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Title
MOVABLE MASK - DESIGN ""H""; ENGINEERING DESIGN

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INTRODUCTION

This engineering note sets forth engineering calculations for the movable mask of beamline VI at Stanford Synchrotron Radiation Lab. After Far ¾ checkout, this mask will be installed at the "SPEAR" electron storage ring at SLAC.

Design "H" is characterized by the power absorbing panels being sloped in the horizontal plane so that the synchrotron radiation power from the wiggler magnet strikes at a small "glancing" angle.

INITIAL DISTRIBUTION:
SLAC: R. Boyce, B. Scott, H. Winick, N. Hower
S.I.F. - BL VI MOBILE MASK - DESIGN "H"

**Configuration**

\[
(x = \pm 4.16 \text{ cm} \\
@ \gamma = 5.74 \text{ m})
\]

\[
(x = \pm 1.98 \text{ cm} \\
@ \gamma = 6.51 \text{ m})
\]

\[
(x = \pm 2.12 \text{ cm} \\
@ \gamma = 6.60 \text{ m})
\]

\[
(x = \pm 0 \\
@ \gamma = 6.97 \text{ m})
\]

\[
\theta_{x} = \pm 1.75 \text{ mrad} (@ 3.0 \text{ GeV, 175 T})
\]

**Plan View**

First Fixed Mask

Movable Mask

Max. Orbit Displacement: ±10.0 mm ±1.34 mrad

Scale: Lateral - Full Size

Longitudinal - 1/10

The Movable Mask Opening of ±2.12 cm allows ±0.04 cm for angularity of rays plus ±0.10 cm for misalignment tolerance.

Don Hunt says 37.1 cm is available in longitudinal direction. This gives a slope of

\[
\frac{37.1 \text{ cm}}{2.12 \text{ cm}} = 17.5 \text{ to one}
\]
S.L.F. BL VI MOBILE MASK - DESIGN "H"

CONFIGURATION (ULD)

CONCEPTUAL

FOLLOWING IS ONE CONFIGURATION THAT SHOULD SATISFY THE CRITERIA. A LONGER LOCK MAY WELL BRING FORTH BETTER WAYS TO DO THE JOB.

2.12 cm (0.835"

ACTIVE LENGTH = 37.1 cm (14.61"

PLAN VIEW SCALE: 1/4

ULTRA-VACUUM

GUARD SPACE CONNECTED TO OUTSIDE WORLD SO NO WATER TO ULTRA-VACUUM LEAKAGE.

BRAZED JOINTS

SECTION A-A (ROTATED)

SCALE: 1/2X

WATER PASSAGES: 0.050" HALF-ROUND ON 0.150" CENTERS
THERMAL ANALYSIS

USE SAME METHOD AS FOR FIRST FIXED MASK IN
ENGRRG. NOTE #1 M5971 (AVERY, 26 Aug 82).
ASSUME SAME WALL CONSTRUCTION AS FOR
ARRANGEMENT "C". AS FOR ARRANGEMENT
"C", THE CONTROLLING SYNCH. RAD. INPUT IS
MODE C (3.0 GeV, 0.12A, 1.75T) WHICH WAS
THE GREATEST TOTAL POWER INPUT OF
6.845 WATTS.

THE ISOTHERM/FLUX PLOT FOR ARRANGEMENT "C"
WILL BE USED HERE ALSO AND IS SHOWN ON
NEXT PAGE. THIS PLOT WAS BASED ON
MODE "C" INPUT FALLING ON SURFACE AT
3 = 6.50 METERS. FOR THE MOVABLE MASK, THE
DISTANCES ARE SLIGHTLY GREATER SO THE
POWER WOULD BE A LITTLE MORE SPREAD
OUT AND THE "CONDUCTION" TEMP. DIFFERENCE
ΘK WOULD BE PROPORTIONATELY A LITTLE
LESS BUT THIS WILL BE IGNORED. THUS,
THE REAL ΘK WILL BE SLIGHTLY LESS
THAN WILL BE CALCULATED HERE.

THE SURFACE POWER DENSITY WILL BE TWICE THAT
FOR THE FIRST FIXED MASK BECAUSE THE
SLOPE HERE IS 1/17.5 COMPARED TO
1/35 FOR THE MASK.

\[
\left( \frac{Q}{A} \right)_{\text{max}} = (15.4 \text{ kW/cm}^2 \times \frac{1}{17.5} \times \frac{7.50}{6.50})^2 = 1.172 \text{ kW/cm}^2
\]

\[\approx 7.56 \text{ kW/inch}^2\]
SICF - BL II Movable Mask - Design "H" Cooling

Thermal Analysts Noted

Fixed Mask - Arrangement "C"

Model: 3.0 MV, 0.2 A, 1.75 T

Isothermal/Flux Plot
Based on Drawn-In Orthogonal Pattern
S.L.F. - BL VI Movable Mask - Design "H"

THERMAL ANALYSIS CONT.

ASSUMPTIONS & METHODS AS FOR FIXED MASK,

\[ \theta_0 = 5\% \text{ of } 2(0.77) \theta_e \cdot \beta = 0.00335' \]

\[ \theta_k = \frac{1}{k} \left( \frac{A}{A_{\text{max}}} \right) \cdot \theta_0 \]

FOR "OFHC" COPPER

\[ k = 9.73 \text{ watts/}(^\circ \text{C} \cdot \text{in}) \]

\[ 98\% \text{ FACES} \]

\[ \theta_k = \frac{(7560 \text{ w/in}^2) \cdot (1.00335)}{(9.73 \text{ w/}(^\circ \text{C} \cdot \text{in}))} N = 2.60 \text{ N} \cdot ^\circ \text{C} \]

OR 2.6 \degree C PER SQUARE.

ASSUME WATER VELOCITY, \( v = 30 \text{ ft/sec} \).

SPECIFIC HEAT TRANSFER RATE AT FILM

\[ \left( \frac{Q}{A_f} \right)_f = \left( \frac{Q}{A_f} \right)_{\text{max}} \cdot \frac{\theta_e}{\theta_e} = \left( 7.56 \times 0.00335 \right) \frac{1}{1} = \frac{0.0253}{6} \]

EQUIV. DIAMETER

\[ D_e = \frac{4A}{P} = \frac{4 \cdot \pi \cdot 2/2}{(2 \pi / 2)^2} = \frac{2 \pi (0.05)}{2(2 + \pi)} = 0.0611'' \]

Sieder-Tate Equation for Film Heat Transfer

\[ \frac{h_{fb} D}{k_f} = 0.027 \left( \frac{D \cdot v}{\mu_f} \right)^{0.8} \cdot \left( \frac{P}{\mu_f} \right)^{1/3} \left( \frac{M_w}{M_f} \right)^{-0.14} \]

RECAST INTO IRAD LAB UNITS

\[ \dot{N} = 0.1138 \cdot C_p \cdot b^{0.333} \cdot \frac{A_f}{A_e}^{0.8} \cdot \frac{d^{0.12}}{d^{0.12}} \cdot \frac{v^{0.8}}{d^{0.12}} \left( \frac{M_w}{M_f} \right)^{-0.14} \]

AT \( T_b = 10^\circ \text{C} \):

\[ 0.869 \cdot \left( \frac{M_w}{M_f} \right)^{-0.14} \]

AT \( T_b = 40^\circ \text{C} \):

\[ 1.278 \cdot \left( \frac{M_w}{M_f} \right)^{-0.14} \]

AT \( T_b = 70^\circ \text{C} \):

\[ 1.630 \cdot \left( \frac{M_w}{M_f} \right)^{-0.14} \]

WHERE

\[ \left( \frac{Q}{A_f} \right) = \left( \frac{Q}{A_f} \right)_f \cdot \frac{1}{T_w - T_b} \]
THERMAL ANALYSIS

<table>
<thead>
<tr>
<th>FLOW LINE</th>
<th>NO. OF SQUARES</th>
<th>$\theta_k$</th>
<th>$\frac{\text{&quot;FILM&quot; WIDTH}}{\text{inch}}$</th>
<th>$\left(\frac{\theta}{L}\right)$</th>
<th>FOR $T_b = 10^\circ C$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>$^\circ C$</td>
<td>kW/inch$^2$</td>
<td></td>
<td>$\theta_f$</td>
</tr>
<tr>
<td>0.50</td>
<td>14.0</td>
<td>36.4</td>
<td>0.025''</td>
<td>1.01</td>
<td>38.9</td>
</tr>
<tr>
<td>0.45</td>
<td>14.6</td>
<td>38.0</td>
<td>0.026</td>
<td>0.97</td>
<td>37.5</td>
</tr>
<tr>
<td>0.40</td>
<td>16.1</td>
<td>41.9</td>
<td>0.030</td>
<td>0.84</td>
<td>32.8</td>
</tr>
<tr>
<td>0.35</td>
<td>18.2</td>
<td>47.3</td>
<td>0.038</td>
<td>0.67</td>
<td>26.6</td>
</tr>
<tr>
<td>0.30</td>
<td>18.8</td>
<td>48.9</td>
<td>0.044</td>
<td>0.58</td>
<td>23.2</td>
</tr>
<tr>
<td>0.25</td>
<td>17.8</td>
<td>46.3</td>
<td>0.041</td>
<td>0.62</td>
<td>24.7</td>
</tr>
<tr>
<td>0.20</td>
<td>16.2</td>
<td>42.1</td>
<td>0.036</td>
<td>0.70</td>
<td>27.7</td>
</tr>
<tr>
<td>0.15</td>
<td>15.7</td>
<td>40.8</td>
<td>0.037</td>
<td>0.68</td>
<td>27.0</td>
</tr>
<tr>
<td>0.10</td>
<td>16.3</td>
<td>42.4</td>
<td>0.043</td>
<td>0.59</td>
<td>23.6</td>
</tr>
<tr>
<td>0.05</td>
<td>17.6</td>
<td>45.8</td>
<td>0.051</td>
<td>0.50</td>
<td>20.2</td>
</tr>
</tbody>
</table>

**AVERAGE**: $(\theta_k + \theta_f) = 71^\circ C$

**CALCULATE ALSO** for $T_b = 40^\circ C$ & $70^\circ C$.

<table>
<thead>
<tr>
<th>FLOW LINE</th>
<th>$\theta_k$</th>
<th>$\left(\frac{\theta}{L}\right)$</th>
<th>FOR $T_b = 40^\circ C$</th>
<th>FOR $T_b = 70^\circ C$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^\circ C$</td>
<td>kW/inch$^2$</td>
<td>$\theta_f$</td>
<td>$\theta_k + \theta_f$</td>
</tr>
<tr>
<td>0.50</td>
<td>36.4</td>
<td>1.01</td>
<td>27.9</td>
<td>64</td>
</tr>
<tr>
<td>0.45</td>
<td>38.0</td>
<td>0.97</td>
<td>26.9</td>
<td>65</td>
</tr>
<tr>
<td>0.40</td>
<td>41.9</td>
<td>0.84</td>
<td>23.4</td>
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<td>0.15</td>
<td>40.8</td>
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<td>19.1</td>
<td>60</td>
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<td>32.4</td>
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<td>0.05</td>
<td>45.8</td>
<td>0.50</td>
<td>14.2</td>
<td>60</td>
</tr>
</tbody>
</table>

**AVERAGE** $(\theta_k + \theta_f) = 63^\circ C$
S.L.F. - BL II MOVABLE MASK - DESIGN "H" Could,

HYDRAULIC CALCULATIONS

ASSUME \( V = 30 \text{ ft/sec} \),

USE 5 WATER PASSAGES ON EACH LEG OF "V",

AS FOR FIXED MASK,

FLOW

\[
G = \frac{V \cdot A}{1321} = \frac{(30 \times 1\frac{1}{2}) \times 0.050}{1321} = 0.37 \text{ gpm}
\]

FOR 5 PASSAGES ON 2 PANELS, TOTAL FLOW

\[ 10G = 10 \times 0.37 = 3.7 \text{ gpm} \]

PRESSURE DROP FOR PANELS (DOES NOT INCLUDE \( \Delta p \) OF FEEDLINES)

\[
\frac{L}{D} = \left( \frac{f \cdot L}{D} + 1 \right) \frac{V^2}{2g}
\]

\[
\frac{L}{D} = \text{ENTANCE + EXIT LOSS FROM DESIGN DATA #36}
\]

\[
L = 37 \text{ cm} = 15''
\]

\[
= \left[ (0.030)(0.0611) + 1 \right] \frac{(30)^2}{2(32.2)} = 117 \text{ ft. of } H_2O
\]

\[
\Delta p = 0.1433L = 51 \text{ psi}
\]

THIS IS APPROX. SAME PRESSURE REQMT. AS FOR THE FIRST FIXED MASK OPERATING AT \( V = 20 \text{ ft/sec} \). THUS, COULD RUN OFF OF SAME WATER SUPPLY.

THEORETICAL HP

\[
HP = (5.82 \times 10^{-4} \times 3.7 \text{ gpm})(51 \text{ psi}) = 0.11
\]

HAVE WATER ENTER AT DOWNSTREAM END OF MOVABLE MASK AND EXIT AT UPSTREAM END (\( f = 6.97 \text{ m} \))
Bulk Temperature Rise

Inlet Water Temp: 10°C on Cold Day
40°C on Hot Day
45°C Hot Day, if separate Recirc. Water System.

Find how much Synch. Rad. Power can fall on one panel (one leg of "U"). Synch. Rad. Power profile (per K. J. Kim printout) is:

\[ \theta_h = 1.95 \text{ mrad} \]

\[ \phi \]

\[ \text{One panel of movable mask} \]
\[ \text{Surtends} \left( \frac{1.98 \text{ cm}^2}{6.51 \text{ m}} \right) = 3.04 \text{ mrad} \]

Shaded Area = 89% of Total

Power in Shaded Area = (0.89)(6845 watts) = 6090 watts

The Isotherm/Flux plot indicates that only 40% of this is carried to the hottest water passage with remaining 60% going to other passages.

Power into Hottest Tube:
\[ \dot{P} = (0.4)(6090) = 2144 \text{ kW} \]
S.L.F. - BL VI Movable Mask - Design "H"

**BULK TEMP. RISE**

Max. Bulk Temp. Rise in hottest water passage

\[
\hat{\theta}_b = \frac{3.8 \times Q_{\text{KW}}}{G} = \frac{3.8 \times 6.44}{0.37} = 25^\circ C
\]

All of the synch. Rad. power can fall on the movable mask, (incl. both panels), so, average Bulk Temp. rise is

\[
\bar{\theta}_b = \frac{3.8 \times 6.45}{3.7} = 7.0^\circ C
\]
"Hot Spot" Temperatures

The maximum value of $(\theta_k + \theta_f)$ occurs directly underneath the $\theta_k$ of the synch. rad. power distribution, whereas the maximum value of $\theta_f$ occurs where the integral under the synch. rad. power curve is greatest, which is near the edge of the distribution. Therefore, hot spot temperature is not linear sum of the maximums. Instead, max. hot spot temperatures occur when synch. rad. power distribution falls approx. as shown below.

$\theta_k = 1.95 \text{ mrad}$

$\theta_f = 1.95 \text{ mrad}$

One panel of movable mask subtends $(1.98 \text{ cm}) = 3.04 \text{ mrad}$
**S.D.F. - RL VI MOUABLE MASK - DESIGN "H"**

"HOT SPOT" TEMPERATURES 

**CORRESPONDING TEMPERATURES FOR WATER INLET TEMP. OF 45°C ARE:**

- \((T_b)_i = 45°C\)
- Mode "C" Input (3.06W, 0.2A, 1.75T)
- \(v = 30\) ft/sec

\(\hat{T}_s \) (FRONT SURFACE HOT SPOT) 
121°C MAX

\(\hat{T}_w = 87°C\) MAX
(WATER PASSAGE WALL HOT SPOT)

\((T_b)_{out} = 69°C\)

\((T_b)_i = 45°C\) MAX.

MOUABLE MASK PANEL = 37.1 cm

MOUABLE MASK

SYNCH. RAD. POWER

ABSORBED ON FIRST FIXED MASK
THERMAL STRESSES

MAXIMUM TEMPERATURE DIFFERENCES OCCUR WHEN
INLET WATER IS COLDEST, \((T_b)_{in} = 10^\circ C\). TEMPERATURES
DIRECTLY UNDER THE BEAM IMPINGEMENT ARE:

\(\Delta T_s = 92^\circ C\), MAX.
(FRONT SURFACE HOT SPOT)

\(\Delta T_w = 57^\circ C\)
(WATER PASSAGE WALL HOT SPOT)

\((T_b)_{out} = 34^\circ C\)

\((T_b)_{in} = 10^\circ C\)

\((T_b)_{in} = 10^\circ C\)

\((T_b)_{in} = 10^\circ C\)

ONE PANEL OF MOVABLE MASK 37.1 cm LONG

ABSORBED ON FIRST FIXED MASK

MOVABLE MASK

SYNCH. RAD. POWER
S.I.F. - BL VI MOVABLE MASK - DESIGN "H"

THERMAL STRESSES

USE SAME ASSUMPTIONS FOR THERMAL STRESSES AS USED IN ENG. NOTE M5971 FOR THE FIRST FIXED MASK (E.G., RESTAINED IN ONE DIMENSION ONLY). USE FULL TEMPERATURE RANGE, EVEN THOUGH REAL VALUE IS SLIGHTLY LESS.

\[ \Theta = \frac{T_e - (T_b)_{in}}{4} = 92 - 10 = 82^\circ C \]

MAX. THERMAL STRESS RANGE

\[ \sigma_t = \times E \Theta = (17 \times 10^6)(17 \times 10^6)(82) = 23.7 \text{ksi} \]

OR AMPLITUDE OF \( \pm \frac{23.7}{2} = \pm 11.85 \text{ ksi} \)

FOR \( N = 10^5 \) CYCLES, "OFHC" COPPER HAS FATIGUE STRENGTH OF \( S_f = \pm 18 \text{ ksi} \), SINCE THE THERMAL STRESS AMPLITUDE HERE IS \( \pm 11.85 \text{ ksi} \), IT APPEARS AMPHIBLY SAFE.

CONCLUSION

THE CALCULATIONS INDICATE THAT DESIGN "H" WITH AN "OFHC" COPPER FRONT SURFACE THAT HAS A 1/17.5 SLOPE AND WITH A WATER VELOCITY OF \( V \geq 30 \text{ ft/sec} \) IS ENTIRELY ADEQUATE FOR THE INTENDED PURPOSE.
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