DESIGN AND R&D STATUS OF NP-HALL BEAM DUMP IN J-PARC

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Abstract

Japan Proton Accelerator Research Complex (J-PARC) is now under construction in Tokai-mura by the High Energy Accelerator Research Organization (KEK) and the Japan Atomic Energy Research Institute (JAERI). J-PARC 50GeV-PS (Proton Synchrotron) aims to provide more than 100 times higher beam power than that of KEK 12GeV-PS. An experimental hall for nuclear and particle physics (NP-hall) [1] is designed to handle intense slow-extraction proton beam and provide kaons, pions, and other secondary particles for multi-purpose physics use.

A beam dump at the aftermost of the primary beam line (A-line) is designed to safely absorb the 750 kW beam power. Its central core is made of copper and iron material with water coolant, and covered by concrete for radiation protection. The beam dump has to be moved to downstream when NP-hall will be expanded in the future. Important issues of the beam dump can be summarized as follows.

1. Heat generation,
2. Radiation safety, and
3. Moving safely to downstream in the future.

The present article reports the current status of our R&D of robust and radiation-resistant cooling system and how to move the beam dump safely.

1. INTRODUCTION

Fig. 1 illustrates the schematic layout of J-PARC. 50 GeV-PS accelerates protons injected from 3 GeV-RCS (Rapid Cycle Synchrotron) up to 50 GeV, and extract them to NP-hall in 0.7 sec duration. The slow-extraction beam is transported through the beam-switching yard, which is designed to separate the primary beam for the future extension. In NP-hall (fig. 2), beam hits the production target, which is made of rotating Nickel disks with total thickness of 54 mm. [2] Through the target, the primary beam is defocused to ϕ400 mm in diameter, and finally absorbed by the beam dump.

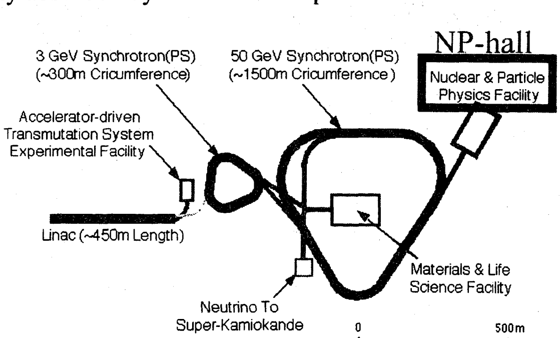

Fig. 1 Layout of the accelerator complex

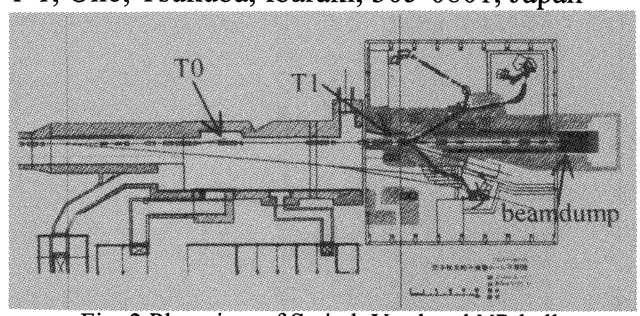

Fig. 2 Plan view of Switch Yard and NP-hall

Table1 the parameter of proton beam

Beam energy	50 GeV
Beam power	750 kW
Beam pulse	3.42 s
Extraction pulse	0.7 s
Number of particles	3.0×10^{14} ppp

2. STRUCTURE OF BEAM DUMP

The structure of the beam dump is shown in Fig. 3. The core of this beam dump is made of Oxygen Free Copper (OFC), which has high thermal conductivity and radiation hardness. The core part has a conical hollow (ϕ400x4000D), which is designed to comfort heat concentration in the material. Iron and concrete shield cover the dump core to keep the dose rate less than the limit of soil-activation and spatial dose rate on the ground. Cooling path of core part must be away from the centre of beam in order to minimize activation of the cooling water.

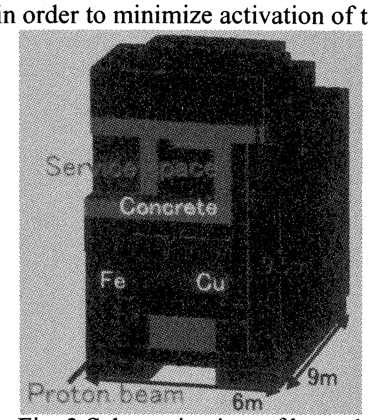

Fig. 3 Schematic view of beamdump

Since the dump-core of OFC ($3000 \times 2000 \times 5000 mm^3$) is too large to be made as a solid, it is comprised of 50 divisions ($3000 \times 1000 \times 200 mm^3$/part) in the beam direction.

The number of division of the core must be minimized to reduce thermal resistance in the gap of each block. In addition, we have to take the available size of OFC in Japan into account to construct the beam dump.

The Service Space (S.S.) over the beam dump is used to do maintenance job of piping, thermocouple thermometer, vacuum, and so on. The S.S. is covered with concrete shield to reduce the radiation exposure in the workspace.

Below the core there are two hollows ($1000 \times 1000 \times 9000 mm^3$) for shifter and rails, and we would install them just before moving to downstream between first and second phase.

3. DEVELOPMENT OF COOLING SYSTEM

The dump core is designed to accept full power of 750 kW proton beam. In this section, the numerical analysis of heat convection and the prototype of cooling system are discussed in detail.

Numerical calculation

The energy deposition in Cu-core by the 50 GeV proton beam was estimated with MARS code [3]. The size of the primary beam at the entrance of the beam dump is ϕ400 in diameter, and heat production is calculated by assuming the beam intensity to be 3×10^{14} proton per pulse (PPP) in 0.7 sec extraction period.

The heat propagation and convection was analysed by the ANSYS program. Based on the calculated energy deposit by MARS code, ANSYS program analysed heat propagation in OFC-core with about 380W/m/K heat conductivity. The heat convection from OFC to cooling water is assumed to be 600 [$W/m^2/K$] on the surface of OFC-core. Fig.4 shows a typical result of heat analysis. The maximum temperature is 264°C at z=3000mm. OFC's softening temperature is around 200°C, so the shape of conical hollow must be optimised to make the energy deposit uniform, or increase heat transfer rate higher than 600[$W/m^2/K$]. To confirm the heat convection from OFC to cooling water, we are testing three cooling schemes.

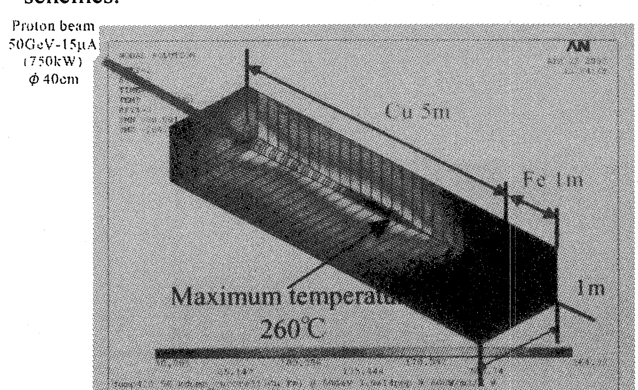

Fig. 4 Result of thermal generation

Cooling test

a) Thermal spraying

This technique of cooling system, which is often used at Paul Sherre Institut (PSI) laboratory, is that cladding by spraying is operated on Stainless steel piping and copper plate along groove. We used aluminium wire spraying to keep high thermal conduction and avoid corrosion.

Heat transfer rate is improved between pipe and plate with applying thermal spraying, and erosion and corrosion can be ignored by using Stainless pipes. However, the demerit is indirect cooling, and so heat transfer rate is lower than that by other ways described below.

For investigating heat transfer rate of thermal spraying, we carried out experiments as follows.

The experimental setup and condition is shown in Fig. 5 and Table2. In this case, we used only aluminium wire spraying without brazing.

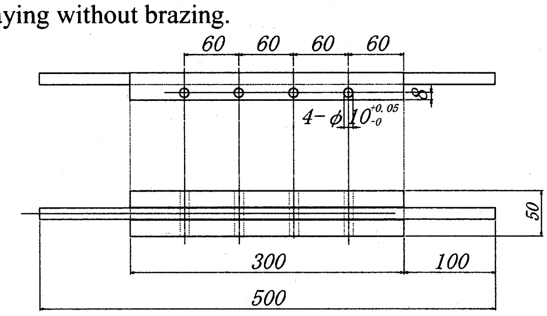

Fig. 5 experimental model

Table 2 experimental conditions of the cooling test

Type of thermal spraying	Aluminium wire
Maximum heat	~800W
Flow rate	5,10,15L/min
Flow velocity	0.9,1.9,2.8m/s
Reynolds number	9900,19800,29800

As a result of this experiment, heat transfer rate between OFC and water temperature were 950, 1110, 1260 [$W/m^2/K$] for the water flow rate of 5, 10 and 15[L/min], respectively. It is noticed that all the results were more than 600 [$W/m^2/K$], which is used in the computer simulation. As shown in Fig. 6, an air gap between SUS pipe and OFC block was found after thermal spraying. It would be possible that the heat transfer rate can be improved if the shape of copper block and the method of thermal spraying are optimized.

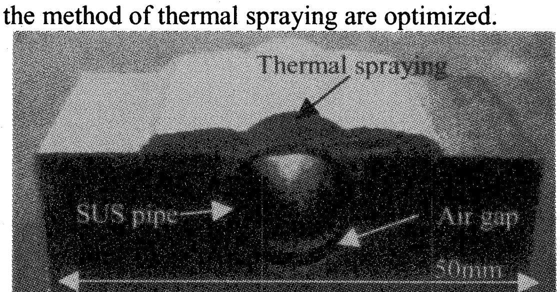

Fig. 6 Cross section of thermal spraying

b) Friction Stir Welding (FSW)

FSW is a gluing method which flows and agitates the inside of mother material by friction. At first we cut cooling paths groove, and cover with the copper cap. Finally FSW was applied along the gap between bank and cap.

The advantage of this method is high heat transfer rate by the direct cooling and low cost. But for direct cooling we must pay attention to erosion and corrosion problems at surface of OFC.

Fig.7 shows a mock-up of FSW cooling test. We can apply heat to this up to 20 kW from the back side. A water path with 6 turns is fabricated in the copper plate. We will test the heat convection with this model soon.

Fig.7 Mock-up for cooling test with FSW

C) Gun drill

Gun drill is a conventional drilling method to make a long hole in the metal block. The maximum length of a hole can be 50~100 times as long as the diameter of the hole. Thus, the cooling paths can be easily made in OFC-core, making holes and connecting them.

This device has the same advantage and disadvantage as FSW because of direct cooling at surface of copper.

4. HOW TO MOVE

Residual dose rate simulated by MARS

It is very important for moving the beam dump to evaluate the residual dose rate at contact for the beam dump after the long-time irradiation of the beam because we have to plan moving procedures in practice.

Fig.8 shows a typical result of the residual dose rate at contact after 1-year irradiation of 50 GeV-15μA beam and half-year cooling. The dimension of OFC-core was determined to be 3m W x 2m H, considering the acceptable radiation exposure during the moving work.

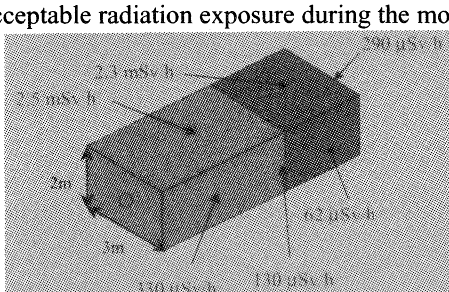

Fig. 8 calculation of residual dose rate

The weight of the beam dump, which can be moved to downstream, is ~1000 ton, and complete weight including moving shield with a crane is ~2000ton. Moving procedure is planed to complete in one day., and floor is able to sustain as heavy as 2000ton. We take into consideration of these, and here are moving scheme:

1. Shutdown experiments in first phase.
2. Cool nuclear radiation for half or a year.
3. Extension works, and cure cooling, thermocouple thermometer and vacuum devices
4. Move to 50 meter downstream.
5. Reinstall peripheral devices.
6. Restart experiments in second phase.

It is remarked that we have to install large radiation shield in front of the beam dump in order to avoid the radiation exposure from the inside of the highly-activated copper core. The adequate thickness of the radiation shield must be carefully evaluated to establish the scenarios of moving and daily maintenance.

6. SUMMARY AND PROSPECT

- The core of this beam dump is mainly made of OFC, which is chosen for high heat conduction and radiation resistance. The core part has a conical hollow in order to make proton beam disperse in moderation.
- Numerical analysis were performed with MARS and ANSYS codes for checking the feasibility of beam dump about radiation and cooling, and we figure out maximum temperature is 260°C more than OFC's softening temperature (200°C). For falling in maximum temperature, we have to carry out that conical hollow is optimised, and heat transfer must improve more than 600[$W/m^2/K$].
- Now we are evaluating three cooling devices (thermal spraying, FSW and gun drill) of beam dump for checking cooling ability, reliability and ease to maintain and comparing with each other.
- The scheme of moving beam dump to 50m downstream was considered and needs to be established in detail.

ACKNOWLEDGMENTS

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