ALUMINA CERAMICS VACUUM DUCT FOR THE 3GEV-RCS OF THE J-PARC

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Abstract

It was success to develop alumina ceramics vacuum ducts for the 3GeV-RCS of J-PARC at JAERI. This duct has titanium flanges and exterior RF shield to reduce duct impedance. The longitudinal duct impedance was sufficient small for stable beam acceleration from impedance measurement by coaxial method. The temperature of titanium flange became 45 C^{o} due to eddy current heating under dipole magnet operation. This duct is usable for the 3GeV-RCS of J-PARC.

INTRODUCTION

Alumina ceramics vacuum ducts have been under development at JAERI [1], [2], [3]. There are two types of alumina ceramics vacuum ducts needed, one being 1.5m-long duct with a circular cross section of 378 mm inner diamater for use in the quadrupole magnet, the other being 3.5m-long and bending 15 degrees, with a race-track cross section for use in the dipole magnet. Since a long ceramic duct can only be manufactured by brazing duct segments, the deterioration of mechanical strength in the brazing joint must be examined. To use a ceramic duct, some electrically conductive layer is necessary on the ceramic so that the wall impedance is reduced and thus the beam is stabilized. The RF shield is designed as a high frequency pass filter, where eddy current cannot be generated. The impedance of the RF shield is affected by the skin depth, which in turn is affected by the electrical conductivity of the RF shield material and by the geometrical structure. The alumina ceramics ducts have copper stripes on the outside surface of the ducts to reduce the duct impedance. In this RF shield, one of the ends of each stripe is connected to a titanium flange by way of a capacitor in order to interrupt the eddy current loop. The electromagnetic field was measured, and based on this it was calculated that the portion of the area around the duct periphery covered by the stripes is required to be 50% or more [4]. We adopted copper stripes as the RF shield, and adopted an electroforming method in which stripes of Mo-Mn metallization layer are first sintered on the exterior surface and then overlaid by PR-electroformed copper (a Periodic current Reversal method) [5]. The electrical conductivity of PR-electroformed copper is almost the same as Oxygen-free copper [6].

In order not only to preclude any charge buildup but also to reduce secondary-emitted electrons when primary protons or electrons strike the surface, TiN film is coated on the inside surface of the alumina ceramics duct. Experimental results of secondary yield measurements using a pulsed electron beam showed a noticeable reduction with a sputter coated TiN film of 1 - 2 nm thickness; the yields of uncoated and 1 nm-coated alumina ceramics were 6 and 1, respectively, with an incident beam energy of 1 keV [7]. This thickness for TiN film is enough for reducing the electron emission from the ceramic.

This paper describes that the production process of the titanium flanged alumina ceramics vacuum duct with RF shield and several kinds of experiments for vacuum duct performance.

PRODUCTION PROCESS

The required duct dimensions and shapes are given in Table 1. The ducts in dipole magnets have a racetrack cross-section and those of quadrupole magnets have a circular cross section.Since it is difficult to produce a long and large aperture alumina ceramics with RF shield, it can be realized to be manufactured by joining duct segments which are 0.5 - 0.8 m long. We decided production process for titanium flanged alumina ceramics vacuum duct with RF shield as follows. (1) unit duct production, (2) metallizing of the unit duct, (3) TiN coating to inner surface of the unit duct, (4) Unit duct segments joint and metal flange weld, (5)RF shield forming.

Table 1: The requirements of duct dimensions and shapes

Magnet type	Length [mm]	Shape	Cross section	Aperture size [mm]
Dipole				
	3500	15-degree bended	Race-track	187 (vertical) 245 (holizontal)
Quadrupole				
	1300	Straight	Circular	257 (diameter)
	1600	Straight	Circular	297 (diameter)
	1500	Straight	Circular	377 (diameter)

Unit Duct Production

Since a ceramic mold is generally deformed during sintering in a furnace, a 3.5 m-long and 15 degree bended duct for the dipole magnet having an race-track cross section is difficult to make with accurate dimensions, when the entire duct is fired at once. We decided that the ceramics duct was manufactured by joining 4 pieces of duct segments that are 0.8 m long with 1.5 and/or 2.0 degree edge angle. The segments should be produced with sufficiently large wall thickness so as to suppress deformation during sintering. In order to obtain a required aperture and required angle, it is necessary to apply

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grinding or polishing process on the outside surface and both edges of the sintered duct.

Metallizing

A stripe pattern of molybdenum-manganese (Mo-Mn) metallization layers is first sintered on the exterior surface and ends of alumina ceramics duct to produce the RF shielding and to joint segments. The metallization layers is sintered in a wet-hydrogen atmosphere at about 1350 ^{o}C. The thickness of Mo-Mn layer is 7~10 μm. A thin layer of nickel, about 2~5 μm thick, is applied by electroplating to protect the metallization layer from oxidation.

TiN Coating

TiN film of 10~15 nm in thickness was coated inner surface of the duct by hollow cathode discharge method in order to reduce secondary electron emission due to proton or other particles bombardment to the surface. The surface of ceramics duct is cleared up before TiN coating due to pre heating at 260 ^{o}C in vacuum.

The variation in thickness of the TiN film was less than ± 10 % for 12 nm thickness on the inside surface of a cylinder 580 mm long and 258 mm in diameter. The ratio of Ti/N was 1/0.98 of the TiN film.

Ceramics Segments Joint and Metal Flange

Since it is difficult to make the change from air for glazing to wet-hydrogen for metallizing, sequentially, a brazing method has been adopted to apply not only to segment joints, but also to joints between the titanium flange and the duct in our project. The segments are joined by both Mo-Mn metallizing the end and brazing with Cu-Ag eutectic alloy (Cu: 72%, Ag: 28%), and the flanges are welded at the sleeve to the ceramics segments by metallizing and brazing. The thickness of the Cu-Ag eutectic alloy is about 100 μm. The brazing is sintered, in a vacuum atmosphere at about 850^{o}C. This joint method produces a rigid duct which need only be supported at its ends and avoid contact with magnet poles which would interrupt the 25 Hz vibration of the magnet.

RF Shield

The alumina ceramics ducts have copper stripes on the outside surface of the ducts to reduce the duct impedance. In this RF shield, one of the ends of each stripe is connected to a titanium flange by way of a capacitor in order to interrupt the eddy current loop. We adopted copper stripes as the RF shield, and adopted an electroforming method in which stripes of Mo-Mn metallization layer are first sintered on the exterior surface and then overlaid by a periodic current reversal method. Electroformed copper stripes (5~6 mm width and 0.5~0.7 mm thick) on the ceramic duct are extended over the braze joint in order to be electrically insulated from the Cu-Ag eutectic alloy. Each stripe is also insulated from the titanium flanges by a capacitor of 330 nF which is welded between stripe and flange.

Figure 1 shows picture of the titanium flanged ceramics vacuum duct with RF shield. The relative permeability are summarized at Table 2 for each process.

Table 2 : Relative permeability

Process	Thickness (μm)	Relative permeability
MoMn	7	1.002 ~ 1.005
MoMn + Ni	7 + 2	1.002 ~ 1.010
MoMn + Ni + Cu	7 + 2 + 6000	1.004 ~ 1.013

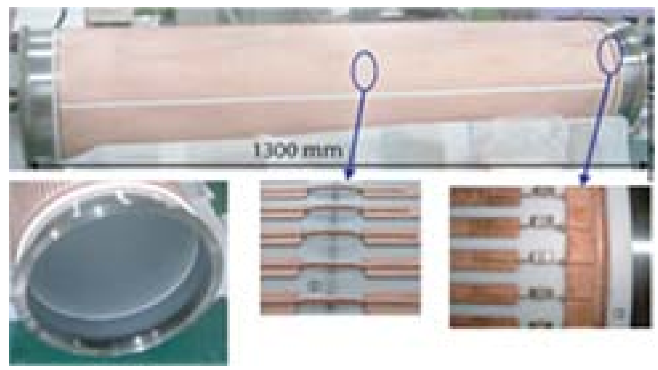

Figure 1: Picture of the alumina ceramics vacuum duct for quadrupole magnet. (1) TiN coating : Thickness is about 15 nnm. (2) Duct joint : Each duct is jointed with metallizing and brazing, and any Cu stripes are bridged over the brazing joint in order to be electrically insulated from each other. (3) Capacitor : Capacitors are welded between each Cu stripes and titanium flange. The capacity is 330 nF.

EXPERIMENTAL RESULTS AND DISCUSSION

Temperature Measurement

In order to determine heat up of titanium flange of the ceramics duct due to eddy current heating under normal operation of a dipole magnet, the temperature of the titanium flange and sleeve was measured. Figure 2 shows temperature of the titanium flange and sleeve under normal operation of dipole magnet. In this figure, the boundary ceramics and Ti means the brazing point ceramics and titanium sleeve, and thickness of titanium sleeve at thick area and normal area is 6 mm and 2 mm, respectively. The dipole operation conditions were 25 Hz repetition and magnetic field changing from 0.17 T to 1.1 T.

The maximum temperature of the titanium sleeve was about 65 ^{o}C and this was almost saturated under 500 minutes continuous operation. A room temperature was kept at 25 ^{o}C. It was found that this temperature rising was caused by eddy current of the dipole magnet from calculation. Since the temperature of the titanium flange was less than 45 °C, clamp chain made of aluminum could be use for this system.

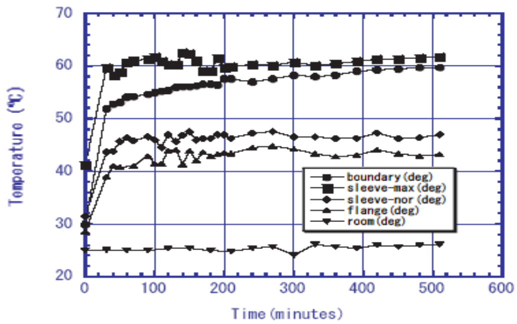

Figure 2: Temperature of the titanium flange and sleeve under normal operation of dipole magnet. The dipole magnet operation conditions were 25 Hz repetition and magnetic field changing from 0.17 T to 1.1 T.

Impedance

Impedance estimates with some formula and a coaxial wire method are obtained for ceramic duct. The stability criteria were applied for this impedance. A copper wore of 0.4 mm diameter was stretched in the ceramics duct under test with appropriate resisters for matching 50 Ω cable at both ends [8]. Network analyzer was connected to measure the S_{21}, transmission coefficient. Transmission coefficient for a dummy duct, same in length and diameter as the ceramic duct, was used as a reference, S_{21}(REF). The transmission coefficient was converted to the coupling impedance with standard log formula as follows.

$$Z_L = -2 Z_C * \mathrm{In} [S_{21}(DUT) / S_{21}(REF)]$$

Where Z_L is longitudinal impedance, Z_C is characteristic impedance (397 Ω) as a coaxial circuit. Figure 3 shows longitudinal impedance measured by this method. The impedance was less than 2 Ω in a frequency range of 20 MHz. Since revolution frequency of beam in 3GeV-RCS is about 1 MHz, this longitudinal impedance is sufficient small for stable beam operation.

CONCLUSION

It was success to develop alumina ceramics vacuum duct for the 3GeV-RCS of J-PARC at JAERI. This duct has titanium flanges and the exterior RF shield to reduce duct impedance. The production process of the alumina ceramics vacuum duct could be established, and mass production has been performing.

The temperature of titanium flange became 45 °C due to eddy current heating under dipole magnet operation.

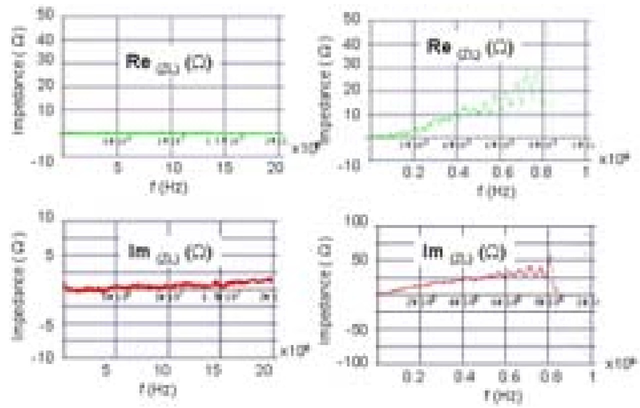

Figure 3: Longitudinal impedance measured by the coaxial wire method. The upper figures are real part of impedance and the bottom figures are ones of imaginary part. The left figures are the longitudinal impedance in the range of less than 20 MHz, and right figures are ones in the range of 1 GHz.

The longitudinal duct impedance was sufficient small for stable beam acceleration from impedance measurement by coaxial method. This duct is usable for the 3GeV-RCS of J-PARC.

The ceramics duct was installed in KEK-PS form January of this year in order to determine the duct installation effect to the beam. Since proton beam has been kept to accelerate stably after installation, it was found that this duct had no big problem for the beam. The preparation of outgassing measurement has been performing, and this measurement will be started from this Jun.

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