OUTGASSING RATE OF HIGHLY PURE COPPER ELECTROPLATING APPLIED TO RF CAVITIES

T. Abe*, T. Kageyama, Y. Saito, H. Sakai, Y. Satoh and Y. Takeuchi,
Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), Ibaraki 305-0801, Japan
T. Nakamura, S. Nishihashi and K. Tsujimoto, Asahi Kinzoku Kogyo Co. Ltd., Gifu 503-0125, Japan
K. Tajiri, Churyo Engineering Co. Ltd., Nagoya 453-0862, Japan
Z. Kabeya and T. Kawasumi, Mitsubishi Heavy Industries Ltd., Nagoya 455-8515, Japan

Abstract

We are planning to apply a new copper electroplating with a high purity and a high electric conductivity to normal-conducting rf cavities for electron or positron storage rings with high beam currents. As reported in 2005 Particle Accelerator Conference, our first test cavity, made of steel, with the electroplated copper surface finished up by electropolishing showed an excellent electric performance compared with the case of cavities made of oxygen free copper. Our next step is to examine the vacuum performance. This paper reports results of the outgassing-rate measurement on our second test cavity together with its fabrication process.

INTRODUCTION

The ARES [1] is a normal-conducting rf accelerating cavity system for KEK B-factory (KEKB). This cavity system has an additional energy-storage cavity with a cylindrical shape in order to store a huge amount of electromagnetic energy for the beam stabilization [2]. The electromagnetic field in the energy-storage cavity is coupled, via a small coupling cavity, to that in the accelerating cavity with a structure for damping higher order modes; therefore, the ARES is a unique three-cavity system.

Since the energy-storage cavity is large, with an inner volume of 1070.4 mm in diameter and 1191.1 mm in height, it is made of steel (SS400) to obtain enough mechanical strength and the inner surfaces are copper-electroplated. The electroplating on the present cavities was performed in a pyrophosphate bath, where brightener was used to make the surfaces smoother and defect-free. We have studied to apply a new electroplating to rf cavities for SuperKEKB [3] and other high power cavity systems, based on the copper electroforming performed in an acid copper sulfate bath without brightener nor other organic additives, where the current is periodically reversed ("PR process"), typically 20 seconds normal for depositing and 4 seconds reverse for etching, in order to prevent growth of rough and large grains in the electroplating and to keep the smooth surface. The DC electric conductivity of the copper surface is so high as comparable to that of the highest-class oxygen free copper. This method was first applied to the J-Parc linac [4]. There are two main differences between our and J-Parc applications. The first one is the thickness; our target of $120\,\mu$m is much thinner. The second one is that we have no mechanical polishing on the electroplated surface before electropolishing.

For accelerating cavity systems, high electric and vacuum performances are required. We examined the electric performance of the new electroplating by measuring the unloaded quality factor (Q_0) for our first test cavity, and found the Q_0 values after electropolishing were almost at the maximum, predicted from the DC electric conductivity of the oxygen free copper [5].

In this paper, the vacuum performance of the new electroplating is examined by measuring the outgassing rate in the orifice (through-put) method. For this purpose, we have constructed a second test cavity which has pumping and other ports.

TEST CAVITY

The second test cavity is also made of steel (SS400) as shown in Fig. 1. This cavity has the same size as the first test cavity with an inner volume of 451.2 mm in diameter and 260.0 mm in height, and has the same types of ports which the ARES energy-storage cavity has; the barrel part has ports for pumping, an input coupler and monitors; the endcap part has a tuner port. One of the two endcaps has additional four monitor ports, which are not seen in Fig. 1. The barrel part has flat-surface rf contacts to the endcaps.

Figure 1: Second test cavity, made of steel (SS400), to examine the vacuum performance of the new copper electroplating. The endcap (left) and barrel (right) parts.

* tetsuo.abe@kek.jp

Copper Electroplating

The copper electroplating followed by electropolishing was performed in the same method as applied to the first test cavity, except for the special treatments for the electroplatings around the ports and the rf contacts.

Fabrication

After electroplating and electropolishing, the two endcaps were welded to the barrel part basically in the same method as applied to the present ARES energy-storage cavities. Figure 2 shows the setup for the TIG welding. The two endcaps and the barrel were stacked and held with pressurization at the top and bottom by a hydraulic jack system. We raised the hydraulic pressure until the Q_0 of the TM_{010} mode, measured by a network analyzer, became almost saturated. Figure 3(a) shows the Q_0 response as a function of the line pressure at the rf contact, where the Q_0 values are normalized to the theoretical prediction obtained using a 3D electromagnetic-field simulator `MICROWAVE STUDIO`. In Fig. 4, the geometry used in this simulation is shown together with the electric fields of the TM_{010} and TE_{011} modes. The welding was performed in three steps as follows:

1. a tack welding with keeping the line pressure at the rf contact of 181 kN/m provided by 50-MPa hydraulic pressurization,
2. an intermittent welding, with keeping the pressurization, between adjacent vertical shafts for holding the cavity,
3. a two-layer continuous welding on the entire circumference after the pressurization and the shafts were removed.

Seventeen hours later after the welding was finished, the relative Q_0 values were measured to be about 101% for both the TM_{101} and TE_{011} modes, as shown in Fig. 3(a) and (b), which are consistent with the results in [5].

From this Q_0 measurement, the following useful data have been obtained;

- the electric performance is excellent also for the second test cavity which has various ports and the same rf contacts as those of the present ARES energy-storage cavities;
- the rf contact is perfect also with the new copper electroplating which is softer than the electroplating applied to the present ARES energy-storage cavities;
- the welding stress produces a high line pressure at the rf contact over 181 kN/m (= 185 kgf/cm).

MEASUREMENT

The outgassing rate has been measured in the orifice method. Figure 5 shows the experimental setup. The main components are an extractor gauge upstream of the orifice (EG1), an extractor gauge downstream of the orifice (EG2),

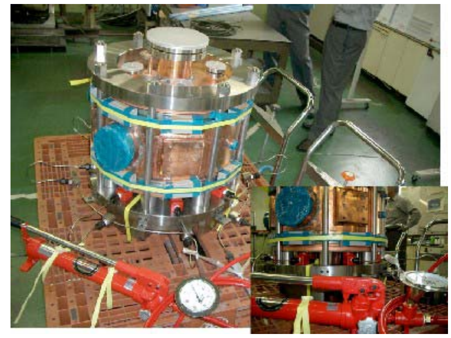

Figure 2: Setup for the TIG welding with pressurization. Eight hydraulic cylinders are put on the lower endcap.

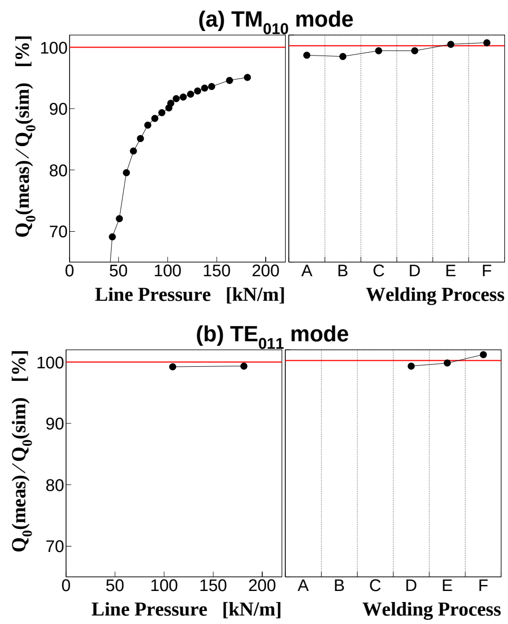

Figure 3: Q_0 measurements (Q_0(meas)) during the increasing pressurization (left) and the welding process (right) normalized to the theoretical predictions (Q_0(sim)) obtained using `MICROWAVE STUDIO` for the (a) TM_{010} and (b) TE_{011} modes. The measurements are corrected for Q_0 at 20°C. In the theoretical calculation, the 100%IACS electric conductivity of copper and the completely smooth surface with no defect are assumed. The steps A-F in the welding process mean (A) after the tack welding, (B) after the intermittent welding, (C) after removal of the pressurization, (D) after the first-layer welding, (E) after the second-layer welding, (F) 17 hours later after the welding was finished, respectively.

an orifice flange, turbo-molecular vacuum pumps (TMPs), thermocouples, and a data acquisition system based on EPICS [6] with device support `NetDev` [7] for communication with a programmable logic controller. The outgassing rate (Q) is calculated according to the following formula,

$$Q = (P_1 - P_2 - P_{\mathrm{BG}}) \times C/S, \tag{1}$$

where P_1 and P_2 indicates vacuum pressures measured by EG1 and EG2, respectively, P_{BG} is a vacuum pressure

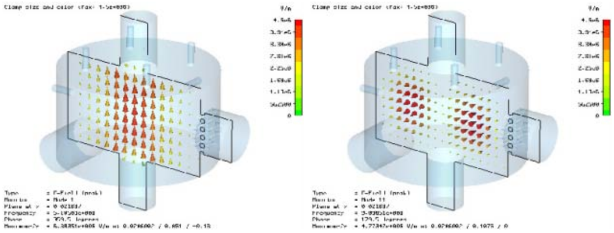

Figure 4: Geometry used in the 3D electromagnetic simulation using MICROWAVE STUDIO together with the electric field of the TM_{010} (left) or TE_{011} (right) mode in the cross section. The surface current flows across the rf contact for the TM_{010} mode, while not for the TE_{011} mode.

measured by EG1 just before the P_1 measurement with the orifice system isolated from the test cavity, S the inner surface area of the test cavity approximated as a simple pillbox, and C is a conductance of the orifice calculated according to the following formula,

$$C = A \times \sqrt{\frac{RT}{2\pi M}}. \qquad (2)$$

In this Eq. (2), A indicates the area of the orifice (7.85×10^{-5} m^2), R the gas constant, T the temperature of the orifice flange in K, and M is the molar mass of nitrogen.

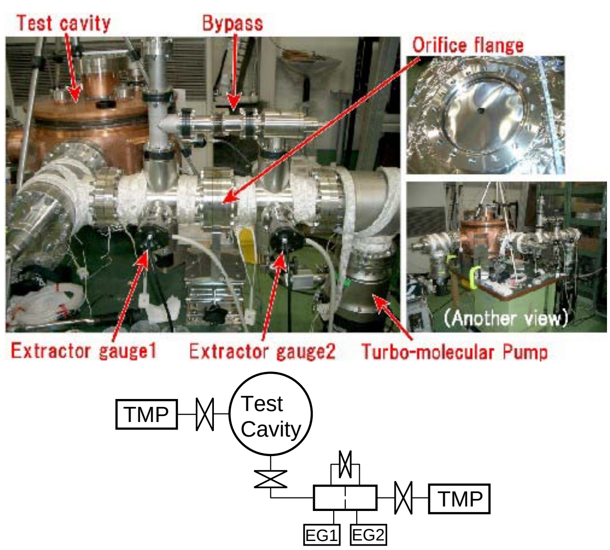

Figure 5: Experimental setup for the outgassing-rate measurement in the orifice method.

Figure 6 shows results of this measurement together with some other measurements. It has been found that our results are consistent with the related measurements, and there could be room for improvement with baking.

CONCLUSION

We have examined the vacuum performance of the new copper electroplating applied to the second test cavity by measuring the outgassing rate in the orifice method. Our results are consistent with the other related measurements. The next step is to measure the outgassing rate after baking.

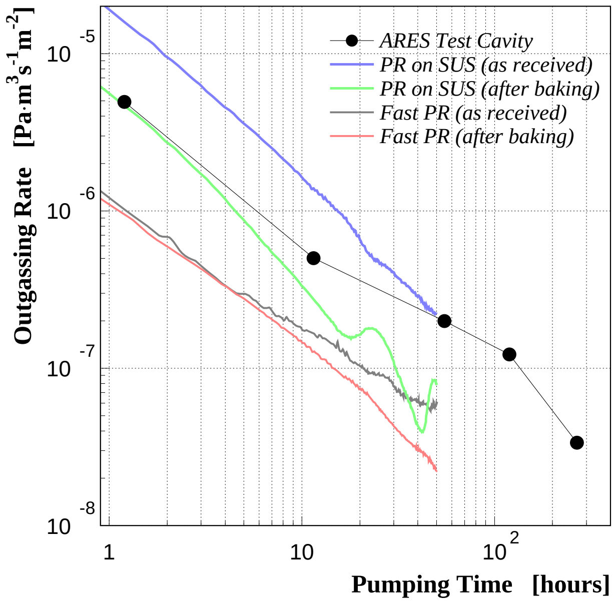

Figure 6: Results of the outgassing-rate measurements at room temperatures. The circles are results of this measurement on the ARES second test cavity performed in the orifice method after pumping for a few months followed by exposure to the air with 42 % humidity for 24 hrs. The blue (green) line indicates results on the copper lining with a thickness of about 1 mm electroformed in the condition for the J-Parc linac without electropolishing before (after) baking (150 °C×23 hrs). This electroforming was performed on a vacuum duct, made of stainless steel, with 150 mm in diameter and 1000 mm in length after electron chemical buffing. The gray (red) line indicates results on the copper foil with 0.3 mm in thickness electroformed on a test piece made of stainless steel with 80×100 mm^2 in area without electropolishing before (after) baking (100 °C×23 hrs) followed by exposure to the air for 7 days. This electroforming was performed in the fast PR method [8]. The measurements shown with lines were done in the conductance modulation method [9]. In all the cases, ultra-pure water rinsing followed by alcoholic dehydration was performed for the copper surfaces.

REFERENCES

[1] T. Kageyama *et al.*, KEK-PREPRINT-98-45.

[2] Y. Yamazaki and T. Kageyama, Part. Accel. **44** (1994) 107.

[3] SuperKEKB Task Force, KEK-REPORT-2004-4.

[4] H. Ino *et al.*, LINAC 2000, eConf **C000821** (2000) THE20.

[5] T. Abe *et al.*, PAC-2005-TPPT007.

[6] http://www.aps.anl.gov/epics/.

[7] J. Odagiri *et al.*, KEK-PREPRINT-2003-76.

[8] K. Kajima, *in Proceedings of the 110th meeting of the Surface Finishing Society of Japan*, p.46.

[9] K. Terada *et al.*, JVST A **7** (1989) 2397.