DEVELOPMENT OF L-BAND POSITRON CAPTURE ACCELERATING STRUCTURE WITH KANTHAL-COATED COLLINEAR LOAD FOR SUPERKEKB

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Abstract

In order to achieve a luminosity of $8x10^{35}$ $cm^{-2}s^{-1}$ in SuperKEKB, the injector is required to provide both e^+ and e^- beams higher in intensity by a factor 4-5 than those for KEKB with the emittance as low as 10-20 µm. A damping ring is used to realize this low emittance for e^+, but the intensity is increased by the higher yield from the conversion target to the damping ring. To this end, the L-band (1.298 GHz) capture system is adopted to increase the transverse and longitudinal acceptance. The capture section consists of a Tungsten conversion target with a flux concentrator followed by two L-band 2.4m-long accelerating structures with continuing to the large-aperture S-band accelerating structure sections. This L-band system is surrounded by solenoid magnets producing 4kG on axis. To adopt compact solenoids, the output coupler part of the L-band accelerating structure is replaced by the Kanthal-coated collinear load section which absorbs the transmitted RF power over the last 5 cells. In this paper, we discuss the design of the accelerating structures and the studies on Kanthal coated accelerator cell.

INTRODUCTION

The inner radius of the solenoids surrounding the L-band accelerator structures is much larger than the outer radius of the main body of the accelerating structure if the RF output waveguide exists. This results in a big cost increase and necessity of a huge infrastructure. Taking these points in mind, the L-band accelerating structure with a collinear load was adopted. To keep the higher capture efficiency, the distance between the two solenoids, one at the tail of an accelerating structure and the other at the head of the following one, should be small to suppress the dip of solenoid field between these [1]. The omission of the output waveguide can help reduce this dip. An L-band accelerating structure has been developed for BCS system from the damping ring [2] and we adopt this as a starting point of the present accelerating structure design. The actual power loss in the load section will be less than 1 kW.

Two kinds of SiC based loads, one the cylindrical cavities with SiC disk [3] and the other the duct-shaped SiC load [4], were considered in addition to the Kanthal(Al-Cr-Fe)-coated load. Both of the SiC loads have potential to damp the Q well, but we do not adopt them because both types suffer from a large temperature dependence of dielectric constant, which may introduce a difficulty in absorbing the RF power in SiC material. On the contrary, the Kanthal-coated collinear load does not have such a problem and actually there exists an example of L-band accelerator in 1965 [5]. LINAC II at DESY also uses the technique. Taking the above information into account, we decided to adopt this technique. Although some parameters, such as magnetic permeability and electrical resistivity were already measured at S-band [6], precise technical information, such as appropriate thickness of coating, has not been reported. Besides, the permeability of coated layer at 2.856 GHz decreases under the magnetic field parallel to the layer [7]. We also need the evaluation at our working frequency, 1.3 GHz. Thus, we studied RF properties of the Kanthal-coated layer by using a test cavity. In addition to the surface resistivity, the surface roughness and the internal structure affects the RF characteristics [7] depending on the coating process, in which melted Kanthal is sprayed on a surface. Many thermal spraying techniques developed for the past 30 years exist and we studied the mechanical and electrical properties to choose the best from those techniques. Based on this basic study, we propose a collinear load consisted of 4 to 5 reduced-Q cells.

DESIGN OF THE LOAD

In the traveling wave accelerating structure operated at $2\pi/3$ mode, the reduction of the transmitted power during the passage over a cell is given by

$$P_{tr} = P_{in} \exp\left(-2\frac{\pi c}{3v_g Q}\right) \quad (1),$$

where P_{in} is input power to the cell, c speed of light, v_g group velocity and Q the Q-factor of the cell. In case of the last part of our L-band accelerator structure, v_g/c is 0.00388 and Q=20650. From the view point of the positron beam transport in the accelerating structure, the tolerable reflection coefficient $\Gamma<0.1$ was intuitively assumed. To satisfy this requirement, 5 loaded cells are considered. If the Q-factors of the Kanthal-coated cells decrease by a factor of 30 as compared to that of the regular cell, a small enough $\Gamma\sim0.02$ at the head of collinear load section is obtained by using eq.(1). The actual Q reduction in a cell depends on the coated area and the surface resistance of the Kanthal layer $R_{s,\text{Kanthal}}$. The Q-factor of the coated cavity is given by

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$$Q_{Cu+Kanthal} = \frac{2\omega_0 U}{R_{s,Cu}\left(\int_{S_{Cu}} |H|^2 ds + \alpha \int_{S_{Kanthal}} |H|^2 ds\right)} \quad (2),$$

$$\alpha = R_{s,Kanthal} / R_{s,Cu} \quad (3),$$

where ω_0 is the angular resonant frequency, U the stored energy and $R_{s,Cu}$ the surface resistance of copper. Figure 1 shows the reduction factor of Q as a function of α for different coating pattern. Note that the effect of the reduction of surfaces resistance in the solenoid field is shown by dashed lines based on the reduction in the magnetic field described in the following section. One of the Q-profile designs is shown in Figure 2. It is found that $\alpha > 50$ is required to if coating patterns shown in Figure 1 are used.

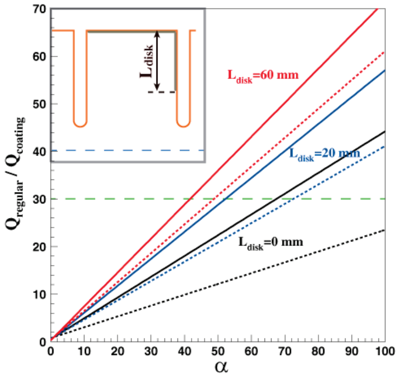

Figure 1: Q-reduction vs. surface resistance. The dashed lines correspond in case of the cell in a 0.4 T solenoid field.

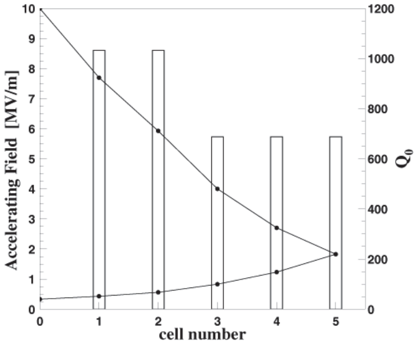

Figure 2: Accelerating field in the collinear load cells. Q-reduction factors of the first two and the last three cells are 20 and 30, respectively. The Γ at the end of regular cell is about 0.03.

SURFACE RESISTANCE

Measurement

In order to measure $R_{s,Kanthal}$ and the shift of the resonant frequency, a test cavity as shown in Figure 3 was used. The Kanthal layer is formed on the copper plate within a radius of 55 mm from the centre. The loaded Q-factor and resonant frequency of the cavity were measured with a network analyzer.

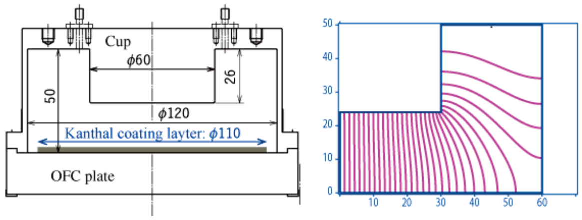

Figure 3: Schematic of the RF measurement. Left: Kanthal layer are coated on copper plate, Right: electric field calculated by SUPERFISH for the measurement at 1.3 GHz.

The surface resistance of the Kanthal coating can be given by using the ratio of Q-factor with and without coating, Q_{Cu} and $Q_{Cu+Kanthal}$. We get from eq. (2)

$$\alpha = \frac{1}{B}\left\{\frac{Q_{Cu}}{Q_{Cu+Kanthal}}(A+B) - A\right\},$$

$$A = \int_{Cu} |H|^2 ds,$$

$$B = \int_{Kanthal} |H|^2 ds.$$

The measured surface resistances are listed in table 1, where the coefficients A and B were obtained with the code SUPERFISH [8]. Here, APS and VPS stand for atmospheric plasma spray and vacuum one, respectively, and HVOF represents high velocity oxygen fuel spray. The APS with NiAl undercoat was used in DESY S-band collinear load but we did not apply it, meaning that we directly coat Kanthal on copper.

Table 1: Measured RF surface resistance, at 1.3 GHz, of Kanthal layer coated by various spraying techniques.

Techniques	**Size [μm]**	**θ_{spray}[deg.]**	**α**
APS with NiAl bonding	53-104	90	55
Wire arc spraying	-	90	60
APS	53-104	90	77
APS	53-104	45	87
VPS	53-104	90	66
HVOF	53-104	90	116
HVOF	20-52	90	61

To make a compact load section and to decrease the coating area, a high RF surface resistance is preferable. The HVOF with bigger particle size showed the highest surface resistance, but in this condition the HVOF could not form the Kanthal layer for the off-normal spray angle. Since the spray injection angle of ~45 degree is required to coat on the accelerating cells, this spray method should be given up. Thus we finally adopted the APS. The surface resistance of the Kanthal layer by using APS is about 80 times higher than that of copper.

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We tried to study the thickness dependence of $R_{s,\mathrm{Kanthal}}$. The measurement of the layer thickness strongly depends on the surface roughness, which is affected by spraying condition. Therefore, the thickness is not simply proportional to the mass per unit area. However, we adopted the mass per unit area as an index representing the thickness, because it is most robust to control the parameters. Thicknesses measured by using micro meter were 180 and 130 μm, in case of 53 mg/cm^2 with normal spray angle and 28 mg/cm^2 with 45 degree spray angle, respectively. The $R_{s,\mathrm{Kanthal}}$ versus weight per unit area is shown in Figure 4. Above 25 mg/cm^2, which corresponds to the thickness of 100 μm, $R_{s,\mathrm{Kanthal}}$ becomes almost constant. This means the effective skin depth is several tens micro meter in this case. If the effective skin depth is described by the exponential decay of the field, $R_{s,\mathrm{Kanthal}}$ is proportional to $(1-\exp(-2d/\lambda))$, where d is the thickness of the layer and λ the effective skin depth. The fit to this functional form is good as shown in Figure 4.

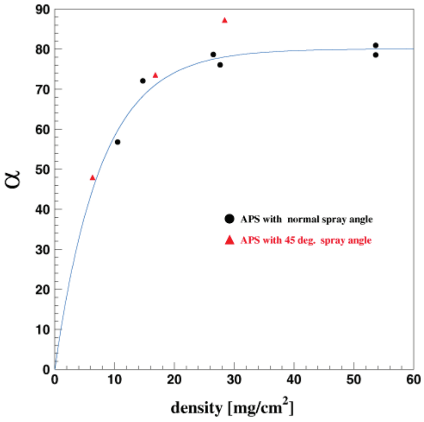

Figure 4: Surface resistance as a function of mass per unit area.

Reduction in Magnetic Field

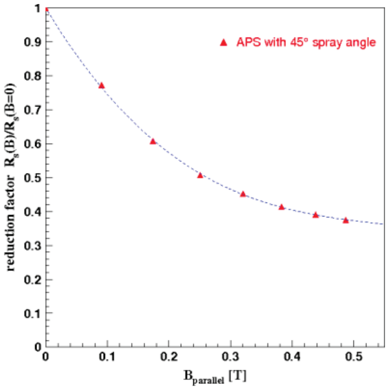

Figure 5: Reduction of surface resistance vs. magnetic field parallel to the coated layer.

It was pointed out that the surface resistance reduces linearly as the magnetic field is applied parallel to the coated layer [7]. The variation of $R_{s,\mathrm{Kanthal}}$ under a magnetic field was measured up to 0.45 T. The surface resistance was almost constant if the magnetic field is normal to the coated layer. To study the parallel case, Kanthal was coated on the inner surface of the cylinder shown in Figure 3. Note that this direction is the same for the application of the coating in the inner wall of the accelerating cell. The measured reduction of $R_{s,\mathrm{Kanthal}}$ in the magnetic field is shown in Figure 6. We found that the reduction of the $R_{s,\mathrm{Kanthal}}$ on the cylinder of the cell in the actual solenoid field is 38% at 0.5T.

OTHER PROPERTIES

The measurements of outgassing rate from the coated layer have been performed. The rate as coated is at most about 10 times higher than that of type 304 stainless ($2.0\mathrm{x}10^{-7}$ Pa m/s).

The tensile strength of the Kanthal layer coated by various thermal spraying techniques was measured. Except for the layer coated by wire arc spray, the tensile strengths of coatings are higher than 70 MPa, which corresponds to the strength of bonding glue for making test sample.

SUMMARY AND PROSPECT

We proposed a Kanthal-coated collinear load, consisting of 5 cells, for the L-band accelerating structure for SuperKEKB. We studied the electrical, mechanical and outgassing properties of the Kanthal layer. The coating can provide with surface resistance large enough to apply to the L-band structure even taking into account the reduction in the solenoid field. We are finalizing the load section including electrical optimization of each cell and mechanical design of the structure based on collinear load.

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