DEGASSING OF KICKER MAGNET BY IN-SITU BAKE-OUT METHOD

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Abstract

New method of in-situ degassing of the kicker magnet in the beam line has been developed. The heater and heat shielding panels are installed in the vacuum chamber in this method. The heater was designed considering the maintainability. The graphite was selected as the heater and the high melting point metals were used as the reflectors just near the heater. The thermal analysis and the temperature measurement with the designed heater was performed. The ideal temperature distribution for the degassing of the kicker magnet was obtained. The outgassing of the graphite during rising the temperature was measured. The result showed that the outgassing was extremely suppressed by the first heating. This means the outgassing of the graphite heater was negligible as long as it is used in the beam line without exposure to the air.

INTRODUCTION

The usual way to reduce outgassing from a device in vacuum is to heat up a whole vacuum chamber containing the device. However, the situation, where this method can be applied, is limited due to the heat expansion of the chamber. Especially in accelerators, where the vacuum chambers are connected with nearby beam pipes, this normal bake-out method may not be applied. If a heat source and heat shields are appropriately installed inside the chamber, heat flux is directed to the device. Therefore the device can be baked out without raising the temperature of the vacuum chamber.

One candidate for such bake-out method to be applied is kicker magnets in J-PARC 3GeV synchrotron (RCS), which are installed in large vacuum chambers. The role of the kicker magnets is to extract an accelerated 3 GeV proton beam to a downstream beam transport line [1]. The voltage of 30 kV is applied from the power supply to the magnets in order to generate the magnetic field whose rise time is about 300 ns. The kicker magnets are installed in vacuum to prevent the discharge by such high voltage. The kicker magnet mainly consists of Ni-Zn ferrite cores, aluminium electrode plates. The total outgassing rate of the materials is large due to the large surface area. Therefore it is very important to develop a degassing method for the kicker magnets in the beam line because the vacuum quality may become poor after repeated exposures to air for the maintenances. The main outgassing component is water vapour [2]. Therefore the bake-out temperature should be above 100 °C, which is the typical desorption temperature of water vapour from the general surface. In the RCS beam line, 3 and 5 kicker magnets are located in vacuum chambers, whose length is 3 and 5 m, respectively. It is undesirable to use a normal baking method like baking the vacuum chamber of the kicker magnets because the large heat expansion of the vacuum chamber, which will be ~5 mm with a temperature rise of 100 ^{o}C for a chamber of 5 m length, will break nearby equipment such as alumina ceramics pipes. By applying the bake-out method, which is mentioned at the beginning of this chapter, only the kicker magnet is heated without raising the temperature of the vacuum chamber. So far, we performed the operability assessment of the new degassing method by the calculation with a simple model and the principal experiments using the R&D kicker magnet, which have the same structure as the production kicker magnets in RCS [3]. As a result, the ferrite cores were heated up above 100 °C while keeping the temperature rise of the vacuum chamber less than 20 °C. One of the technical issues was the design of the heater, which has a good maintainability. In this report, first, we will show the design and concept of the newly developed heater. Next, the temperature distribution of the kicker magnet and the vacuum chamber using the new heater is also presented. Finally, the vacuum characteristic of the heater material is reported.

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DESIGN OF THE HEATER

Any heater is possible to be damaged eventually. Thus the exchange of the heater should be easily performed. The vacuum chambers for the kicker magnets in the RCS beam line has ports with flanges under each kicker magnets. The heater was designed to be inserted from the port. Therefore, the size of the heater should be less than the inner diameter of the port (ϕ 130 mm). In the previous calculation, it was known that about 1000 W is needed for the heater to rise the temperature of ferrite sufficiently above 100 °C [3]. When the 1000 W is supplied to the heater with about 100 mm diameter, the heater temperature would be more than 1000 °C. We selected graphite as the heater material, which meets such requirement. The physical properties of the selected graphite are summarized in Table 1. In addition to the suitable electrical resistivity, the high mechanical strength is the reason of choice. Figure 1 shows the appearance of the heater. The design was performed with checking the temperature distribution of the heater by the thermal analysis. In the analysis, about the heat transfer from the each material surface, the radiation was taken account for the vacuum side, while the natural convection was considered for the atmospheric side, The result of the thermal analysis when 1000 W was supplied to the

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graphite heater is shown in Fig. 1. In the final design, the heater mainly consists of a heater body, radiation reflector, electrodes, and support rods. The heat reflecting plates that covers the entire bottom of the kicker magnet has a hole with 140 mm diameter in order to insert the heater from bellow. The radiation reflectors of the heater are required to ensure that the heat flux does not leak downward from the hole. The high melting point metals, such as molybdenum alloy and Inconel, were used for the reflectors, electrode rods, and support rods. The length and diameter of the support rod were designed so that the temperature of the flanges can be suppressed to about 100 °C. All the materials were vacuum fired in the furnace, whose pressure was less than 10^{-3} Pa during the process, in order to reduce the outgassing components in the bulk.

Table 1: Material Properties of the Graphite, which is used as the Heater

Flexural strength	79 MPa
Compressive strength	125.5 MPa
Electrical resistivity	12 μΩ m
Apparent density	1.8 g/cm^3
Open porosity	65 %

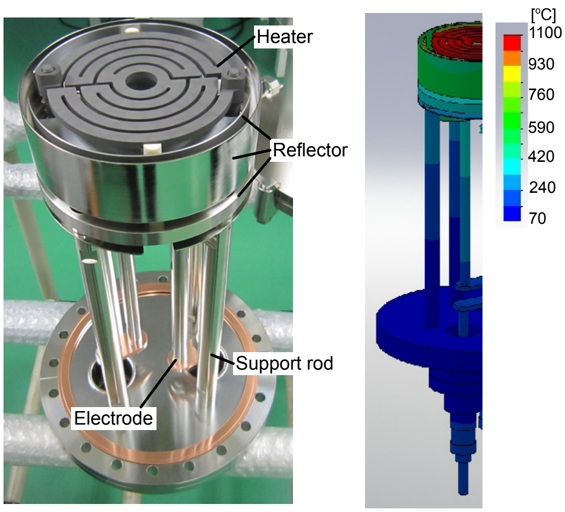

Figure 1: Design and calculated temperature distribution of the graphite heater.

IN-SITU DEGASSING OF THE KICKER MAGNET

Temperature Distribution

Thermal calculation analysis was performed in order to confirm whether the desirable temperature distribution of the kicker magnet and vacuum chamber was obtained by the designed heater. Figure 2 shows the calculated temperature distribution of the kicker magnet and a vacuum chambers. The 1/2 of the R&D kicker magnet and vacuum chamber was modelled for the calculation. The heater power in this case is 1110 W. The calculation result shows that there is relatively large temperature difference between the ferrite cores located in center and the edge because the heat flux is focused on the bottom center of the kicker magnet due to the small heater size. However, all the ferrites are sufficiently heated up above 150 °C. The calcurated temperature of the side plates of aluminum alloy, which support the weight of the ferrite cores and aluminum electrode plates, is distributed from 100-150 °C. The bake-out temperature should be above 100 °C to reduce the water vapour outgassing. On the other hand, the mechanical strength of the aluminum alloy extremely decreases above 150 °C. Therefore this thermal results is ideal. The temperature rise of the vacuum chamber was well suppressed to less than 20 °C except for the surround of the port, from where the heater is inserted.

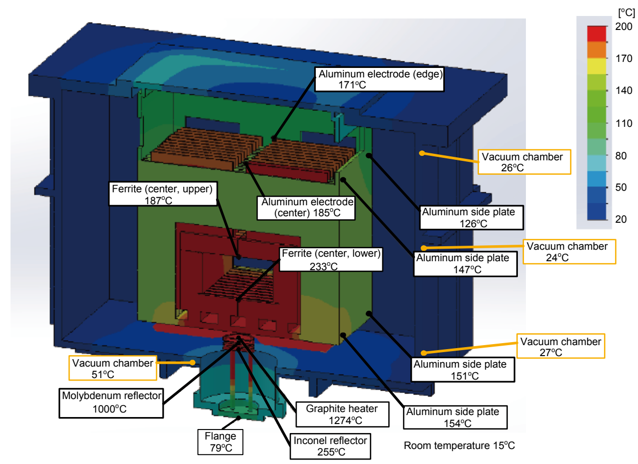

Figure 2: Calculated temperature distribution of the R&D kicker magnet and vacuum chamber.

We performed the temperature measurement of the each part of the kicker magnet. The temperature was measured by the type-K (chromel-alumel) thermocouples. The result of the 1000 W heater power case is shown in Fig. 3. The measured temperature of the ferrite cores and electrode plates were 20-45 °C higher than the calculated temperature. Those parts are located in area, which is surrounded by the aluminum side plates and the stainless steel bottom plates, and they have many contact part. Because the calculation did not take into account the small gap at the contact area, the heat transfer to those part by the conduction would be overestimated. Anyway, all the part of the kicker magnet became above 100 °C by a wide margin. For the temperature rise of the vacuum chamber difference from the calculation is very small and it is less than 25 °C at maximum except for the neighbourhood of the bottom port. These results of the thermal analysis and measurement gave the prospect of the in-situ degassing of the kicker magnet by using the new method, where the heat source and the reflectors were installed in the vacuum.

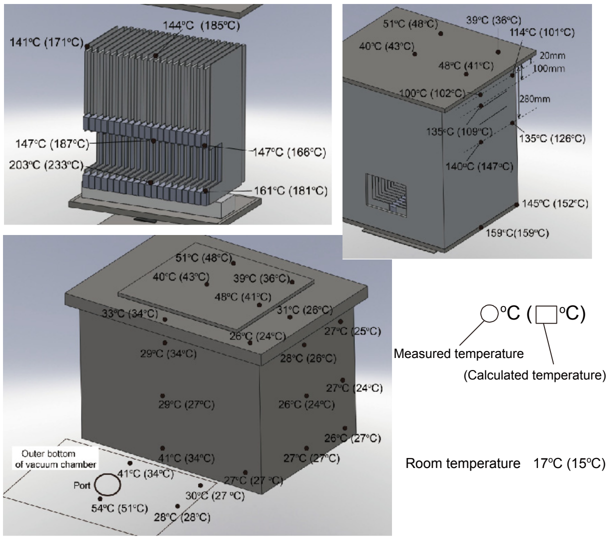

Figure 3: Measured temperature distribution of the R&D kicker magnet and vacuum chamber.

Outgassing Reduction

The vacuum characteristics were measured during the bake-out of the kicker magnet. The vacuum chamber was pumped by the 0.42 m^3/s turbo molecular pumps through the pipe with 0.54 m^3/s conductance. Total pressure are measured by a Bayard-Alpert gauge. The total surface are of the ferrite cores and aluminum electrodes are about 5 m^2 and 35 m^2, respectively. The typical outgassing rate per unit is shown in Fig. 4. The final outgassing rate per unit area is ~1×10^{-8} Pa m^3/(s m^2). This is the similar value for the stainless steel with clean surface, which is widely used as the ultra-high vacuum material.

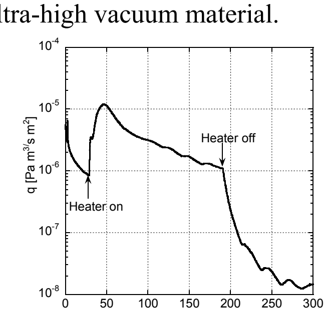

Figure 4: Typical outgassing rate per unit area of the kicker magnet during the degassing process by the graphite heater.

VACUUM CHARACTERISTICS OF THE GRAPHITE

Vacuum characteristics of the graphite had been studied as the candidate for the plasma facing material in nuclear fusion power research [4]. The study showed that outgassing differed depending on the type of graphite. Therefore the outgassing of the graphite, which is used for the kicker degassing, was investigated. The thermal desorption measurement was performed by using the 5 mm × 5 mm × ^{t}1mm graphite samples. The total and partial pressure were measured during the sample was heated up to 1000 °C. The measurement was performed 3 times. After 1st measurement, the sample was cooled down to the room temperature. After that, 2nd measurement was performed without exposing the sample to the atmosphere. The sample was one taken out and stored in the atmosphere for about 1 week. After that it was again installed and 3rd thermal desorption measurement was performed. Figure 5 shows the results of the pressure during the thermal desorption measurement. The pressure increased double digits during the 1st measurement. The pressure increase was extremely suppressed during the 2nd measurement. This is because outgassing source was depleted by the heat treatment in 1st measurement. However, the pressure during the 3rd measurement became similar to that in 1st measurement due to the re-adsorption. From these results, if the graphite heater is once heated up during the degassing of the kicker magnet with keeping the beam line in high vacuum, the outgassing from the graphite heater will be negligibly small.

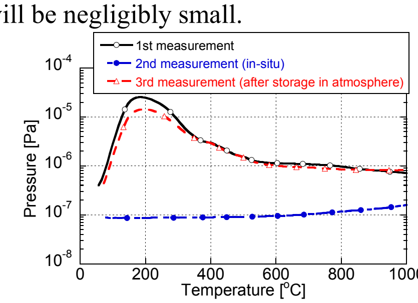

Figure 5: Pressure during the thermal desorption measurement.

SUMMARY

The new degassing method for the RCS kicker magnet, where the heater and reflectors were installed in the vacuum, has been developed. The temperature of the kicker magnet was successfully raised by the graphite heater with reflectors without raising the temperature of the vacuum chamber. The measured outgassing rate per unit area was reduced to ~1×10^{-8} Pa m^3/(s m^2) by this baking method. The outgassing of the graphite was suppressed by the heating process. We will fabricate the production version of the heaters and install them in the RCS beam line in the near future.

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