HIGH HEAT LOAD COMPONENTS IN TPS FRONT ENDS

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Abstract

National Synchrotron Radiation Research Center (NSRRC) will build a new synchrotron accelerator (TPS, Taiwan Photon Source) with a great heat-load power. Various IDs have been proposed. For instance, at 3.3GeV, 350mA, superconductivity wiggler SW4.8 may generate 5.8mrad wide, 57kw/mrad^2 power whereas undulator CU1.8 will be 0.7mrad, 148kw/mrad^2. The function of the fixed mask in TPS front ends not only to protect the downstream vacuum from being hit by the radiation during miss-steering, but also shadow the unwanted power. More than one fixed masks are introduced in some high heat load front ends. High conductivity, high thermomechaical strength GlidCop® is used; design and thermomechanical analysis is also presented in this paper.

INTRODUCTIONS

TPS 3.3GeV, 350mA synchrotron accelerator will create high energy photon source. Front end is will be the first area shapes ID power to suit the need not only for protection but also for the beam line users. The power type includes insertion devices (ID) and bending magnet (BM). Various high heat load components such as crotch absorber, fixed mask, photon absorber and slit will be designed to take the power.

Crotch absorber in the storage ring is the last high heat load components prior to front end, however it is meant to take bending magnet not IDs, therefore fixed mask is the first component to encounter the power load that is generated by ID. Some IDs have high total power and power density which needs more than one fixed mask to dissipate the heat. The reason using more fixed masks is because

- Very small grazing angles needed to lower the peak power density, and small tapered angles requires additional machining length, which is limited to 300-400mm long using EDMing in Taiwan. That is, to shadow wide ID such as SW4.8, two fixed masks is required to dissipate the heat load.
- First fixed mask is used to confine the area of the ID so that it prevents the downstream components from being heated by the synchrotron radiation. That is, during normal operation only very small amount of the power is intercepted by the first fixed mask. However, CU1.8 has high power density as well as relatively high total power (20kw), without additional absorber between the first fixed mask and photon absorber (PAB), the latter component will have to endure its total power when interlock is enabled.

Finally, the very last front end components, slit, which represents the defining aperture, is use to shape the beam size that beam line user requires. Table 1 lists the ID power parameters and the corresponding heat flux densities:

Table 1: Table of ID Parameters and Power Densities

Undulator Radiation	EPU10	EPU7	SW4.8	EPU4.6	IU2.8	SU1.5	CU1.8
Period length (cm)	10.0	7.0	4.8	4.6	2.8	1.5	1.8
Number of Periods	88	64	30	97	160	67	250
Maximum B Field (T)	1.14	1.00	4.20	0.76	0.90	1.50	1.34
Effective total length (m)	8.80	4.48	1.44	4.46	4.48	1.01	4.50
Deflection Parameters	10.65	6.54	18.83	3.27	2.35	2.10	2.25
Total Power (kW)	27.6	10.8	61.3	6.2	8.8	5.5	19.5
Horizontal Span Angle (mrad)	3.30	2.02	5.83	1.01	0.73	0.65	0.70
Vertical Span Angle (mrad)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Peak Power (at ψ=0)	11	7	14	8	16	11	36
G(K)	1.00	1.00	1.00	0.99	0.99	0.98	0.98
Peak Power per Ω (kW/mrad^2)	45	29	57	33	64	44	148
Proposed beam line number (phase I)	2(0)	2(1)	3(0)	2(0)	8(1)	1(0)	3(1)

Note that from above chart, SW4.8 owns very high total power (60kw) and relatively high peak power. In addition, CU1.8 will generate 148 kw/mrad^2 and its total power is nearly 20kw. These two ID power makes the design of high heat load components in TPS front end relatively challenging.

In observing above ID's heat load, we choose CU1.8 as our and representative prototype in the design phase due to its very high power density and small beam size.

HIGH HEAT LOAD COMPONENTS

Three high heat load components are identified as fixed mask, PAB and slit. In a typical front end, fixed mask will be the first high heat load component, PAB is the second, and slit is the last one before the shielding wall.

As was described before, one additional fixed mask is introduced and will shadow half of the total power, thus PAB only needs to sustain half of the total power.

Slit is the last high heat load component that defines the final aperture to shape the beam size required by the beam line users. Thus it intercepts the rest of the power once the slit is completely closed.

As shown in the following CAD model, GlidCop® (orange colour) is the absorber body to take the heat. It is then brazed with two SST tubes before they are TIG welded onto flanges on both ends.

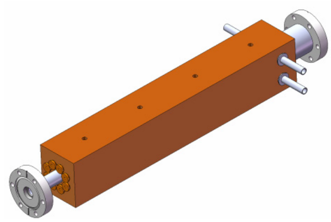

Figure 1: Design of TPS Fixed Mask

In the middle of the absorber body a tapered rectangular tunnel is fabricated by EDM. Eight 9 mm diameters blind water channels are drilled surrounding the tunnel used to dissipate the power. These Eight water channels are sealed by brazing eight SST (or Copper) plugs. As shown in Figure 2, total of four holes are drilled horizontally, each water holes connect to two longitudinal water channels. SST tubes are to braze onto these four holes for supply and return cooling water.

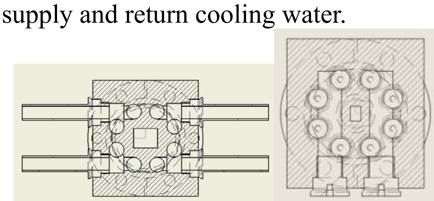

Figure 2: Sectional View of the Water Channels

On the other side, as shown in figure 2 on the right, two vertical blind holes are drilled to open the connection of four longitudinal channels. These two holes will be brazed with SST plugs to close the water loop.

The distance between cooling surface to the heating surface (tapered surface) will be at least 6~7 mm. this thickness should be sufficient to prevent absorber from leaking even at high water pressure 100~120psi.

Except PAB, the designs of fixed mask and slit are alike. The main difference is only their apertures. The upstream aperture of the absorber is determined by the envelope of where the beam might miss-steers, whereas the downstream aperture is determined by how much of the power magnitude the absorber is designed to intercept. The longer the tapered angle between the upstream and downstream aperture the lower its power density striking on the heating surface. Due to the aspect ratio of the beam size geometry, horizontal grazing angle is always more beneficial to lower the temperature than that of vertical grazing angle. However, the tapered length of the absorber is set to be 350mm due to the machining capability.

The following chart lists the aperture of the high heat load components of CU1.8 front end:

Refer to table 2, the first fixed mask receives only 1.1kw during normal operation, however if CU1.8 undulator beam miss-steers, the worst situation is it might deposit the total power to the first fixed mask. Therefore the first fixed mask should be designed to receive total amount of power 19kw. In the ANSYS model, we generate a full 3D geometry and apply entire 19kw beam size on the upper right heating surface. The finite element result shows the temperature rise contour in Figure 3.

Table 2:CU1.8 High Heat Load Component Apertures and Thermomechanical Analysis Results

Component	Distance from ID	Upstream aperture (mm)		Downstream aperture (mm)		Normal Power density	Normal Operation Power deposited	Maximum Designed Power Deposited	Maximum Peak power Density on the Heating Surface (w/mm^2)	Maximum Peak Power Density on	Peak Temperature Rise	Peak Von Mises stress
	(m)	Horizontal	Vertical	Horizontal	Vertical	(w/mm^2)	(kw)	(kw)	Horizontal	Vertical	(°C)	(MPa)
Fixed mask 1	14	23	17	11	8	758	1.1	19	12	9.6	177	350
Fixed mask 2	14.6	15	12	5	7	700	10	19	9.8	5.3	136	269
PAB	16.5	12	12	0	0	546	0	10	11	N/A	156	253
XY slit1	17.6	22	23	7	6	480	0~5	10	10	11.5	140	277
XY slit2	18.2	22	23	7	6	450	0~5	10	9.5	10.8	131	260

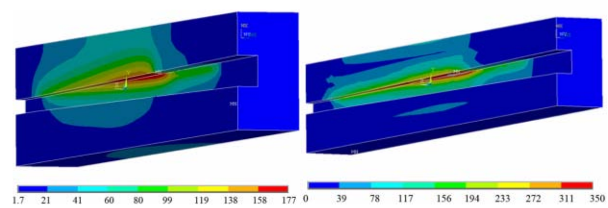

Figure 3. Temperature Rise Contour of First Fixed Mask (in °C, left) and Thermal-Induced Effective Stress (in MPa, right)

The peak temperature rise is 177 °C when film coefficient 1 $w/(cm^2\ {}^{o}C)$ is assumed in the model. The corresponding Von Mises thermal stress is also on the right hand side of Figure 3.

The maximum thermal stress is around 350MPa, which is less than that of the yield stress of the GlidCop® at 393MPa. The analysis shows that the design is passively safe even when full power strikes on the first fixed mask.

Limiting by the first mask aperture, with appropriate opening, the second CU1.8 fixed mask designed to only receive 10kw power. Since the grazing angles of the second fixed mask is smaller than that of the first one, without going to the finite element analysis one can estimate that the maximum temperature rise will be less than 140 °C whereas the peak thermal stress is found to be 270 MPa.

PAB is one type of high heat load absorber. During normal operation, beam will fully pass through to a straight opening tunnel 12mm x 12mm. As interlock situation occurs, PAB drops down to block the rest of the beam. The following sectional view shows the geometry of the tunnel and the heating surface:

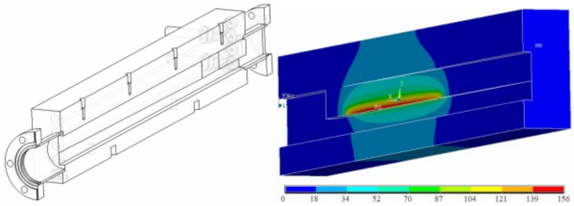

Figure 4: Sectional View of PAB (left) and Temperature Rise Contours of PAB (in ^{o}C, right)

The cooling passages fabricated inside the PAB are similar to that of fixed mask as was described earlier. In general during normal operation it doesn't take any heat power. Except when interlock is taking place and PAB drops down to protect the downstream front end equipments from being heated by the synchrotron radiation. Under this circumstances, PAB will receive rest of the power, which is approximately another 50% (10kw) leftover from the second fixed mask. Finite element analysis shows that the temperature rise contours when synchrotron power deposits 10kw (half horizontal power width) to the edge of the grazing tapered surface. Refer to Table 2, the thermal stress is found to be 253 MPa, which again is lower than GlidCop®'s yield strength.

Slits has similar design geometry, there will be two identical XY slits work together to confine the final beam size, one slit is able to move upper right and the other moves lower left. The interception of these two downstream apertures defines the final beam size left to the users. The worst scenario is that when one of the slit moves in such a way that it fully blocks the beam, under this circumstance it subjects to taking rest of the 50% power heating (10kw), the peak temperature rise may be up to 140 ^{o}C and thermal–induced Von Mises stress is 280 MPa or so, as shown in Table 2.

DEFINING APERTURES

The last defining aperture is controlled by moving the last two XY slits. The question is always being that, in front end what is the targeted defining beam size for the beam line users?

As suggested by Takahashi [1] in Spring-8, and some others such as Klysubun [2] in NSRC, spatial distribution of first harmonic flux density is used to determine the final beam size. The chart below shows the spatial distribution of first harmonic flux density, power density relative to the current CU1.8 high heat flux aperture designs using Table 2.

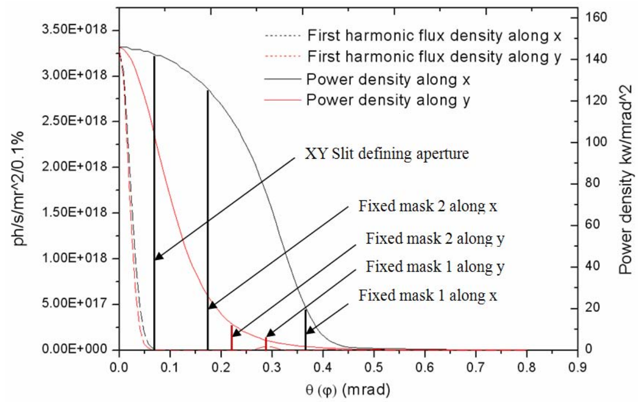

Figure 5: Spatial Distribution of First Harmonic Density vs. Power Density

As shown in Figure 5, when XY slits shape the beam to the size of first harmonic flux density (along x and y are almost identical) so that only 0.06mrad (according to Figure 8) passes through, the total integrated power left to the beam line is found to be only 1.5kw, which is appropriate power level for cooled mirror in the beam line to receive.

CONCLUSIONS

High heat load components of TPS front end has been identified and designed. GlidCop® material is chosen as absorber body due to its high conductivity and equally high yield strength mechanical properties. Small grazing angles are fabricated to spread the beam along the longitudinal direction. Parallel cooling channels are surrounded to dissipate the power load. The finite element numerical analysis shows that all the high heat load components will be passively safe for CU1.8 undulator.

First harmonic flux density vs. power density plot suggests the defining aperture for the XY slits, which provide us a better picture of how the unwanted undulator power can be distributed along every high heat load components in a more optimized manner.

REFERENCES

[1] S. Takahashi, et al, "Design of the Front End for the Very Long In-Vacuum X-Ray Undulator at Spring-8" , Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volumes 467-468, Part 1, 21 July 2001, Pages 758-761.

[2] P. Klysubun, "Heat Load Calculation for the NSRC Undulator Beamline Front-end", NSRC Technical Note, NSRC-TN-2004/10.