DESIGN OF THE MUON TARGET AT J-PARC

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Abstract

At J-PARC muon science facility, the most intense pulsed muon beam will be produced by 3 GeV/1 MW/25 Hz proton beam. As a muon target, we are going to adopt an isotropic graphite (IG-43) with a thickness of 20mm, which shape is like a disk. As a frame, copper is adopted and a stainless steel tube is buried in the copper frame. The heat loss, which is generated by the proton beam, is estimated to be 3.3kW on graphite and 600W on the copper frame in NMTC/JAM [1]. Figure 1 shows a schematic view of the target and the picture of the target.

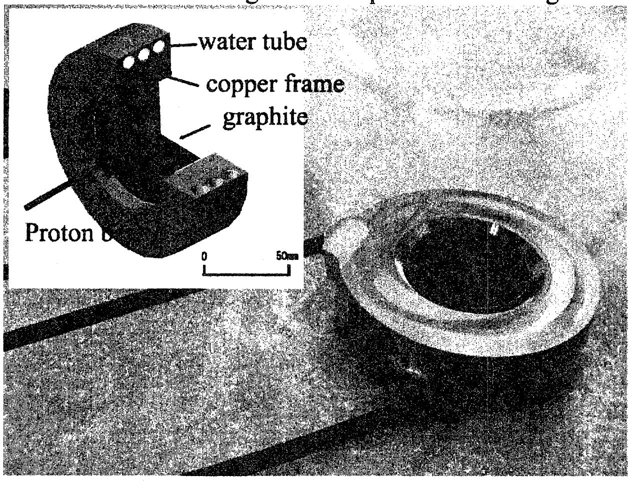

Fig.1: The schematic drawing of the target and the picture of the target

In the first section, static properties, calculated by the finite element methods ANSYS are reported. Thermal problem and stress from the gradient of the temperature are discussed. In the second section, dynamic properties such as mechanical shockwave and thermal transient response are described. In the third section, the experiments to test the calculations by ANSYS are demonstrated.

STATIC PROPERTIES

At first, the static properties such as temperature and stress, were evaluated. The target is placed in the vacuum chamber, therefore almost all of the heat must be removed by the flow of water in the copper frame. Considering thermal properties of graphite, thermal conductivity of graphite under neutron irradiation has to be taken into account. Figure 2 shows temperature dependence of the thermal conductivity of graphite in cases of the various conditions of neutron-irradiation [2].

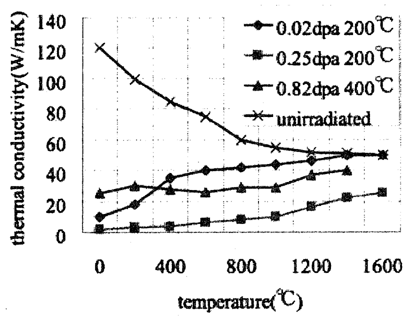

Fig.2: Temperature dependence of the thermal conductivity of graphite in cases of the various conditions of neutron-irradiation.

Thus, the gradient of the graphite temperature is much enhanced under the neutron irradiation. By the calculation of the finite element methods ANSYS, the maximum temperature of graphite (on the centre of target) reaches upto 1500 degC. This value is much below the melting point of graphite. At this temperature the vapour pressure is also negligible small. At the first design, we adopted one turn of the stainless steel tube, resulting in the surface temperature of the water tube to be more than 250 degC. In order to get rid of boiling, three turns of water tube are adopted. Consequently the temperature of the surface of the tube became about 110 degC, which is lower than the boiling point under the 0.3MPa to be 140 degC.

Because of the large gradient of the temperature, the thermal stress must be considered. If the copper is just placed around graphite, the stress on graphite is very close to the strength to stress. Therefore in order to absorb the thermal stress, the titanium layer is adopted as an intermediate material between the graphite and the copper. Table 1 shows the stress on graphite in case that there is no titanium layer as a stress absorber and in case that there is a titanium layer with a thickness of 2 mm.

Table1: The stress on graphite in case of no titanium layer and in case of 2 mm titanium layer. As a reference, the strengths of graphite are also on the table.

	Strength (Stress)	**No Ti**	**Ti 2mm**
Temperature (degC)		1462	1492
Tensile stress (MPa)	37	35	8
Compressive stress (MPa)	90	40	42
Share stress (MPa)	18	17	6

In case that the thickness of titanium layer is 2 mm, the compressive stress is 42 MPa (compared with the strength 90 MPa) the tensile stress is 8 MPa (compared with the strength 37 MPa), and the share stress is 6 MPa (compared with the strength 18 MPa). Figure 3 shows the distribution of the maximum principal stress (S1) and the minimum principal stress (S3) in case that the thickness of the titanium layer is 2 mm. Now the stress is concentrating on the titanium layer, and it must be checked whether the stress on the layer is less than the elastic limit of titanium, that is 190 MPa. It's also calculated that the stress is 150 MPa by ANSYS.

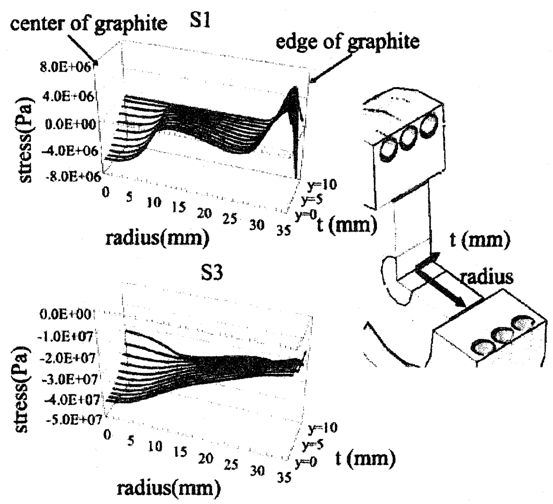

Fig.3: The distribution of the maximum principal stress (S1) and the minimum principal stress (S3). The thickness of the titanium layer is 2 mm.

DYNAMIC PROPERTIES

Next, the dynamic properties such as the mechanical transient response, so-called shockwave, and the thermal transient response were evaluated. The pressure increment in a pulse, which is induced by a sudden increment of the temperature, is estimated to be only 0.6 MPa by a thermo-elastic calculation [3]. From the calculation by ANSYS, it is checked that there is no amplification of stress.

The thermal response were analysed for two cases, the normal operation and the accidental operation. In the normal operation, at first it was estimated how long it takes from the room temperature (30 degC) to the maximum temperature (1460 degC) and from the maximum temperature to R.T. Calculating by ANSYS, it's proved that it takes 60 seconds from the R.T. to the maximum temperature and 100 seconds from the maximum temperature to the R.T. And there was no extraordinary gradient of temperature, which will produce a local stress.

Then it was estimated how much temperature will change in a proton pulse. Under the maximum temperature, the rise of the temperature in a pulse is 6 degC. The repeated stress induced in a pulse is small enough to be 0.1 MPa. It won't lead to the fatigue of the repeated stress. Figure 4 shows the rises of the temperature in a proton pulse on the centre of graphite in the cases of 700 degC and the maximum temperature.

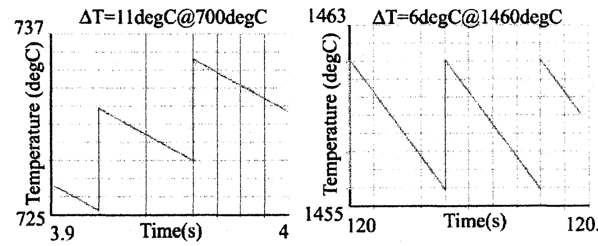

Fig.4: The rises of the temperature in a proton pulse on the centre of graphite in the cases of 700 degC and the maximum temperature.

In the accidental operation, the water flow was assumed to be stopped. This issue is important to construct the safe interlock system. Even if we have the interlock signal of the water flow to stop the proton beam, the target must have the two stages of interlock system. Another signal should be prepared for the case that the proton beam couldn't be stopped by the signal of the water flow. Figure 5 shows the response of the temperature on the target and the frame when the water flow stops. As the flow of water doesn't stop, the temperature of graphite raises gradually, on the other hands the copper frame raises rapidly. When the temperature of the copper frame reaches 300 degC in 20 seconds, the temperature of the graphite is still 1470 degC. When the copper frame reaches 680 degC (melting point of silver blazing) in 70 seconds, graphite is 1660 degC. In 120 seconds, the copper frame reaches 1040 degC and starts to melt. From this calculation, the upper limit of the temperature of the copper frame is less than 680 degC.

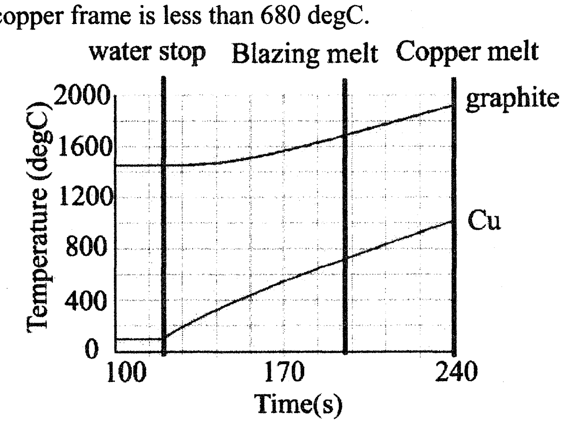

Fig.5: The response of the temperature on the target and the frame when the flow of water stops.

But in the actual operation, the water flow will not recover soon after the proton beam stops. In this condition, the enthalpy that is on the centre of the target will spread to outside. Figure 6 shows the spread of the enthalpy when the proton beam stops at the temperature of the copper frame to be 500 degC. At least the temperature of the copper frame must be less than 500 degC in the interlock system. Finally the temperature of the copper frame to stop the proton beam is set to 200 degC

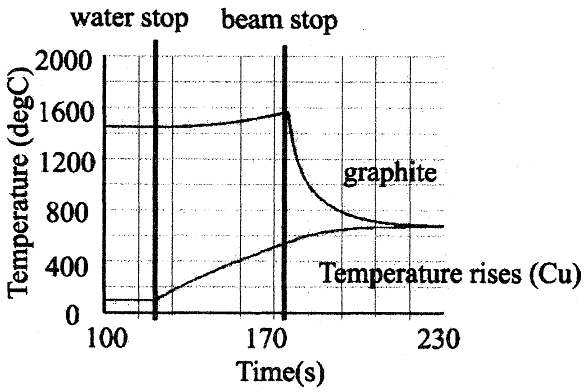

Fig.6: The spread of the enthalpy when the proton beam stops at the temperature of the copper frame to be 500 degC.

EXPERIMENTS

So far, according to the calculated design, we made a lot of efforts to produce a prototype of muon target. At first silver blazing and casting methods were tried to bond the stainless tube to the copper frame, resulting in a failures. The silver blazing cannot acquire enough thermal transfer because whole water tube cannot be covered. In the casting, it was impossible to fix the tube in the precise position, as the deformed stainless steel has the residual stress. Finally it turned out that HIP process worked very well. Then titanium layer and graphite was bonded to copper frame by silver blazing in vacuum simultaneously. Since HIP was achieved at the temperature of 850 degC, silver blazing, which has the melting point of 680 degC was adopted. Figure 1 shows the picture of the produced target.

On the next step, the target was heated by two electron beams by both sides. Approximately 4 kW of heat generation by the proton beam is calculated on the target. In this experiments, it was succeeded to supply 4.2 kW of heat on the target. Figure 7 shows a picture of the filament.

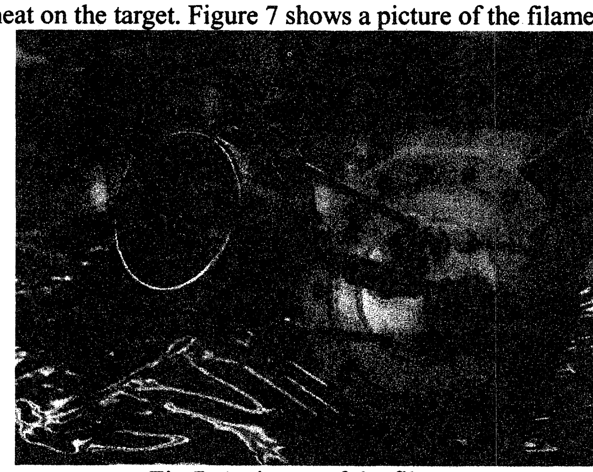

Fig.7: A picture of the filament

In this experiment, we should consider that the raw material without the neutron irradiated was used and the heat generation is just on the surface. But on the calculation of ANSYS, the temperature of copper frame is almost same as the operation of proton beam. There are two purposes in this experiment. The first is to check the bonding of each interface. The second is to acquire the thermal transfer coefficient between the surface of the water tube and water. In general, the value from the experience was used for this parameter [4]. However it depends on a lot of conditions, such as the material, the shape of tube, the roughness of the surface, and so on. Therefore it's better to have the experiments in the same conditions. In order to check this parameter, the heat generation and the temperature of copper frame is measured in the electron beam experiment. In this experiment, it's proved that the value of thermal transfer coefficient was 2000 $W/m^2/K$, while thermal transfer coefficient was supposed to be 3800 $W/m^2/K$ from the experiences. On the other hands, the bonded silver blazing looked well. In figure 8, the temperatures measured in the experiments are plotted, and the solid line is a calculation assuming thermal transfer coefficient to be 2000 $W/m^2/K$.

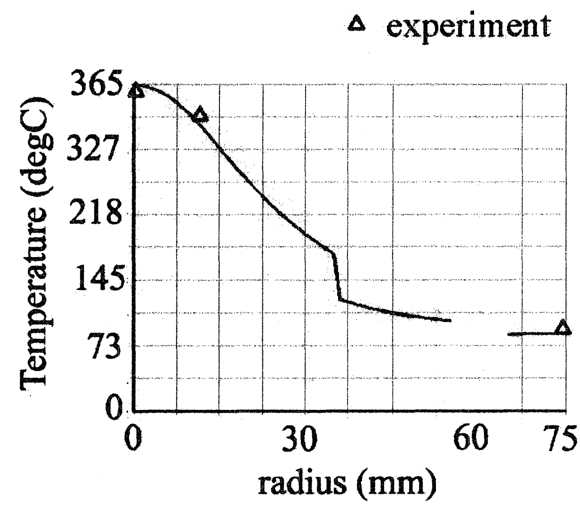

Fig.8: The temperatures measured in the experiments are plotted, and the solid line is a calculation assuming thermal transfer coefficient to be 2000 $W/m^2/K$.

REFERENCES

[1] N.Kawamura, KEK-MSL Report 2000 (2000)13.
[2] T.Maruyama and M.Harayama, "Neutron irradiation effect on the thermal conductivity and dimensional change of graphite materials," Journal of Nuclear Materials 195 (1992) 44-50.
[3] Z.Tang and K.Anderson, "Shock Waves in P-bar Target," FERMILAB-TM-1763 (1991)
[4] JSME Data Book, "Heat Transfer", The 4th Edition