Design of a Pre Slit for the SPring-8 Undulator Beamlines

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1. Introduction

The pre slit is the component in undulator beamlines which absorbes the off-axis part of the photon beam so as to reduce the heat load on a XY-slit and a graphite filter. The pre slit is located at about 30 m from the undulator, then it may receives a normal incidence peak power density of about 300 W/mm^2. To handle the heat flux, besides inclined geometry, we adopt volumetric heating techniques which is a way to dissipate high surface heat flux in depth by utilizing low-Z materials[1].

Figure 1 shows schematic drawings of the pre slit assembly. The assembly includes four fixed masks installed in one vacuum chamber, each of which is composed of an irradiated body made of graphite (low-Z materials) and a cooling holder made of oxygen-free high-conductivity copper (OFHC). The two materials are brazed together with nickel base braze alloy (MBF-15) at about 1000°C.

For practical use, there are three items to be examined, besides the conventional thermal and thermo-mechanical researches. These are;

(1) influences of an attached rate of the brazed joint (real attached brazed joint area / total brazed joint area) on thermal and thermo-mechanical issues,

(2) static strength and fatigue properties of the brazed joint,

(3) vacuum properties of the graphite blocks.

Hence, we report the analytical researches on the item (1) and the experiments concerning the item (2).

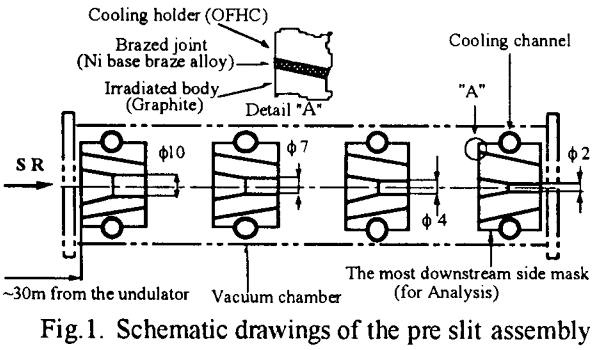

Fig.1. Schematic drawings of the pre slit assembly

2. Analysis

2-1 Boundary conditions

The ANSYS finite element analysis was performed on the most downstream side mask which is subjected to the highest heat load[2]. Elements in the beam path were assigned absorbed power in the same way as the previous work [3].

In the analytical model, the brazed joint gap was treated as an independent volume of metal nickel with a thickness of 0.05 mm. We simulated the non-attached part of the brazed joint by forcing the corresponding elements to be deactivated using "KILL ELEMENT" command in ANSYS.

2-2 Results and discussion

(1) Thermal analysis

In the case of the standard undulator (U032V), thermal analysis results indicate a maximum heated surface temperature (T_s) of 334°C and a maximum cooling channel temperature (T_c) of 86°C at a beam current (I_b) of 100 mA and a heat transfer coefficient (h_f) of 0.01 W/mm^2•°C. Although T_s rises to 638°C at I_b=200 mA, T_c reaches to 141°C, which is nearly equal to the saturation temperature at 4 kg/cm^2 (143°C). Then, it is necessary to enhance h_f at least to 0.0125 W/mm^2•°C (corresponding velocity : 2.8 m/s) at I_b=200 mA. On this condition, T_c goes down to 120°C.

Figure 2 shows the variations of the maximum temperatures with the attached rate of the brazed joint. While T_c remains constant independently of the attached rate, T_s increases suddenly below the attached rate of 70%.

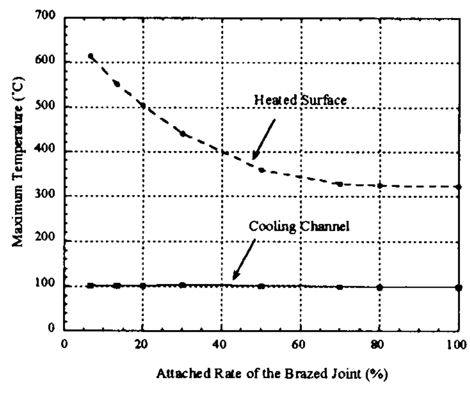

Fig.2. The variations of the maximum temperatures with the attached rate of the brazed joint.

(2) Thermo-mechanical analysis

Due to different thermal expansion constraints, high thermal stress will be generated on the brazed joint. The resultant stress values should be judged by the two kinds of the criteria, namely the static strength and the fatigue strength. The allowable stress of the static strength is set to be less than a value which is the smaller between the tensile strength and twice the yield strength, because the thermal stress is a secondary stress[4].

At I_b = 100 mA and h_f = 0.01 W/mm^2•°C, the maximum thermal stress represented by Mises's equivalent stress is estimated at 4.5 kgf/mm^2 on the brazed joint, and the local maximum thermal stresses in the graphite block and the OFHC holder are 3.9 and 1.3 kgf/mm^2, respectively. The induced stresses in the graphite block and the OFHC holder are less than the allowable stresses. However, we don't have any conclusive remarks on the brazed joint since there is no data to be refered to.

Figure 3 shows the the maximum stresses in five cases of the variations with the non-attached element's position and the attached rate of the brazed joint by a cross-sectional view of the brazed joint in the analytical model. The grid in this figure corresponds to the border of elements. When the non-attached elements exist on the joint edge (CASE1), the maximum thermal stress comes to an extremly high value (~2000 kgf/mm^2). In the cases that the non-attached elements are inside, if an area per a non-attached part is less than about 2% of the total area, the thermal stresses are almost the same as the perfectly attached case. Further, when two non-attached parts both of whose area is within 2% are exist simultaneously, there is no remarkable increase in the resultant thermal stress.

Since there are no references for the S-N curve of both the brazed joint and the graphite block, we have not yet reached to conclusive remarks about the thermal fatigue.

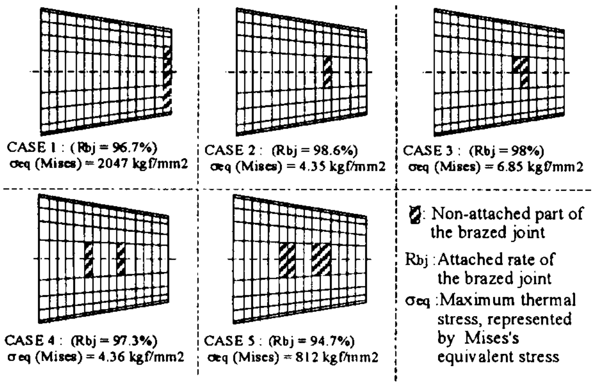

Fig.3. The maximum stresses in five cases of the variations with the non-attached element's position and the attached rate of the brazed joint by a cross-sectional view of the brazed joint in the analytical model.

3. Experiments

3-1 Heat loading test

The electron beam irradiation test was carried out to study thermally-induced fatigue damage in the brazed joint. A 1kW electron beam was supplied cyclically on a graphite block of a prototype mask, which has the same configuration as the analyzed one.

Figure 4 shows the maximum temperatures on the irradiated surface and the brazed joint, monitored by a radiant thermometer (Avio camera) and a thermo-couple, respectively. Drastic changes at 600 cycles and 900 cycles are caused by a break in the operation and a fine adjustment of beam position. Keeping these happenings in mind, it can be said that the maximum temperatures remain constant up to a thousand heated up and cooled down cycles. After 1000 cyclic heat load, no specific deformation and damage were observed on the prototype mask.

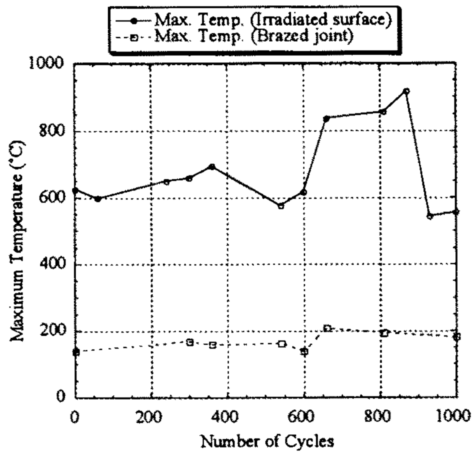

Fig.4. The maximum temperatures on the irradiated surface and the brazed joint as a function of number of cycles.

3-2 Static strength evaluation tests

Applying load in the axial direction on test pieces which were brazed by the same way as the prototype mask, while fixxing OFHC, the necessary load to exfoliate the brazed joint (separate graphite from OFHC) were 1460 ~ 2125 kgf. Therefore, considering the joint area and the tapered angle, the shearing strength of the brazed joint is estimated at 0.6 ~ 0.9 kgf/mm^2.

We are now preparing for estimating the critival load in the radial direction to exfoliate the brazed joint, namely tensile strength.

3-3 Intended tests

We also start to prepare for taking the S-N curve of the brazed joint and evaluating the vacuum properties of the prototype mask by the ultra-high vacuum test stand [5].

References

[1] D.M.Mills et al., IEEE Trans. Nucl. Sci. NS-26, 3854 (1979).

[2] S.Takahashi et al., SPring-8 Engineering Note, FE-011-95 (1995.11.28).

[3] H.Sakae et al., SPring-8 Annual Report 1994, P168

[4] ASME Boiler & Pressure Vessel Code, Sec III, (1980).

[5] S.Takahashi et al., SPring-8 Engineering Note, ID-003-95 (1995.8.23).