12.5 Å) AND PAGE 37 (20 Å)

△ - FACTOR $\Sigma(\Delta hf)_i$ HAS BEEN NUMERICALLY CALCULATED FOR 8, 12.5 & 20 Å AND ARE SHOWN ON PAGES 34, 36 AND 38 RESP.

△ - 8 Å ANGULAR ERROR DUE TO THICKNESS GROWTH:

$$\left| \frac{((\Sigma(\Delta hf)_i)_1 - (\Sigma(\Delta hf)_i)_2)}{x_1 - x_2} \right| = \left| \frac{3.0 - 1.2}{5.5 - 2.5} \right| = .900$$

$$\theta_{ms} = (3.5 \times 10^{-6} / ^\circ\text{C}) \times (.49) \times (.900) \frac{\mu\text{RAD}}{10^{-6}\text{RAD}}$$

$$\theta_{ms} = 7.54 \mu\text{RAD}$$

△ - 12.5 Å ANGULAR ERROR DUE TO THICKNESS GROWTH:

$$\left| \frac{((\Sigma(\Delta hf)_i)_1 - (\Sigma(\Delta hf)_i)_2)}{x_1 - x_2} \right| = \left| \frac{3.0 - 1.45}{1 - .4} \right| = .517$$

$$\theta_{ms} = (3.5 \times 10^{-6} / ^\circ\text{C}) \times (1.3^\circ\text{C}) \times (.517) \frac{\mu\text{RAD}}{10^{-6}\text{RAD}}$$

$$\theta_{ms} = 2.35 \mu\text{RAD}$$

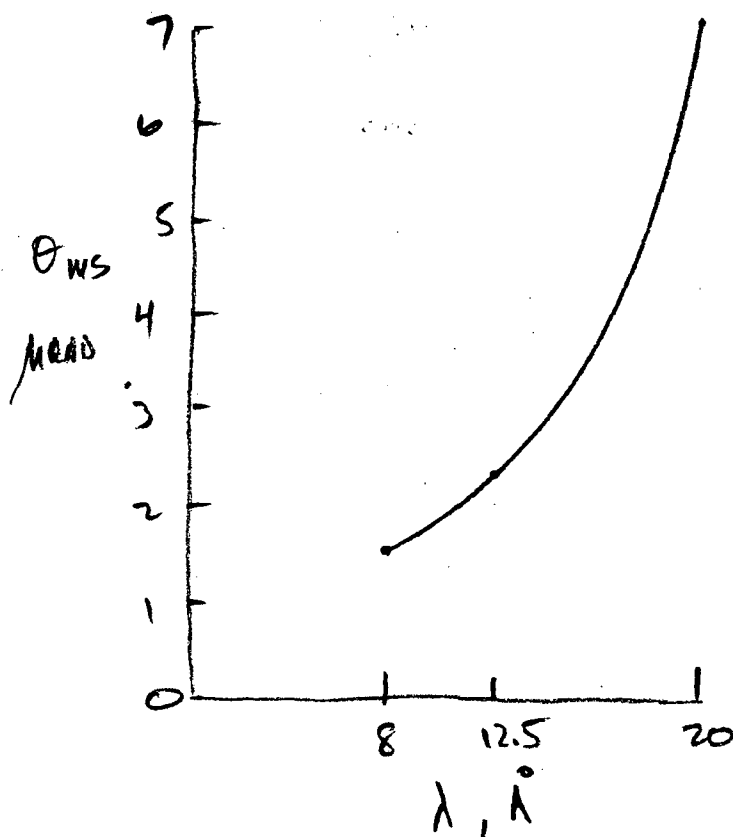
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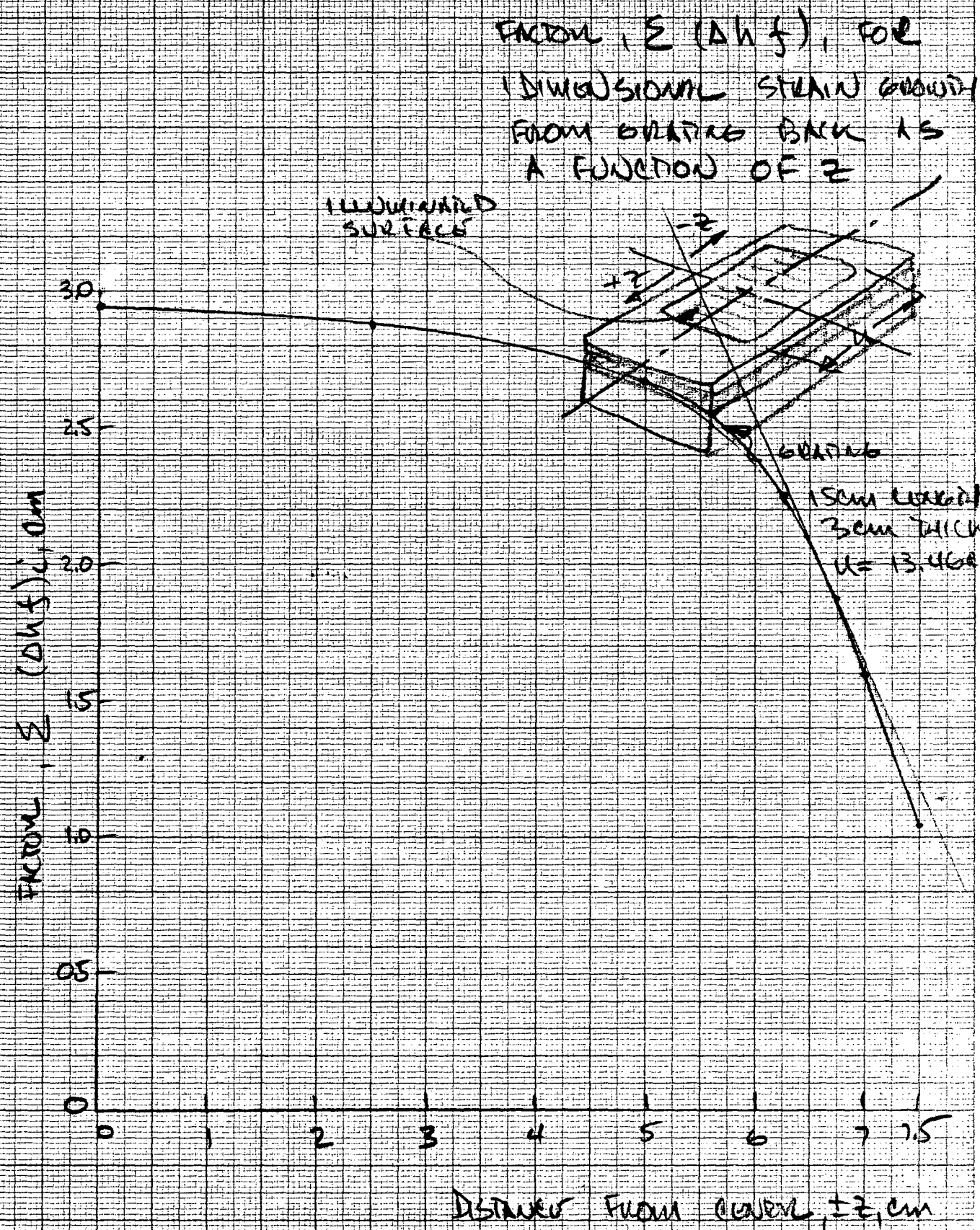
- 20 Å ANGULAR ERROR DUE TO THICKNESS GROWTH

$$\left| \frac{(\epsilon(\Delta hf)_i)_1 - (\epsilon(\Delta hf)_i)_2}{\lambda_1 - \lambda_2} \right| = \left| \frac{2.6 - .97}{0 - 5.0} \right| = .326$$

$$\theta_{ms_{20}} = (3.5 \times 10^{-6} / ^\circ\text{C}) (6.2^\circ\text{C}) (.326) \frac{\mu\text{RAD}}{10^{-6}\text{RAD}}$$

$$\theta_{ms_{20}} = \underline{7.07 \mu\text{RAD}}$$



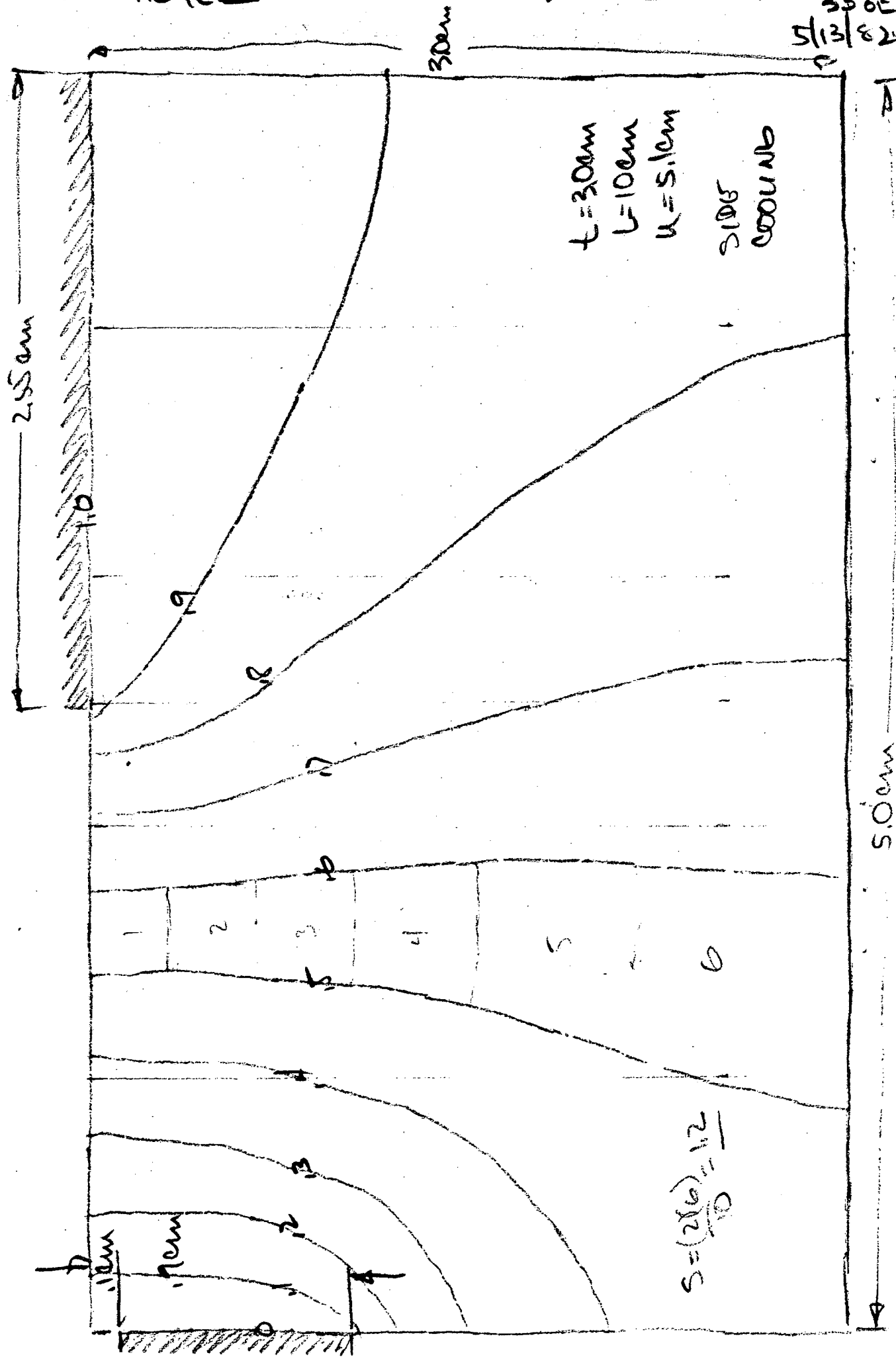


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COMPONENTS PROFILE FOR 3.0cm

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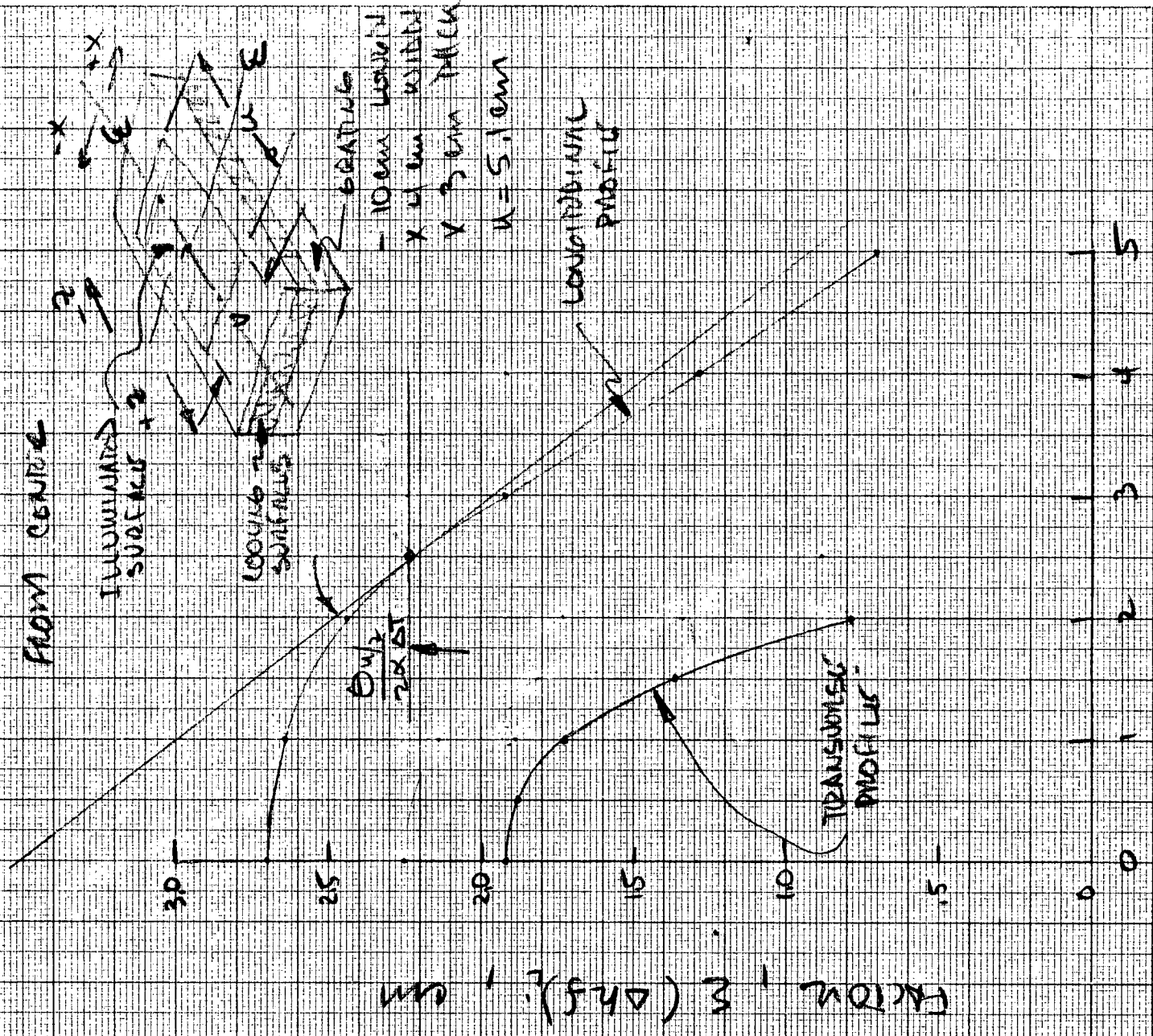
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5/13/68

ERROR (Δh_f), FOR ONE DIMENSIONAL
STRAIN GROWTH FROM GRATINGS
BACK AS A FUNCTION OF DISTANCE
FROM CENTER



DISTANCE FROM CENTER, x , cm

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① SIDE COOLING WITH WIDOW BRATING:

THIS CASE VARIES FROM CASE ③ IN THAT THE DT'S ARE LARGER:
DT'S ARE GIVEN ON PAGE 30 FOR THIS CASE:

① - 8 A ANGULAR ERROR:

$$\theta_{WS} = (1.91) \left(\frac{.65}{.491} \right) = \underline{2.04 \mu \text{RAD}}$$

① - 12.5 A ANGULAR ERROR:

$$\theta_{WS} = (2.33) \left(\frac{7.75}{1.3} \right) = \underline{3.14 \mu \text{RAD}}$$

① - 20 A ANGULAR ERROR:

$$\theta_{WS} = (7.07) \left(\frac{8.26}{6.2} \right) = \underline{9.42 \mu \text{RAD}}$$

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COMBINED DISTORTION:

THE MACRO AND MICRO DISTORTIONS ARE BASED ON 1 DIMENSIONAL HEAT TRANSFER. IN REALITY, THERE IS 2 DIMENSIONAL HEAT TRANSFER WHICH LOWERS THE ΔT 'S.

CORRECTION FACTOR FOR 2 D HEAT TRANSFER:

$$CF = \left(\frac{S_x u}{S_x u + S_z v} \right)$$

S_x = TRANSVERSE S FACTOR

S_z = LONGITUDINAL S FACTOR

TOTAL ANGULAR ERROR:

$$\theta_T = CF(\theta_E + \theta_m)$$

(B) SIDE COOLING

(A) - 8 Å TOTAL ANGULAR ERROR

$$CF_{s8} = \frac{(2.4)(13.46)}{(2.4)(13.46) + (2.4)(3)} = 0.82$$

$$\theta_{T_{s8}} = (0.82)(2.67 + 1.54) = 3.5 \text{ mrad}$$

- 15 Å - TOTAL ANGULAR ERROR:

(A)

$$CF_{s15} = \frac{(2.4)(4.1)}{(2.4)(4.1) + (1.2)(3)} = 0.73$$

$$\theta_{T_{s15}} = (5.05 + 3.0) \cdot 0.73 = 5.9 \text{ mrad}$$

(A) - 20 Å - TOTAL ANGULAR ERROR:

$$CF_{s20} = \frac{(2.4)(2.71)}{(2.4)(2.71) + (0.8)(3)} = 0.73$$

$$\theta_{T_{s20}} = (6.87 + 7.07) \cdot 0.73 = 10.7 \text{ mrad}$$

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① SIDE COOLING WITH WIDEN GRATING

- 8 Å - TOTAL ANGULAR ERROR:

$$\triangle A \quad CF_{WS \frac{8}{8}} = \frac{(1.8)(13.46)}{(1.8)(13.46) + (2.4)(3)} = \underline{.77}$$

$$\theta_{T \frac{WS}{8}} = (1.63 + 2.04)(.77) = \underline{2.6 \mu\text{RAD}}$$

- 15 Å - TOTAL ANGULAR ERROR:

$$\triangle A \quad CF_{WS \frac{15}{15}} = \frac{(1.8)(4.1)}{(1.8)(4.1) + (1.2)(3)} = \underline{.67}$$

$$\theta_{T \frac{WS}{15}} = (3.08 + (3.0)(\frac{1.5}{1.3}))(.67) = \underline{4.8 \mu\text{RAD}}$$

- 20 Å - TOTAL ANGULAR

$$CF_{WS \frac{20}{20}} = \frac{(1.8)(2.71)}{(1.8)(2.71) + (0.8)(3)} = \underline{.67}$$

$$\theta_{T \frac{WS}{20}} = (4.18 + 9.42)(.67) = \underline{9.1 \mu\text{RAD}}$$

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SUMMARY

BASED ON THIS CRUDE ANALYSIS, PG 42a

(A)

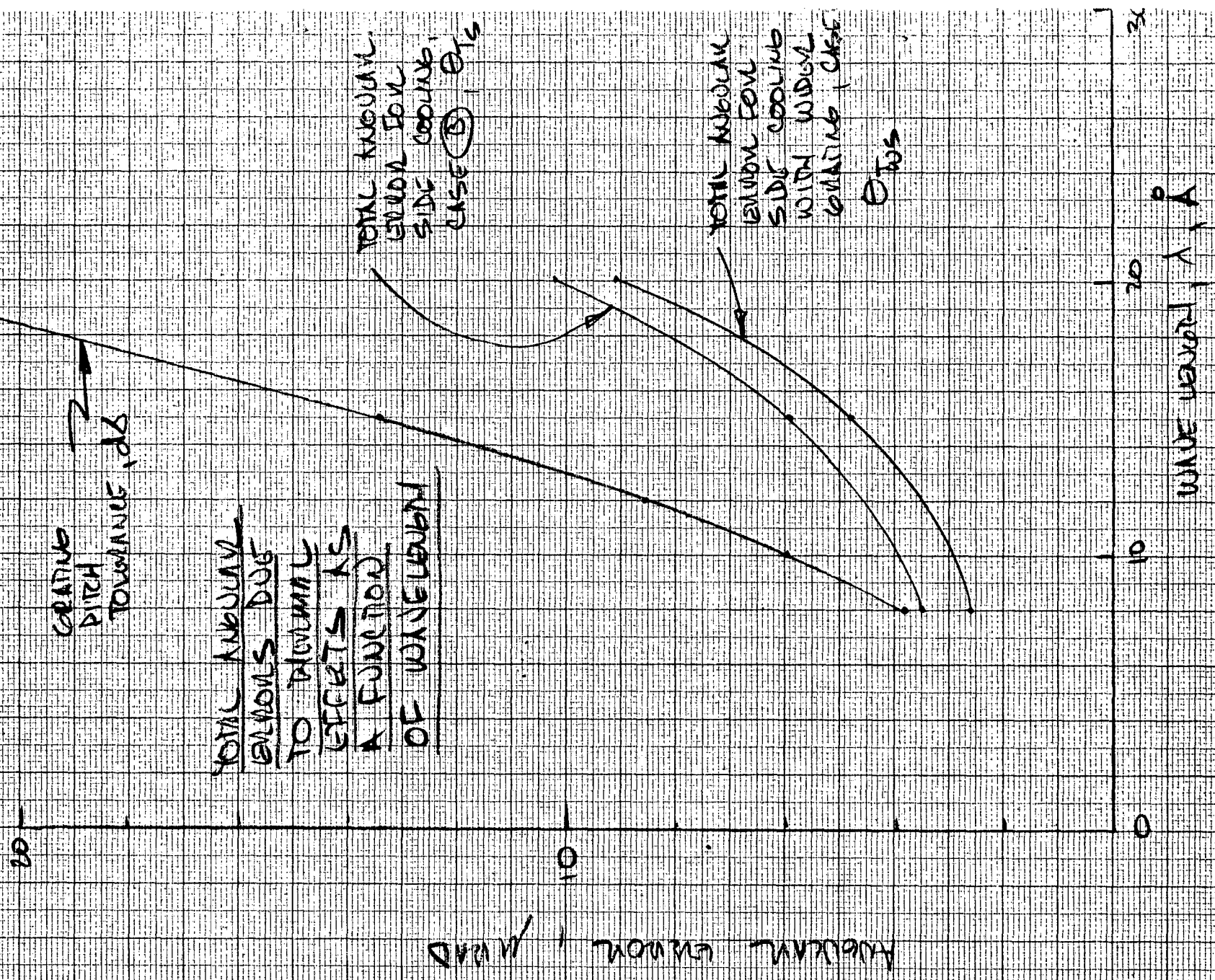
SUMMARIZES THE TOTAL ANGULAR ERRORS AS A FUNCTION OF WAVE LENGTH. FOR THE SIDE COOLING CASES (B & D) AND SHOWS THAT THEY ARE LESS THAN THE GRATING PITCH TOLERANCES FOR 8-200 Å. THE WIDER GRATING IS BETTER.

FACTORS THAT EFFECT THE ABOVE RESULTS:

- THE MACRO DISTORTION WAS BASED ON THE TRANSVERSE TEMPERATURE PROFILE. IF THE LONGITUDINAL PROFILE WOULD INCLUDED THE RESULTANT CURVATURE WOULD BE LESS.
- THE ANALYSIS USED CONSTANT TEMPERATURE AT THE ILLUMINATION AREA. IF CONSTANT FLUX WOULD USED (COMPARE PAGES 19 & 20) THE RESULTANT MACRO CURVATURE WOULD BE GREATER. THE MICRO GROWTH WOULD BE GREATER IN THE CENTER (PAGE 43)
- 1 DIMENSIONAL STRAIN WAS USED. 3 DIMENSIONAL STRAIN WILL PROBABLY LESSON THE GROSS CURVATURE.
- THIS ANALYSIS IS POOR IN THE CORNER REGIONS OF ILLUMINATION. A WIDER GRATING DIMINISHES THIS PROBLEM.

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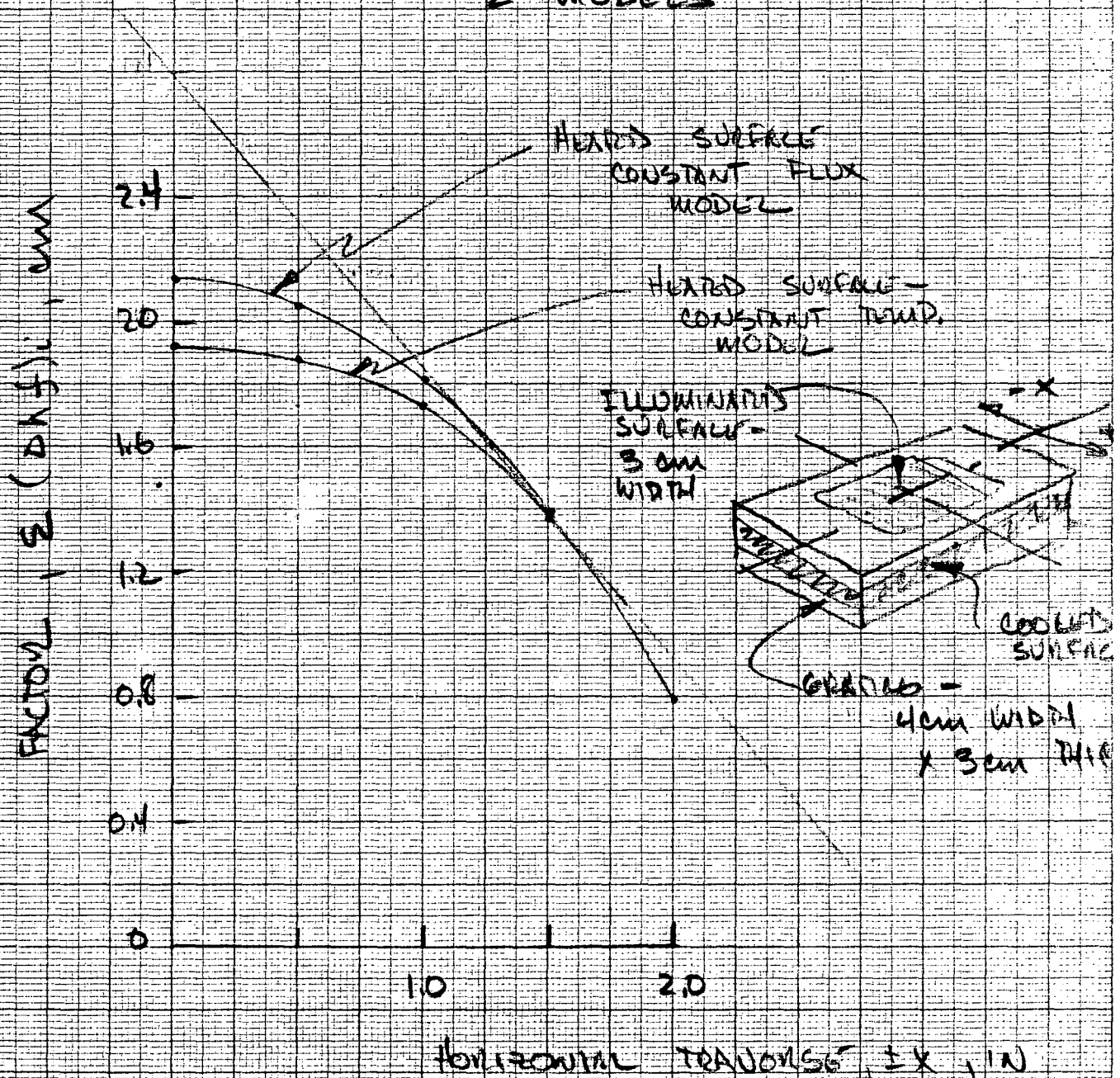


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EGON HOYER

FACTOR, $\Sigma(\Delta f)_i$, FOR ONE
DIMENSIONAL STRAIN GROWTH
FROM GRATING BACK AS A
FUNCTION OF TRANSVERSE
POSITION FROM THE CENTER
OF THE GRATING USING
2 MODELS



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