NEW CONCEPT FOR RADIATION ABSORBERS IN TRISTAN ACCUMULATION RING (TAR)

T. Momose, O. Kon'no*, H. Hirayama and H. Ishimaru

National Laboratory for High Energy Physics
1-1 Oho, Tsukuba, Ibaraki, 305, Japan
*Laboratory of Nuclear Science, Tohoku University
1-2-1, Mikamine, Sendai, 982, Japan

Abstract

Beam intensity in TAR is limited as 20 mA at 8 GeV to protect weak part against heat stress of ceramic chambers from the synchrotron radiation. Instead, 100 mA at 8 GeV is required in future plan of physics experiments. Linear power density and surface power density are 10.7 kW/m and 230 W/mm^2 for 100 mA at 8 GeV. To realize the requirement, present absorbers made of aluminum pieces can not be used because both incident power and temperature rise on the small absorbers are high. Then the absorbers can be called as localized absorbers. Absorbers made of copper or copper-aluminum claded pieces are localized ones and also can not satisfy the requirement. Therefore two kinds of new type aluminum absorbers are designed for bellows and ceramic chambers. The new ones for bellows can be called as distributed absorbers because heat load distributes wider range than that of localized ones. As a matter of course, less temperature rise is obtained. The new absorbers are basically one part of a bending (B) or a quadrupole (Q) magnet chamber. For ceramic chambers, new absorbers with thin thickness structure will be equipped. Basic idea of the new absorber for ceramic chambers is that much power is transmitted to outside of the chamber to decrease heat load at the absorber. The common idea for the two new absorbers is to utilize longer absorption mean free path (λ abs) of aluminum for photons than that of copper. Simulation experiment using electron beam having equivalent power and absorption mean free path showed effectiveness of the idea of the new two absorbers.

Introduction

TAR has been operated more than 6 years. Including the period of TAR design, about 10 years have passed as the TRISTAN era. Much experience on the TAR vacuum system has been stored during the era. As LEP and SLC were begun to operate, "future TRISTAN at KEK" has been discussed in various fields. In any cases, higher beam current of TAR is required. To realize higher beam current, the main beam limiting condition must be removed using new type absorbers to protect ceramic chambers. A ceramic chamber consists of a ceramic tube and two aluminum bellows. They are brazed in a vacuum furnace. Because the brazing part is weak against heat stress, the part is protected from direct synchrotron radiation with absorbers and wider aperture structure in ceramic chambers (Fig. 1). In spite of these protections, several troubles occured due to heat load of synchrotron radiation on the brazing part. It is found that with beam energy increase the traditional aluminum piece absorbers became not enough to block synchrotron radiation on the brazing part due to the shortage of absorption mean free path. So the absorbers for ceramic chambers were exchanged to Cu-Al claded absorbers because Cu has shorter absorption mean free path than Al (Fig. 2).

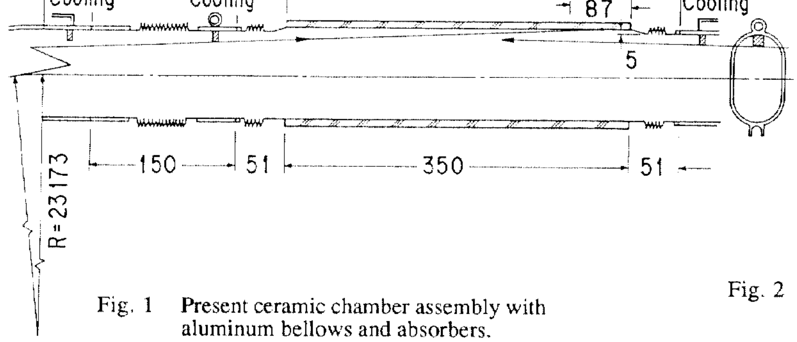

Fig. 1 Present ceramic chamber assembly with aluminum bellows and absorbers.

Both the traditional and the claded absorbers still have upper limit for incident power to suppress temperature rise less than 130°C. That is, the future beam current requirement brings about much temperature rise in these absorbers. Therefore two new absorbers for ceramic chambers and bellows are designed. The new absorber for bellows can be called as distributed absorber. It is designed not to concentrate heat load at the absorber itself. On the other hand, a new absorber for ceramic chambers has thin thickness structure not to stop whole power. The detail of the two absorbers is described.

Requirements

Required beam condition in future plan of physics experiments is 100 mA at 8 GeV. Corresponding linear power density due to synchrotron radiation along beam chamber is 10.7 kW/m, where the bending radius is 23.173 m for TAR and the incident angle in B chambers is 3.57 degrees from chamber wall. Corresponding surface power density for normal incidence is 230 W/mm^2 in case of 1 mm vertical size. This is just the upper limit power density for Al,[2] i.e., with the power density surface melting of aluminum occurs. Equivalent power with the required condition is obtained 230 mA (at 6.5 GeV) which is 7 times higher than the present limit, 30 mA at 6.5 GeV for synchrotron radiation experiment mode. The parameters at

	6.5 GeV, 30mA	8 GeV, 20mA	8 GeV, 100mA
Loss/turn	6.8 MeV/turn	15.6	15.6
Watt/m	205 kw/turn	313	1565
	1.4 kw/m	2.15	10.7
Photon Numbers	1.58×10^{20} photons/s	1.29×10^{20}	6.47×10^{20}
Critical Energy	26 keV	50	50
Absorption mean free path : Al	3 mm	20	20
Absorption mean free path : Cu	0.08 mm	0.55	0.55

Table I. Parameters of Synchrotron Radiation

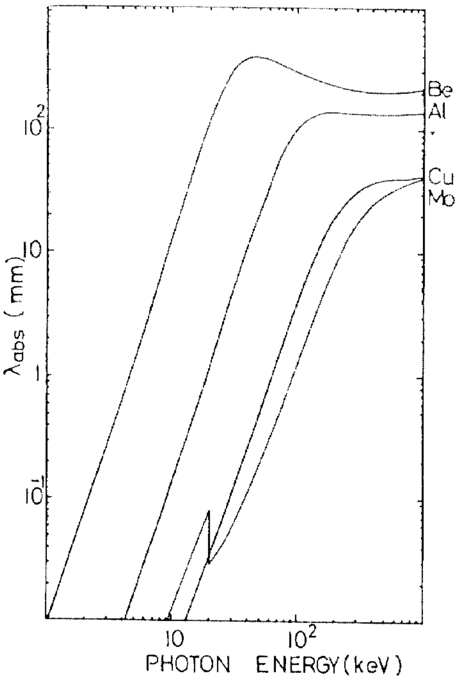

Fig. 2 Absorption mean free path (λ abs) of aluminum (Al), copper (Cu), molybdenum (Mo), and beryllium (Be) as a function of photon energy.

30 mA-6.5 GeV, 20 mA-8 GeV (beam transfer mode to TRISTAN e^+e^- colliding ring) and 100 mA-8 GeV are compared in Table I. The required power can easily cause heating problems at the brazing part in ceramic chambers, further in vacuum chambers and vacuum equipments if they were not designed well.

Present Status

Traditional Aluminum Absorbers

In arc section of TAR, race track type bellows of 150 mm long with 0.3 mm thick are used. Close to the bellows at the ends of B or Q chambers, traditional aluminum absorbers (axial length 5 mm, vertical size 10 mm, height from the wall 10 mm) are welded as a radiation shield for protection of thin bellows. Vertical size of the absorber is enough compared with vertical size of beam and of synchrotron radiation. Height from the wall is determined if the shadow length of the absorber is enough or not. At the ends of a B chamber, a 10 mm height absorber makes 182 mm long shadow. The height receives the power corresponding 7.3 mrad in a bending magnet (170 mm long on the beam axis). Incident power on the absorber is 360 W for the present and 1800 W for the future requirement. Assuming that the incident power distributes homogeneously at the area of the absorber 5 mm high from the wall, estimated temperature rise is 160°C for present condition, where 10 mm vertical width of synchrotron radiation is always assumed in this paper. This assumption is not so bad because measured temperature rise is ~ 80°C at the outside of chamber. On the other hand, temperature rise for the requirement is estimated to be 800°C. It is clear that the present absorber can not be used for the future requirement. As the absorber stands further from the ends of a B chamber, the shadow length becomes longer. 10 mm height is enough for bellows shielding.

Axial length needs to absorb whole incident power. The bellows length depends on the energy spectra of synchrotron radiation. The absorbers with 5 mm axial length are effective during operation for the beam energy less than 6 GeV. However, they became not so effective for ceramic chamber shielding above 6 GeV beam operation, because transmitting power through 5 mm in length increases.

Absorbers for Ceramic Chambers

The tendency of transmitting power increase was realized with ceramic chamber troubles at the brazing part because the aluminum absorbers have been used for both bellows and ceramic chambers.

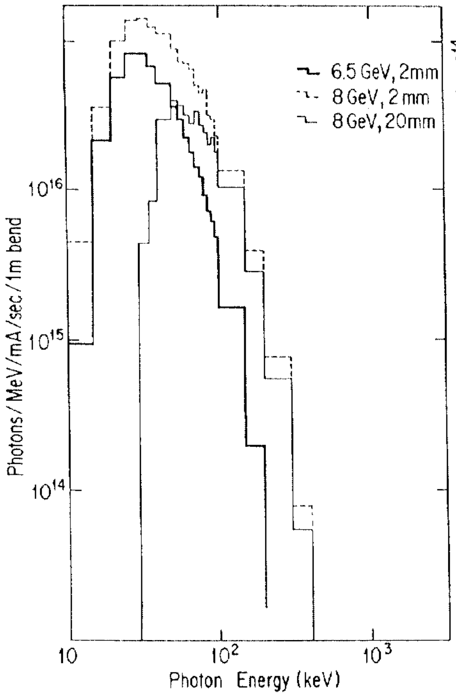

Fig. 3 Transmitted photon energy spectrum at 6.5 GeV and 8 GeV beam energy in TAR for 2 mm and 20 mm thick aluminum.

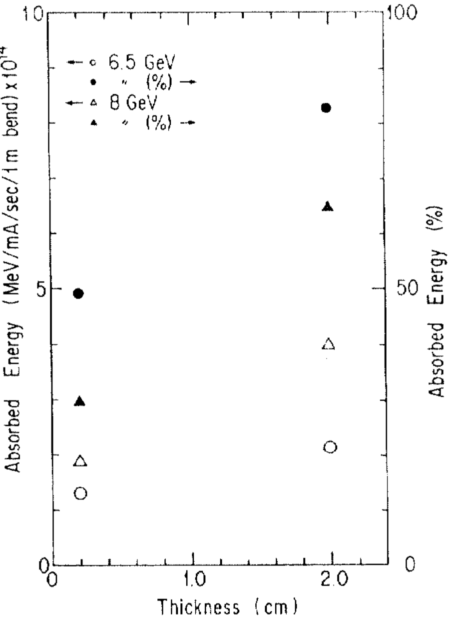

Fig. 4 Absorbed photon energy for 2 mm and 20 mm thick at 6.5 and 8 GeV beam energy in TAR.

As shown in Fig. 2, absorption mean free path of aluminum is 1 mm and 20 mm for critical energy 20 keV (beam energy 6 GeV) and 50 keV (8 GeV), respectively. Above 6 GeV, transmitting power through absorbers is not negligible (Fig. 3). The transmitting power radiated around the ends of ceramic chambers. Then heat stress broke the brazing part of ceramic chambers. Therefore the aluminum absorbers are exchanged to new ones using Al-Cu clad material (Cu ~ 4.5 mm and Al ~ 5.5 mm in axial length). Simple calculation shows that the total temperature rise at the claded absorbers is 188°C for the present and 940°C for the required condition. The claded absorbers themselves also can not satisfy the requirement.

The temperature at brazing part for the ceramic chambers ranges between room temperature and 70°C at 30 mA of 6.5 GeV. The higher ones are basically due to the shortage of shadow length of absorbers. 15 mm difference between the outside wall and the top of the absorber makes 314 mm long shadow, where ceramics end locates 401 mm from the absorber (Fig. 1). Shortage of shadow length of 87 mm has been compensated with 4.5 mm shift by pushing one end of ceramics chambers. But the ceramic chambers are used in a critical state. The present temperature at brazing part suggests that temperature at the requirement can be close to 400°C. As it is estimated that the troubles of ceramic chambers in the past occured more than 140°C at the brazing part, the present assembly of the ceramic chambers in TAR can not satisfy the future requirement.

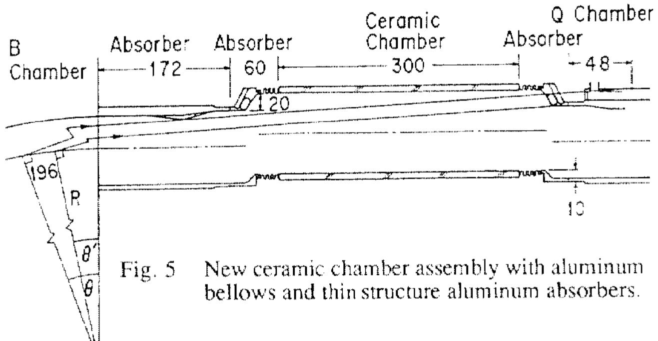

Fig. 5 New ceramic chamber assembly with aluminum bellows and thin structure aluminum absorbers.

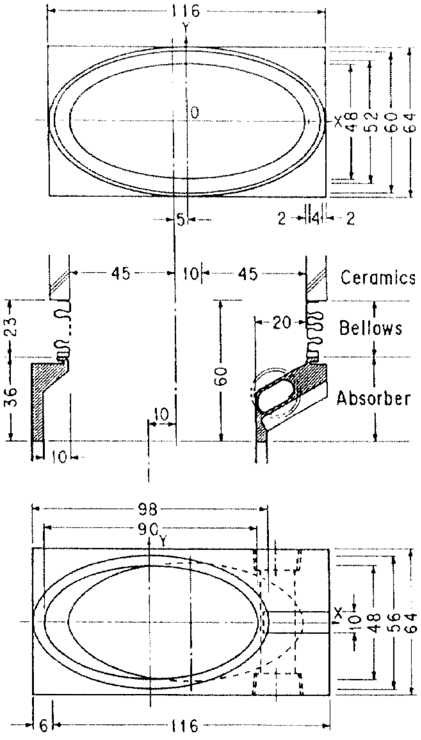

Fig. 6 Thin structure aluminum absorber for ceramic chambers.

Design

Absorbers for Ceramic Chambers

The present cross-section of ceramic chambers is 95 mm in horizontal length. From the beam axis, inner length is 45 mm and outer 50 mm. The outer length is made wide more 5 mm to obtain enough shadow on the end of ceramics. Then, distance between the beam axis and outer wall of ceramics in ceramics chambers is 20 mm. Further, total height of absorbers is 10 mm (5 mm-contribution from the distributed absorber plus 5 mm-one from the localized absorber) and the absorbers are set close to ceramic chambers to obtain enough shadow length. Totally a 30 mm step can make shadow of 600 mm long, where the length of two coupling bellows and a ceramic tube is 370 mm. At the both ends of a ceramic chamber, new absorbers are set, where the absorbers are 1 mm thick and watercooled. The parts take 72 mm (36 mm x 2) in axial length. In addition, an absorber and the space for welding need 60 mm. So, 502 mm is used. Remained 98 mm is used for correcting axial misalignment about 4 mm of the chamber. The thin structure passes much power out to decrease heat load at the structure. Energy absorption and transmitted photon energy spectrum[3] for 6.5 and 8 GeV beam energy in TAR is shown in Fig. 4 for 2 mm and 20 mm thick aluminum. It is clear that there is a two times difference between the two cases. Designed assembly around the ceramic tube and absorbers is shown in Figs. 5 and 6. The temperature rise at the absorber is estimated to be 63°C for 2.1 kW normal incidence under the most severe condition in several ceramic chambers.

Absorbers for Bellows

The traditional absorber causes concentration of heat load because of approximately normal incident radiation on the absorber and of its small size. About 10 mm height is needed to make shadow 182 mm long for 150 mm long bellows at the ends of a B chamber. Therefore a 10 mm thick distributed absorber in a B chamber was at first considered. However, 10 mm in thickness causes beam aperture decrease, weight increase and higher temperature rise, 173°C calculated for homogeneous power distribution, 107 W/cm. On the other hand, for 5 mm thick distributed absorber calculated temperature rise is 144°C. To obtain 10 mm height, a semi-localized absorber with tapered structure of 5 mm high and 40 mm long must be added on the 5 mm thick absorber (Fig. 7). Calculated temperature rise for the absorber is 130°C. For a Q chamber, only 5 mm thick in distributed type absorber with tapered structure is accepted (Fig. 7). The reason is that the absorber in a Q chamber must make shadow on the bellows against radiation from the right hand side in Fig. 7. This means that the source point of radiation is in the B chamber in the right hand side and far more than 1200 mm from the bellows. Therefore 5 mm height makes 221 mm shadow length which is enough to shield the bellows. This situation can be also applied to the absorbers in Q chambers next to ceramic chambers (Fig. 6). The same tapered structure receives heat 1.39 kW (5.62 mrad, 130 mm long on the beam axis). The estimated temperature rise is 132°C.

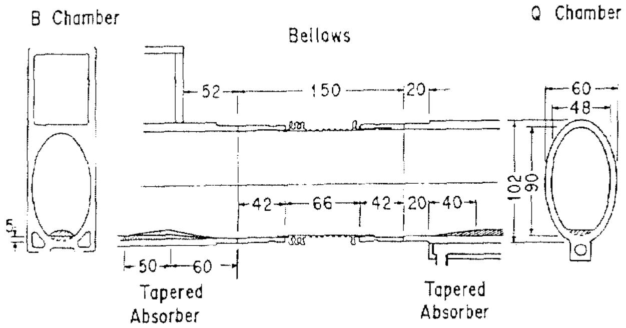

Fig. 7 New absorber assembly for bellows relative to a bending and a quadrupole magnet chambers.

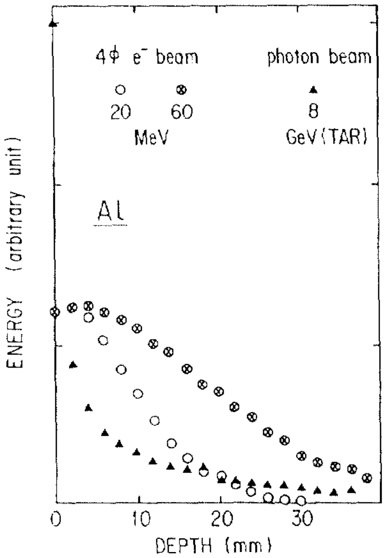

Fig. 8 Energy distribution for aluminum surface at 20 and 60 MeV electron beam and for photon beam at 8 GeV beam energy of TAR.

Power Loading Experiment

The effectiveness of the idea for the new two absorbers was evaluated using high energy electron beam experiment at the Laboratory of Nuclear Science, Tohoku University. The electron beam energy was determined by calculating power distribution for 20 and 60 MeV using the EGS4 Code system.[3] The result is shown in Fig. 8. At the 20 MeV electron beam energy, power distribution in the bulk is approximately the same with that of photons with critical energy (50 keV) for 8 GeV beam energy as shown in Fig. 8. Big difference between electron and photon beams is the intensity of the utmost surface. This is contribution from the low energy component of photon beam. Heat load of 1.2 kW (20 MeV x 60 μA, beam diameter ~ 5 mmϕ, ~ 60 W/mm^2) was applied to the two absorbers for a B and a Q chambers and the thin (2 mm) and thick (20 mm) type absorbers for ceramic chambers. Temperature rise close to beam edge is 35°C and 60°C for the B and the Q chambers, respectively. They can be used as absorbers for the future requirements, 1.8 kW, 1.5 times of this experiment. Temperature rise close to the beam edge for the ceramic chamber absorber is 70°C for the thin type and 140°C for the thick type, respectively. The result suggests that the thin type absorber can be used, but not for the thick type for the future requirement. As shown in Figs. 3 and 8, real radiation due to 8 GeV beam has component of lower energy. In addition, surface power density of this electron beam is lower than that of the synchrotron radiation. Real power load is severe than this electron beam simulation. Therefore further investigations about higher power application using lower energy electron beam and mechanical strength of the thin structure are necessary.

Summary

Required beam (power) condition for TAR is 100 mA at 8 GeV, i.e., 10.7 kW/m as linear power density and 230 W/mm^2 as surface density. As this is just melting limit of aluminum surface, the present absorbers can not be used. The new absorbers for bellows and for ceramic chambers are designed so as not to concentrate power on small area. The former is basically distributed absorber and is one part of beam chambers. The latter is thin thickness structure so as to pass much power out through the structure. With the electron beam simulation experiment, the effectiveness of the basic idea for the new absorbers were confirmed at 2/3 of the required power condition. To complete our design, higher power loading with lower energy electron beam and strength investigation of the structure must be carried out.

References

1) J. H. Hubbel, "Photon Mass Attenuation and Energy Absorption Coefficients from 1 keV to 20 MeV", Int. J. Appl. Radiad. Isot., 33, 1982, 1269.

2) N. Hower and C. Jako, "Thermal Test of Synchrotron Radiation beam Port Model, "SSRL Technical Report, 78-TM-02, June 1978.

3) W. R. Nelson, H. Hirayama and D.W. O. Rodgers, "The EGS4 Code System", SLAC-Report-265, Dec. 1985, Stanford, California.