MEASUREMENT FOR THE KANTHAL ALLOY USED FOR COLLINEAR LOAD AND THE S-BAND LOAD DESIGN *

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Abstract

We have developed the method to determine the permeability and the electrical conductivity of the Kanthal alloy available. The alloy is coated inside the walls of disk-loaded cavities, which is used for the collinear load. The collinear load absorbs the remaining RF power over the last cells of the section while still accelerating the beam. Based on the experimental results of permeability and the calculated value of the conductivity, the computation study of the collinear load has been made by Microwave Studio. The attenuation in the collinear load is 16.02dB.

INTRODUCTION

There are many advantages in the collinear load as compared with a standard output coupler [1]. The collinear load is symmetric, which avoids transverse excitation of the beam. It does not contribute to the growth of the emittance. The Kanthal alloy which is coated inside the load is magnetic and high-resistance material. Its outgassing rate meets the ultra-high vacuum requirement. It can be used for the absorbing material. Using metal foams technique, the resistivity of Kanthal may be increased highly.

In general, the collinear load development is made by experimental methods under the conduction of not knowing accurately the used alloy property. In this paper, the permeability of Kanthal alloy is investigated by coaxial resonance cavity method. The calculation of the electrical resistivity of metal foams alloy is given. The collinear load design at S-band is also shown.

THEORY

The cross-section of the coaxial line is shown in figure1. The inductance per unit length of coaxial transmission line can be given by [2]

$$L = \frac{\mu}{\left|I_0\right|^2} \int_S \left|\overrightarrow{H}\right|^2 ds \qquad (1)$$

Here μ is the magnetic permeability, I_0 is the electric current, S is the cross-section area, H is the magnetic field.

After integral we can get

$$L = \frac{\mu_0}{2\pi}\ln(b/a) + \frac{1}{4\pi}\sqrt{\frac{\rho_2\mu_2}{\pi f a^2}}\left[\sqrt{\frac{\rho_1\mu_1 a^2}{\rho_2\mu_2 b^2}} + 1\right] \qquad (2)$$

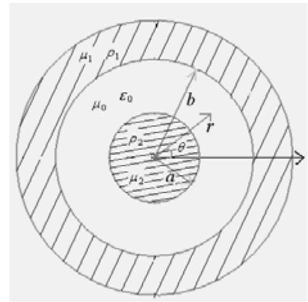

Figure 1: The cross-section of the coaxial line.

Here a is the inner wire radius, b is the outer pipe radius, μ_0 is the permeability of the air between the conductors, f is the operation frequency, ρ_1, μ_1 are the electrical resistivity and magnetic permeability of the outer tube, and ρ_2, μ_2 are the corresponding quantities for the central wire. If the central conductor is the Kanthal alloy wire, $\sqrt{\frac{\rho_1\mu_1 a^2}{\rho_2\mu_2 b^2}}$ may be neglected.

$$L = \frac{\mu_0}{2\pi}\ln(b/a) + \frac{1}{4\pi}\sqrt{\frac{\rho_2\mu_2}{\pi f a^2}} \qquad (3)$$

The capacitance of the cable per unit length is $C = \frac{2\pi\varepsilon_0}{\ln b/a}$ .so

$$LC = \mu_0\varepsilon_0 + \frac{\varepsilon_0}{2\ln(b/a)}\sqrt{\frac{\rho_2\mu_2}{\pi f a^2}} \qquad (4)$$

As we know that $v_p = 1/(LC)^{1/2}$ and $c = \sqrt{1/(\mu_0\varepsilon_0)}$ are the velocity of propagation in free space and along the cable system respectively. There are the equations of $v_p = \lambda_g f$ and $c = \lambda_0 f$. Introducing the symbols $d_0 \equiv \lambda_0/2$ and $d \equiv \lambda_g/2$ for the half-wavelengths in free space and along the cable, the inner relative permeability may be written

$$\mu_2' = 240\pi^2 \frac{a^2}{\rho_2}\left(\ln\frac{b}{a}\right)^2 \frac{\left(d_0 - d\right)^2}{d_0 d^4} \qquad (5)$$

μ_2' can be deduced from a , b , d , d_0, ρ_2.

RESULTS

First of all we should get the electrical resistivity of the Kanthal alloy.

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Calculation of Electrical Resistivity of the Kanthal Alloy

According to the equation $\rho = R\frac{S}{l}$, if we know R, S, l, we can deduce the electrical resistivity of the wire. Through measurement we get the resistance $R = 1.5\Omega$, the length $l = 2m$, the diameter $\overline{\Phi} = 1.55916mm$, so we get $\rho = 1.432\mu\Omega \bullet m$.

The quality factor is defined as 2π times the relation of the total energy W to the total loss P over one period T:

$$Q = \frac{2\pi}{T}\frac{W}{P} = 4\pi W\sqrt{\frac{f}{\pi\mu\rho}}\oint\left|H\right|^2 ds \propto \sqrt{\frac{1}{\mu\rho}} \qquad (6)$$

In order to reduce Q value, ρ should be large.

In recent years metal foams have rapidly developed. The characteristic of metal foams is very high porosity. The porosity of metal foams can be made above 97% [3]. There is an equation between the resistivity of the metal foams and the porosity [4].

$$\rho = \left[1 - 0.121\bullet(1-\theta)^{\frac{1}{2}}\right]\bullet\frac{3}{1-\theta}\bullet\rho_0 \qquad (7)$$

Here ρ is the resistivity of the porous metal, ρ_0 is the resistivity of compact metal, θ is the porosity of metal foams. When θ is 97%, ρ_0 is $1.432\mu\Omega \bullet m$, then ρ is $\rho = 140.2\mu\Omega \bullet m$.

Measurement of d_0 and d

The measurement system of permeability that is shown in figure 2 is a coaxial resonating cavity with a movable shorting piston. Two similar cable systems were used, in one of which the central conductor is a nonmagnetic wire (copper). In the other cable the central conductor is the Kanthal alloy wire. Between the conductors the media is the air.

Figure 2: The measurement system of the permeability.

The operation frequency is 2.856GHz, so the half wavelength is $d_0 = 52.484mm$.

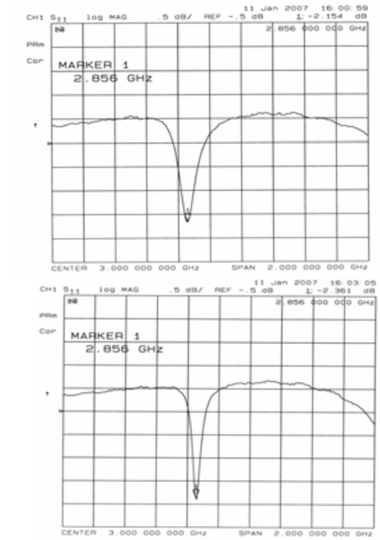

Figure 3: Resonance curves of nonmagnetic copper coaxial cable.

When the material of central wire is copper, moving the shorting piston, we can get the resonance curves in figure 3 and get the measured value $d_0' = 52.30$ mm, the percentage error is $\frac{52.484 - 52.30}{52.484} \times 100\% = 0.35\%$. This means the measurement system is perfect. In order to reduce random error, we repeated measurement five times. When the material of the central wire is Kanthal alloy, we get the resonance curves in figure 4 and the measured average value $\overline{d} = 51.10mm$.

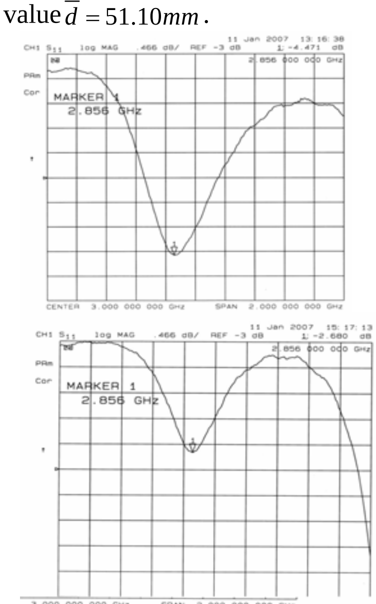

Figure 4: Resonance curves of cable with alloy central wire.

Result of μ_2'

Using equation (5) and these parameters:

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$\rho = 140.2\mu\Omega \bullet m$, $d_0 = 52.30mm$, $a = 0.035mm$, $b = 8mm$, $d = 51.10mm$, we can get $\mu' = 3.696$.

COLLINEAR LOAD DESIGN

There are two methods in design the collinear load: constant Q-value collinear load and constant power-loss collinear load. We combine these two merits and design a collinear load of three cavities of constant power-loss and one cavity that is the same as the third in Q-value. The attenuation of the front three cavities is 10 dB.

In a travelling wave accelerating structure, the power flow P_z can be written as

$$P_z = P_0 e^{-2\alpha z} \tag{8}$$

Here P_0 is the remnant RF power of the accelerator section, α is the attenuation coefficient. The attenuation A can be written as

$$A = 10\lg\frac{P_0}{P_z} \tag{9}$$

The power-dissipation in each cell ΔP_i can be expressed by

$$\Delta P_i = \frac{\Delta P}{n} = \frac{P_0}{n}\left(1 - 10^{-A/10}\right) \quad (i = 1, 2, 3) \tag{10}$$

Here ΔP is the total power-dissipation of the front three cavities. The Q-value of each cell can be expressed as [5]

$$Q_i = \frac{2\pi f}{2\alpha_i \beta_g c} \quad (i = 1, 2, 3) \tag{11}$$

Here $\beta_g = 0.01095$ is the group velocity, $f = 2.856GHz$ is the operation frequency, c is the velocity of light, $z_i = 34.975mm$ is the length of each cell. The results of A_i and Q_i are shown in table 1.

Table 1: RF parameters of each cell in the collinear load

No.	Q_i	A_i/dB
1	536.3	1.55
2	341.8	2.43
3	138.0	6.02
4	138.0	6.02

Therefore, the attenuation in the collinear load is 16.02dB. On the assumption that the terminal of the load is total reflection, the voltage reflection coefficient of the input end of the load Γ is given by $\Gamma = \sqrt{P_-/P_+} = 10^{-A/10}$. The attenuation from the input coupler to absorb load is about 5 dB, then the Voltage Standing Wave Ratio (VSWR) in the input coupler is about 1.0153 which is satisfy the requirement of power matching. The main parameters of the collinear load f, Q_i and β_g can be determined by computer simulation design with MWS. These parameters in table 1 can be achieved. The sketch of the collinear load is shown in figure 5.

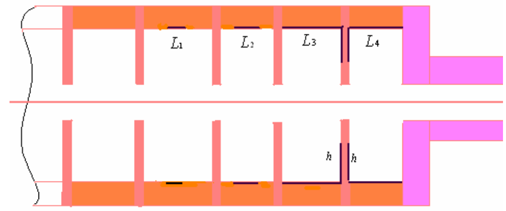

Figure 5: the diagram of the collinear load

The collinear load not only absorbs the remaining RF power but also accelerates the beam. When an electron accelerated at the crest of the travelling wave, the corresponding energy gain is expressed respectively for the constant Q-value collinear load and the constant power-loss collinear load.

$$\begin{aligned} \Delta u_1 &= \frac{E_0 L}{\tau_1}\left(1 - e^{-\tau_1}\right), \\ \Delta u_2 &= \frac{E_0 L}{1 - e^{-2\tau_2}} \frac{2}{3}\left(1 - e^{-3\tau_2}\right) \end{aligned} \tag{12}$$

Here $\tau = \alpha L$ is the attenuation constant, $E_0 L$ is the energy gain of the usual disk-loaded cavities. Using above data, we get $\Delta u_1 = 0.7215 E_0 L_{\rm I}$ ($L_{\rm I} = 34.975mm$), $\Delta u_2 = 0.7173 E_0 L_{\rm II}$ ($L_{\rm II} = 104.925mm$).

SUMMARY

In general, based on these parameters of the Kanthal alloy: $\mu' = 36.696$, $\rho = 140.2\mu\Omega \bullet m$, We designed S-band collinear load in theory. The experimental arrangement will be progressed.

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