GAMMA-RAY IRRADIATION EXPERIMENTS OF COLLIMATOR KEY COMPONENTS FOR THE 3GEV-RCS OF J-PARC

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Abstract

It was success to develop the radiation resistant components using for beam collimator. Turbo molecular pump could be operated more than 15 MGy of gamma ray irradiation dose. Stepping motor developed at JAERI could be operated with good performance in the gamma ray dose of more than 70 MGy. PEEK sheathed cables and connector have kept good performance during gamma ray irradiation more than the dose of 10 MGy. It was cleared that the function of the heat pipe disappeared at 30 kGy gamma ray irradiation dose.

INTRODUCTION

Japan Atomic Energy Research Institute (JAERI) and High Energy Accelerator Research Organization (KEK) have been working on the Japan Proton Accelerator Research Complex (J-PARC) project for a high intensity proton accelerator [1]. The accelerator complex consists of a 400 MeV linac, a 3 GeV rapid cycle synchrotron (3GeV-RCS), and a 50 GeV synchrotron ring. The major requirements for the accelerator may be summarized as follows (1) The accelerator complex should provide a 1 MW beam with a repetition rate of 25 Hz and a pulse length less than 1 μs to enable full use of pulsed spallation neutrons. (2) It should provide the several ten GeV, beam with a beam power of 0.75 MW for nuclear and particle physics experiments. As for the design of such a high intensity proton accelerator, from the experience of the past accelerator operation, the average beam loss should be kept at an order of 1 watt per meter to allow hands-on maintenance [2]. It is very difficult to control the beam loss at such a low level, and the best measure we can take is to localize the beam loss in a restricted area where discrete modules are provided for quick coupling and remote handling is enabled in order to mitigate the doses to persons. In order to localize the beam loss in the restricted area, the beam collimation system is prepared in the RCS [3]. The amount of the localized beam loss on the one collimator is estimated about 1.2kW, and that loss generates a large quantity of the secondary radiation. So the beam collimator was designed to be covered with enough shielding and to use the components with reliability and long lifetime at the high radiation area. As the part of the collimator development, we have performing to study the collimator cooling system and developed the key components that had high durability for radiation. In this paper, we describe that the radiation damage of collimator key components which are turbo molecular pump, heat pipe, stepping motor, cables, and so on, when exposed to high radiation and the present state of development of the new devices.

RESULTS AND DISCUSSION

Gamma-Ray Irradiation Setup

The gamma ray irradiation test has been typically performed using the No. 2 gamma ray cells in the No. 1 Co-60 building of Takasaki Establishment at JAERI. The shape of the radiation source is a slab type and consequently the gamma flux is uniform in the wide area, the radiation activity of the source is 7.80 x 10^{15} Bq and the range of dose application rate is from 395 $Ckg^{-1}h^{-1}$ to 1.4 $Ckg^{-1}h^{-1}$ depending on the distance from the source. The interior environment in the cell is not subject to specific conditions, although fresh air is always blown in to expel ozone. Consequently, the environment for the irradiation experiments basically comprised the outside atmosphere with ambient temperature and humidity.

Turbo Molecular Pump

In general, the magnetic suspension pump uses semiconductor chips for magnetic suspension control. However, this semiconductor chip has problems in radiation and high temperature applications such as accelerator operation. The pump used for the experiment is magnetic suspension compound molecular pump model-TG1300M produced by Osaka Vacuum, Ltd., which is designed without using a semiconductor chip. The magnetic suspension of TG1300M is an active 5-axis control magnetic bearing system, with position sensors and electromagnets that provide high reliability and stable control. TG1300M could operate properly about 3.5 MGy absorption dose under gamma-ray irradiation environment until elastomer O-ring seals caused leak [4]. Since the DC fan, the rubber O-ring and the Teflon sheath of lead wires cannot be used under radiation from those irradiation experiment, we modified the design of the new pump (TG420MR) to employ natural convection cooling, metal seals, hermetic seals without epoxy resin and radiation hard sheaths of lead wires. Figure 1 shows a cross section view of TG420MR. TG420MR was improved on TG1300M for several parts as follows, (1) elastomer O-ring was changed to metal O-ring, (2) a material of connector was changed from epoxy to glass, (3) a material of a sheath of lead wires inside the pump was changed from Teflon to ETFE (Ethylene Tetra fluor ethylene), and (4) cooling fin system was set around pump body instead of cooling DC fan.

The gamma-ray irradiation testing of the new pump has been performed and has kept to be operated more than 15 MGy absorption dose under gamma-ray irradiation environment.

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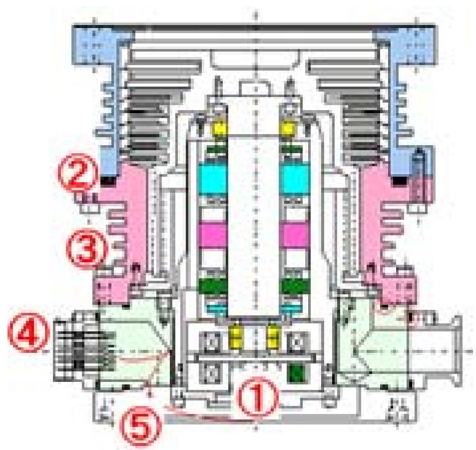

Figure 1: Cross section view of TG420MR that is used for gamma-ray irradiation experiment. (1) pick-up coil, (2)metal vacuum seal, (3)cooling fin, (4) ceramics hermetic seal, (5) PEEK sheath material

Heat Pipe

Since heat pipes have an effective thermal conductivity many thousands of times that of copper, we had planed to use for cooling system of the beam collimator. In order to determine radiation damage of the heat pipe, the gamma ray irradiation test was performed. Figure 2 shows set up of the heat pipe for gamma ray irradiation test and experimental results. Heat load of 100 W were supplied continuously at the bottom of the heat pipe by heater. The temperature of top and bottom of the heat pipe was measured by thermocouple. The black line shows the temperature at the top of the heat pipe, and the red one is the temperature on the bottom in Fig. 2. During the heat pipe has good performance, the temperature of top and bottom is almost same. The blue line in Fig. 2 shows the difference between top and bottom temperature of the heat pipe. Since this blue line became increasing after the gamma ray dose of 30 kGy, it was cleared that the function of the heat pipe disappear at this irradiation dose.

The mechanism of the heat pipe during good performance as follows. Inside the container is a water liquid under its own pressure, that enters the pores of the capillary material, wetting all internal surfaces. Applying heat at any point along the surface of the heat pipe causes the liquid water at that point to boil and enter a vapour state. When that happens, the liquid water picks up the latent heat of vaporization. The water vapour, which then has a higher pressure, moves inside the sealed container to a colder location where it condenses. Thus, the water vapour gives up the latent heat of vaporization and moves heat from the input to the output end of the heat pipe. However, it was found that the heat pipe disappear the function, because water vapour was analysed into oxygen and hydrogen due to gamma ray irradiation.

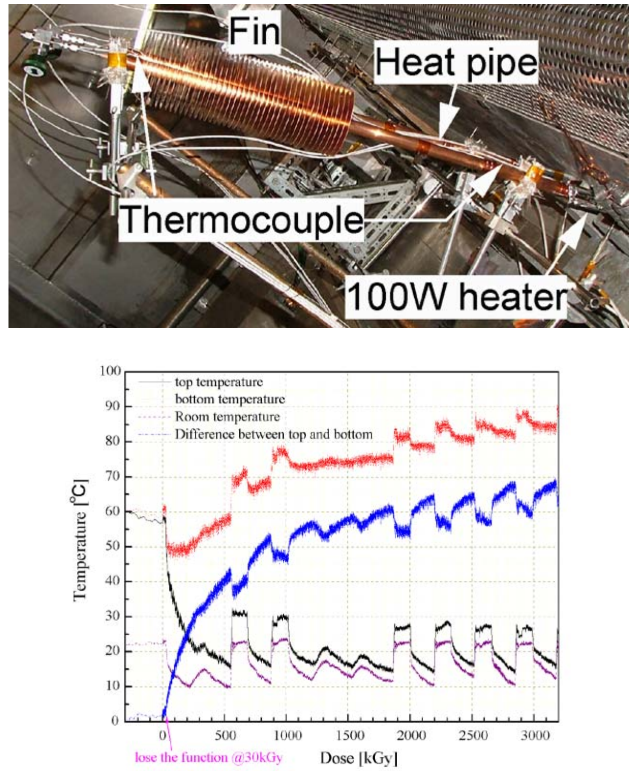

Figure 2: Set up of the heat pipe for gamma ray irradiation test and experimental results. The black line shows the temperature at the top of the heat pipe, the red one is the temperature on the bottom, and the blue one is the difference between top and bottom temperature of the heat pipe.

Stepping Motor

It was success for stepping motor that has high durability for gamma ray irradiation. The stepping motor has been operated during gamma ray irradiation. Figure 3 shows motion of the stepping motor. The red line shows motor driver current and blue one is stepping motor motion. Since grease becomes hard due to gamma ray irradiation, it is difficult to be operated on and off for the stepping motor. Three pattern operations that were continuously, at an interval of one week, and an interval of one month have been done. All stepping motor could be operated with good performance in the gamma ray dose of more than 70 MGy.

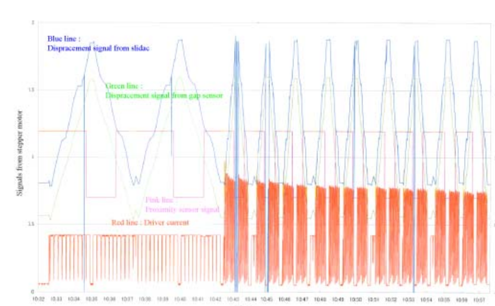

Figure 3: Motion of the stepping motor. The red line shows driver current and blue one is stepping motor motion.

Others

(1) Outgassing measurement of PEEK

In order to determine the radiation damage of the PEEK material, an outgassing rate of the PEEK material was measured for several kinds of absorption dose. The experimental data is shown in fig. 4. The PEEK material sample was irradiated in gamma ray in an ambient atmosphere environment. The out gassing rate increasing depending on absorption dose increasing. The value of the outgassing rate of the sample irradiated 10 MGy became 3 times the value of non irradiated sample after 4000 sec pumping. It seems that the increase in the outgassing rate after high irradiation is caused by increase in the effective surface of the sample due to radiation induced radicals. However, the increasing of the outgassing rate due to irradiation is not so big, it is appropriate to use the PEEK material under exposed to high radiation circumstances.

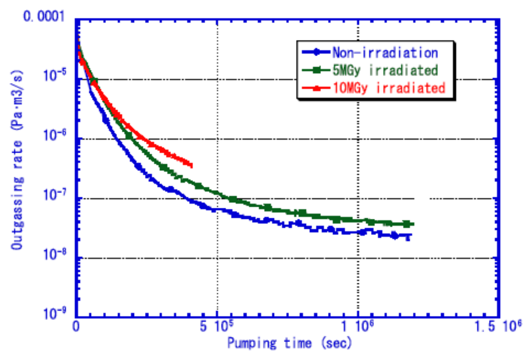

Figure 4: Outgassig rate of PEEK material. The blue line shows the rate before irradiation, the green one is after 5 MGy irradiation, and the red one is after 10 MGy irradiation.

(2) Cable

PEEK sheathed cable shown in Fig. 5 has been developed at JAERI. In order to determine the radiation damage of this cable, burning test (VTFT) and high voltage insulated test were performed with 10 MGy gamma ray irradiated cables. It was found that there was no damage and still kept good performance for the cable in both tests. It is being prepared for same test with 30 MGy irradiated cables.

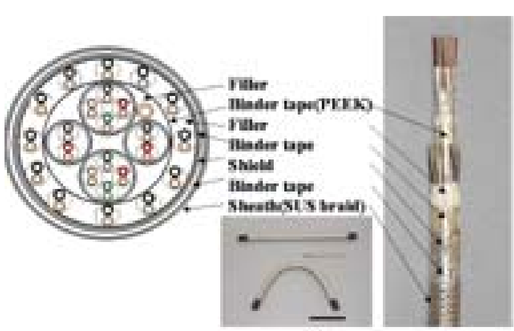

Figure 5: Schematic view and pictures of the PEEK sheathed cable.

(3) Connector

PEEK sheathed connector shown in Fig. 6 has been developed at JAERI. In order to determine the radiation damage of this connector, high voltage insulated test was performed with 30 MGy gamma ray irradiated samples. It was found that there was no damage and still kept good performance for the cable in this tests..

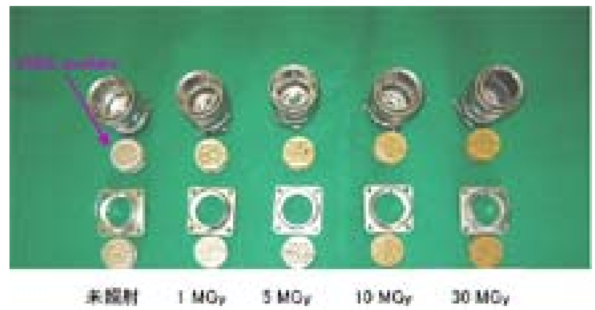

Figure 6: Picture of PEEK sheathed connector.

CONCLUSION

In order to determine radiation damage of key components of the beam collimator, a gamma-ray irradiation experiment was performed at JAERI. The turbo pump could operate if the absorption dose was more than about 15 MGy under gamma-ray irradiation environment. The goal of the development of the turbo pump would be realized by minor optimization of the hermetic seal and lead wire.

Since it was cleared that the function of the heat pipe disappear at the dose of 30 kGy irradiation dose, we gave up to use the heat pipe for cooling system of the beam collimator and has been performing to design new cooling system based on the thermal conductivity.

It was success for stepping motor that has high durability for gamma ray irradiation. This stepping motor could be operated with good performance in the gamma ray dose of more than 70 MGy.

Since it was found that no damage of PEEK material due to gamma ray irradiation, PEEK sheathed cable and connector has been developed. These cables and connector have kept good performance during gamma ray irradiation more than the dose of 10 MGy.

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