DEVELOPMENT AND CONSTRUCTION OF THE BEAM DUMP FOR J-PARC HADRON HALL

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Abstract

Hadron hall at Japan Proton Accelerator Research Complex (J-PARC) is designed to handle intense slow-extraction proton beam from the main accelerator, i.e. 50-GeV-PS. The civil construction of Hadron hall had been completed in Jun. 2007. The first proton beam was successfully transported to Hadron hall on Jan. 27th, 2009.

The beam dump constructed at the end of the primary proton beam line in Hadron hall is designed to safely absorb 15 μA (=750-kW) proton beam. The central core of the beam dump is made of copper (Oxygen Free Copper) with two water cooling channels, and is surrounded by iron and concrete blocks for radiation protection. We made thermal and mechanical FEM analysis to investigate heat generation and thermal stress from energy deposition. We also made the systematic cooling experiments to measure heat transfer coefficient of cooling devices. Based on the experimental results, we have determined to make long holes near the surface of copper core with Gun-drill.

In addition, the beam dump itself is designed to securely move to downstream in future expansion of Hadron hall.

This paper reports development and construction of the beam dump at Hadron hall.

HADORON-HALL BEAM DUMP

The beam dump is made of 200-ton copper (Oxygen Free Copper) with water cooling channels, is surrounded with 2700-ton iron and 5400-ton concrete for radiation protection. Total weight of shielding blocks used in dump hut, shown in figure 1, is 8300 tons. Copper is chosen as the core part of the beam dump because of high heat conductivity and radiation resistance. The total size of the copper core is $2^W \times 2^H \times 5^L$[m]. The copper core consists of 40 thick OFC plates (2000×1000×250 [mm/plate]). The copper core has a conical hole to distribute heat deposit of incident beams. Each OFC plate has narrow slits to reduce thermal stress. In order to reduce maximum temperature rise and thermal stress, we needed to apply efficient cooling system for the copper core.

Besides Hadron hall has a plan to expand to downstream and to construct the second production target at the current place of the beam dump for near future. Therefore the beam dump is designed to securely move to the downstream.

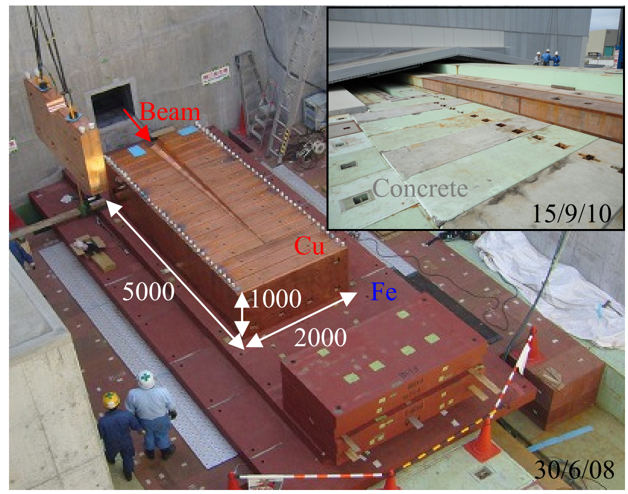
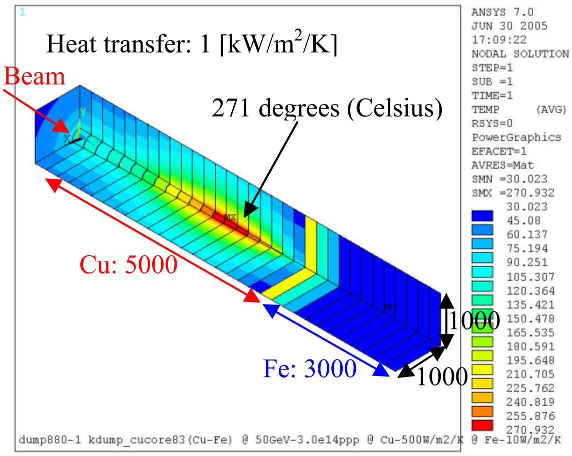


Figure 1: The beam dump at Hadron hall (under construction).

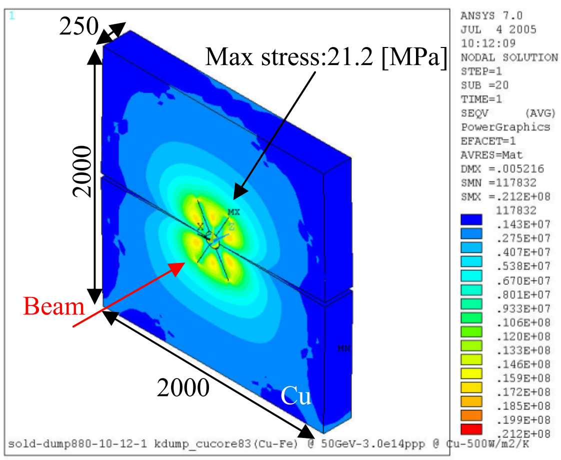
NUMERICAL DESIGN

The beam dump is designed to safely absorb 750-kW proton beam. The cooling device is fabricated near the outer surface of the copper core, and the water path should be apart by 1-m from beam axis in order to reduce water activation. Heat deposition in copper and iron core by incident 3×10^{14} proton beam per pulse was estimated with MARS code [3]. Thermal and mechanical FEM analysis was calculated with ANSYS for investigating heat distribution and thermal stress. The total size of a calculated model is 1×1×8[m], which is a quarter of real product. Heat transfer coefficient at the outer surface of the copper core is assumed to be 1 [kW/m^2/K] for water cooling.

Figure 2 indicates results of thermal and mechanical FEM analysis. The maximum temperature rise at the centre of the copper core was 271 degrees (Celsius) that is considered to be safe against deterioration of the core. Boiling of cooling water is not expected because the temperatures on the outer surface of the core do not exceed over 100 degrees (Celsius). The maximum stress of 21.2 [MPa] is lower than the allowable stress of 28.5 [MPa], according to the tensile test at 300 degrees (Celsius).



a) Result of thermal analysis



b) Result of mechanical analysis

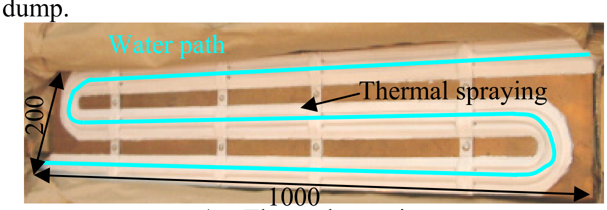
Figure 2: Results of numerical analysis.

COOLING TEST

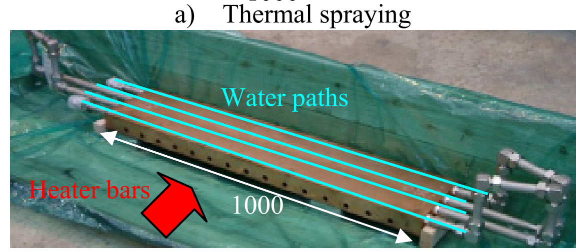
Figure 3 shows the results of cooling tests by different cooling methods applied to the test plates. Figure 3 a) shows a test example by thermal spraying method, that SUS pipe and copper body are contacted with aluminium build-up thermal spraying. Figure 3 b) shows a test example by Gun-drill method that long holes of direct cooling paths are drilled in copper with Gun-drill. The merit of thermal spraying method is that seamless SUS pipe which is resistant to erosion and corrosion can be used for cooling path. However, heat transfer coefficient of thermal spraying method was lower than that of Gun-drill method, due to indirect cooling by the SUS pipe.

Cooling tests were made to measure heat transfer coefficient of the cooling devices. The total sizes of an example copper plate were 200×1000×50 [mm]. The heater bars inserted into the copper plate from the backside produced 5 [kW] heat deposit on the example plate. The flow rates of the water cooling path were 5~23 [l/min]. Temperatures at the surface of the copper plate were measured by thermocouples. The number of cooling paths about Gun-drill method can be changed from 1 to 4 by changing pipe connections.

The results of the cooling test are shown in Figure 4. The measured heat transfer coefficients of two paths or more of Gun-drill method was higher than that of the assumed value in calculation. As a result, we decided to adopt Gun-drill method to the cooling device of the beam dump.



a) Thermal spraying



b) Gun-drill

Figure 3: Candidates of cooling device

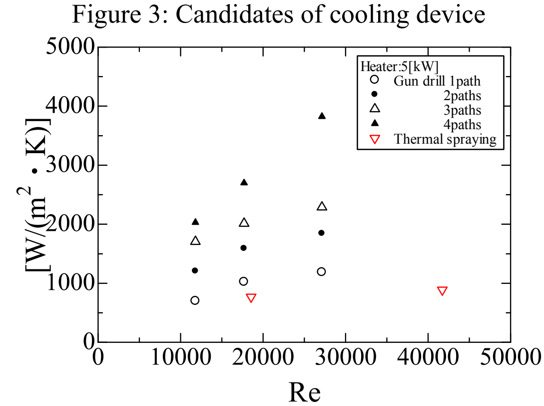


Figure 4: Result of cooling test, x-axis: Reynolds number [-], y-axis: heat transfer coefficient[W/m²/K].

Figure 5 shows the real product of the copper core. Two independent cooling paths near the outer surface of copper were fabricated with Gun-drill. If water leakage occurs at one of the cooling paths, we can still operate the cooling system with the remaining paths. Copper bodies and pipes were connected with Electron Beam Welding, EBW, because heat capacity of copper is too high to make TIG welding. The copper core of the beam dump had installed in the dump hut in Aug. 2008. The beam dump has been operated for up to 4-kW continuous proton beam in Nov. 2010.

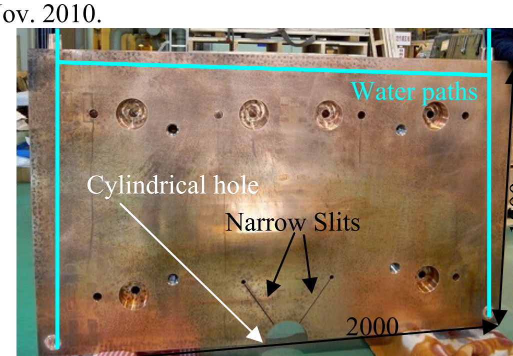


Figure 5: Copper product.

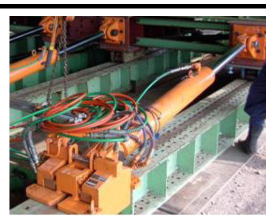
TRAVELLING SYSTEM

The beam dump core and surrounding peripherals have to securely move to the downstream when Hadron hall is expanded in future. The conditions to move the beam dump can be summarized as follows.

- Weight: 1000 tons
- Time: 8 hours (working hours a day)
- Distance: 50 meters
- Handling highly activated shields

We newly adopted a travelling system which consists of jack and slide, hydraulic cylinders and cramps. The travelling system is commonly used at construction of bridge and building. Table 1 shows travelling devices and its advantages. Jack and slide has advantages of two functions about jack up and slide at one device. This also has a feature of space-saving to reduce air activation. Hydraulic cylinder as a shifter function can make fine adjustment of ±10 [mm], and have a long stroke of 1.0 [m]. Cramp prevents runaway shift of the beam dump during operating and stopping hydraulic cylinder.

Table 1: Travelling Devices

Device	Advantage	Photograph
Hydraulic cylinder	Fine adjustment Long stroke 1 meter/2min	
Jack & Slide	Jack up+slide Space-saving Good linearity	

The illustration of the travelling system is shown in Figure 5. The travelling system can be remotely controlled to move by hydraulic pressure. It takes 150 minutes to move the 1000-ton dump to 50-m downstream, and this system meet the conditions as described above.

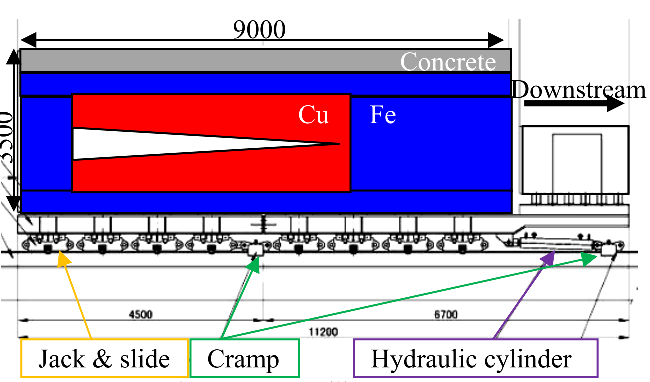


Figure 6: Travelling system.

SUMMARY

- The beam dump at the end of the primary proton beam line in J-PARC Hadron hall is made of copper, iron and concrete. The copper core has the conical hole to distribute heat deposit and the narrow slits to reduce thermal stress.
- We estimated thermal and mechanical analysis with MARS and ANSYS. It turned out that the maximum temperature rise and thermal stress of the copper core were 271 degrees (Celsius) and 21.2 [MPa], respectively. Thermal stress was lower than the allowable stress (28.5[MPa]) at 300 degrees (Celsius).
- We also made the systematic cooling test to measure heat transfer coefficient of the cooling devices. The measured heat transfer coefficients of Gun-drill method were higher than those of the assumed value in calculation. As a result, Gun-drill method is chosen as the cooling system of the beam dump.
- The travelling system is chosen to securely move the beam dump to the downstream for future extension of Hadron hall. This system consists of jacks and slides, hydraulic cylinders and cramps. The travelling system can be remotely controlled to move by hydraulic pressure. It is estimated to take 150 minutes to move the 1000-ton dump to 50-m downstream.
- The construction of the beam dump had been completed in Oct. 2008. The beam dump has been operated for 4-kW proton beam in Nov. 2010.

ACKNOWLEDGMENT

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