DC POWER LINES FOR TRISTAN AR MAGNET SYSTEM

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ABSTRACT

Most of the DC power lines for exciting the magnets of TRISTAN accumulation ring (AR) are composed of the water cooled Al conductors. The reason for adopting them are the reduction of the cost and weight of the conductor. Many months were spent in investigating the properties of Al as the conductor material, because of the first experience in Japan. In this report the method of the connection of Al and Cu conductors, cooling of the Al busbars, insulation and support of the conductor, and properties of Al and Cu are discussed.

INTRODUCTION

The AR main magnet power supply system is composed of 26 individual power supplies. One is the bending magnet power supply (B-PS) with the maximum current 1800A and the others are the quadrupole magnet power supplies (Q-PS) with 1340A. B-PS and 10 Q-PS's are installed in the west building and 15 Q-PS's in the east building. The Cu DC power cables from each power supply are wired to the one side of the Cu busduct in the cable pit. The typical length of the Cu cable is about 20 m . The other side of the busduct is connected to the Al busbar in the AR tunnel which are extended to the respective magnet. Near the magnet the Al busbar and magnet are connected with the water cooled Cu pipe.

MATERIALS FOR THE DC POWER LINE

CONDUCTOR MATERIAL

For the electric conductor usually Cu is used, but in the case of the AR system it is difficult to use the Cu cables or busbars because of their heavy weight and the small available space for cabling in the tunnel. From the viewpoint of the wiring materials, it must have the following properties,

1) high electric conductivity
2) enough mechanical strength
3) abundance in the earth
4) low cost
5) relatively light weight
6) good workability

and so on. As an alternative, Al was investigated for the wiring material of the DC power line. Table 1 shows the properties of Al and Cu. As seen from Table 1 the weight of the Al conductor is about 1/2 of Cu for the cross section of the same conductivity.

There are many types of Al alloys. In the AR system the type A-1060F which is the grade for the electric use is adopted. It is a standard industrial Al alloy having high Al purity (99.6 %), high electric conductivity, high thermal conductivity and high stability against corrosion.

Fig.1 shows the specification of the Al busbar and Cu pipe. Both conductors are cooled by pure water at the operation. The type of the Cu pipe is C-1100T and it has also high electric conductivity and high stability against the aqueous corrosion.

	Al	Cu
Specific resistance	2.82 x 10^{-8} (Ω m, 20°C)	1.72 x 10^{-8} (Ω m, 20°C)
Temp. coeff.	4.0 x 10^{-3} (1/°C)	3.8 x 10^{-3} (1/°C)
Coeff. of thermal expansion	23 x 10^{-6} (1/°C)	16.7 x 10^{-6} (1/°C)
Density	2.69 (g/cm^3)	8.89 (g/cm^3)

Table 1. Properties of Al and Cu

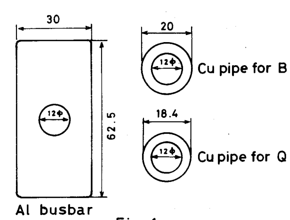

Fig.1

MECHANICAL STRENGTH AGAINST THE SHORT CIRCUITING

When the power supply happens to be trouble or short circuiting happens at the loading point, the large current will flow in the Al busbar. So it is necessary to estimate the mechanical strength of the Al busbar and its supporting structure against the stress. Fig.2 shows the supporting structure of the Al busbar. Here the maximum short circuiting current of 12.5 KA is assumed. The electromagnetic force between two parallel Al busbars is expressed by the formula,

$$F = 2.04 \times (1/S) \times K \times I^2 \times 10 \qquad (kg/m)$$

where I : short circuiting current (A)
S : distance between conductors (m)
K : correction factor depending on the conductor geometry .

Using this formula electromagnetic force F is 38.3 kg/m for the bending system and 52.3 kg/m for the quadrupole. The stress in the conductor is expressed as follows,

$$\sigma = ((F/1000) \times L^2) / (12 \times Z) \quad (kg/mm^2)$$

where F : electromagnetic force (kg/m)
L : supporting interval (mm)
Z : section modulus of the conductor (mm^3).

Assuming L = 1000 mm and Z = 7731 mm^3, the stresses are about 0.41 kg/mm^2 for the bending and 0.56 kg/mm^2 for the quadrupole. The A-1060F Al alloy stands for the stress more than 3 kg/mm^2. From the results it is clear that the Al busbar can endure the mechanical stress by the electromagnetic force in the AR system.

The mechanical force applied to the supporting structure by the large impulse current may be assumed to be twice the static electromagnetic force. In the case of the quadrupole circuit the force amounts to 104.6 kg/m taking into account the supporting interval of 1 m. The Al busbar is supported by the insulators as shown in Fig.2, so the stress applied to it is 0.06 kg/mm^2. In this system the insulator stands for about 100 times of this force. As a result it seems to be clear that the supporting system has enough strength against the short circuiting impulse.

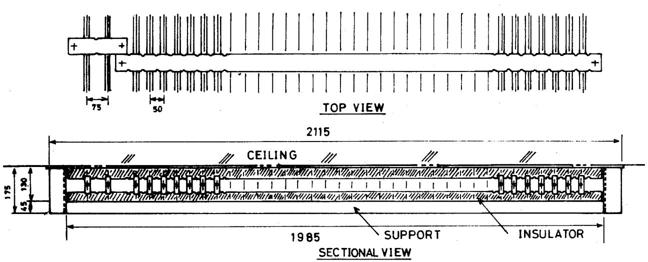

Fig. 2

TEMPERATURE RISE OF AL BUSBAR

The surface of the Al busbar becomes large in order to maintain the same conductivity as Cu, because the electric conductivity of Al is smaller than Cu. So the water cooling was adopted for the AR system to reduce the heat transfer to the environment. The cooling circuits were designed under the following assumptions,

continuous current of B-PS	:	1400 A
continuous current of Q-ps	:	1000 A
water pressure	:	10 a.t.m.
water flow rate	:	712 l/min
inlet temp. of water	:	30 ℃
outlet temp. of water	:	35 ℃
pressure drop in busbar	:	< 4 a.t.m.
temperature of environment	:	28 ℃
total length of Al busbar	:	9000 m

The pressure drop (Fig.3) is estimated from the following formula,

$$\Delta P = 4.12 \times 10^{-10} \times G^{\frac{7}{4}} \times d^{-\frac{19}{4}} \times l \quad (kg/cm^2)$$

where G : required water flow rate (l/s)
l : length (m)
d : hydraulic diameter (m) .

The maximum lengths of the cooling circuits of the Al busbar are less than 130 m for the B-circuit and 190 m for the Q-circuit.

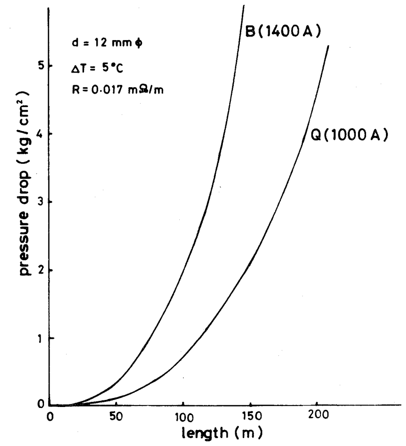

Fig. 3

CORROSION BY THE COOLING WATER

If the cooling water contains the Cu ions, it erodes the Al fiercely in the worst case. However, the cooling water is ion free and its resistivity is more than 100 kΩcm. Fig.4 shows the example of the corrosion test[1]. The corrosion rate decreases if the Al purity increases. Assuming the corrosion rate = 0.1 mdd (mg/dm^2·day) for the industrial Al of 99 % purity the corrosion is estimated to be less than 1.4 x 10^{-3} mm/year on an average.

The C-1100A Cu pipe used in this system has the corrosion resistance against not only natural water but also pure water. This pure Cu is superior to other Cu alloys.

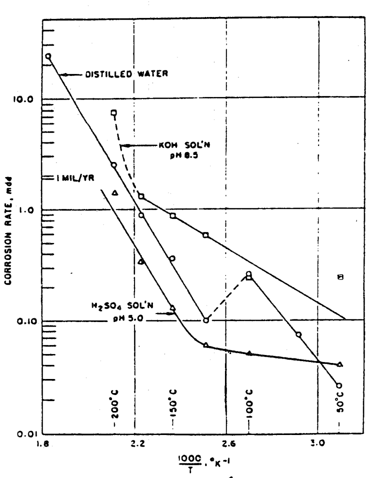

Fig. 4[1]

RADIATION RESISTANCE OF INSULATION MATERIALS

The insulation materials of the Al busbar and Cu pipe are exposed in the high radiation environment during the accelerator operation. So the materials which do not change the quality in that circumstances must be chosen as the insulators. The following materials are used in this system.

polyethylene

: insulation for Al busbar and Cu pipe

EPR (ethylene-propylene-rubber)

: rubber pipe for water cooling

polyester-premix

: supporting structure for Al busbar

Polyethylene, EPR and polyester-premix endure the dose of 10^7 rad, 10^8 rad and 10^8 rad respectively. To reduce the Compton scattered radiation from the Al vacuum chamber, it was covered with 3 mm thick Pb sheet. Therefore, these figures are considered to be by far larger than the radiation dose during 20000 hours' operation of the accelerator which corresponds to 10 years.

ELECTROLYSIS OF AL BY CU CONTACT

In general there are two methods for reducing the contact resistance and electrolytic corrosion. One is the plating method and the other the use of the joint compound. The former employs the Cu to Cu contact by plating the Al surface with the Cu thin film tightly, but it is rather costly. For the contact of Al and Cu the joint compound is usually used. The detail discussion is made in the reference[2]. Fig.5 shows the example of the measured data of the resistance of Al-Cu contacts for few kinds of the joint compounds. For the AR system the type A joint compound is used. As shown in the figure the type A is more stable than other compounds. And it must be taken care of the following matters,

1) removing the oxidized thin film from the contact surfaces perfectly just before painting the joint compound
2) using different brushes for Al and Cu
3) giving the uniform pressure to the contact surfaces by bolting .

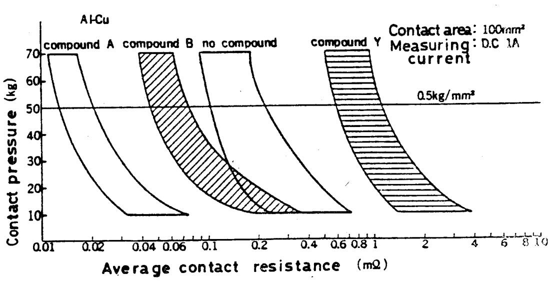

Fig.5 Resistance of aluminum-copper contacts 2

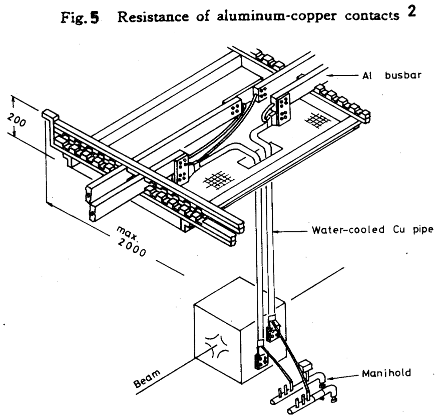

Fig.6

Performance of the contact will be same as the plating method by these processes.

CONSTRUCTION OF THE SYSTEM

The construction of the system began by manufacturing the Al busbar. It was manufactured by the extrusion of the Al ingot at Furukawa Electric Co. Ltd. The produced long Al busbar was wound upon the large cable drum. Then the Al busbar was insulated on the cable insulation line. Total length of the Al busbar amounts to 9000 m. This busbar was cut to a size of 17 m or less to carry by a big trailer. Many short cut busbars were carried in the tunnel. Other materials were also manufactured and carried in KEK at the same time.

These busbars were welded in the argon atmosphere to the desired length. The Al-Al welding was performed carefully and the further insulation was made around the welding point. After finishing the long Al busbar was installed in the supports which were fixed on the ceiling by the anchor bolts. Fig.6 shows the features of the connection between Al busbar and magnet coil. The cooling water for the Al busbar is supplied from the manifold of the magnet.

Finally all busbar system was covered with the punched metal for security. And the thermo-relays have been used for the interlock system to avoid the accident due to the water circuit troubles.

As the acceptance tests, the pressure and insulation tests were performed and the resistances of busbars were measured.

The simplified DC power line diagrams of all bending and quadrupole magnets are shown in Fig.7 in which the feeding points of the water cooling are also shown.

REFERENCES

1. J.E.Draley and W.E.Ruther, The 12th Ann. Conf. and Exhibition, Nat. Ass. of Corrosion Eng., New York, 1956.
2. K.Tomari, The Furukawa Electric Review, No.52, 1972.

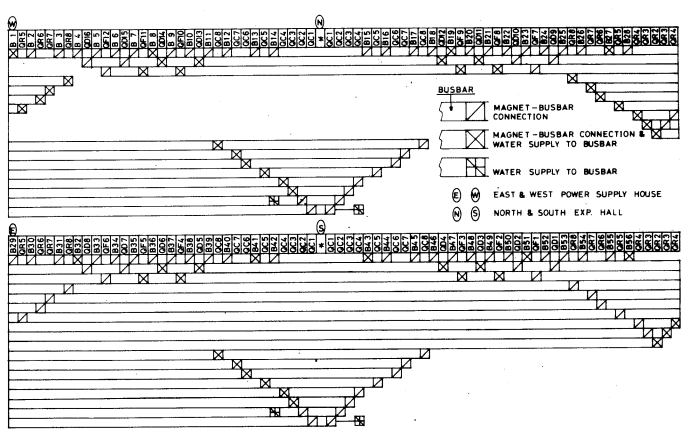

Fig.7