HIGH POWER COLLINEAR LOAD COATED WITH FeSiAl*

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Abstract

Aimed at substituting output coupler to absorb remnant power of the LINAC, collinear load coated with high loss materials is expected to come to reality. FeSiAl load is studied. The effect of the coating volume upon the cavity frequency and *Q* factor is analyzed and the dimension compensations of the cavities are suggested to tune the load cavities at 2856 MHz. Orthogonal Experimental Method is utilized to investigate the sensitivity of permittivity (both real part and imaginary part) and permeability (both real part and imaginary part) to cavity characteristics. Some cavities coated FeSiAl are designed and manufactured. Their *Q* factor agrees very well with the theoretical value. Simulation shows the FeSiAl load can support average power over 15 kW and the one-way attenuation is about 30 dB.

INTRODUCTION

The coaxial load replacing waveguide type absorption load can make the accelerator structure more compact, furthermore, to realize the accelerator miniaturization. Therefore, the ongoing efforts have done. K. Jin experimentally developed constant power-loss collinear load for a X-band low power LINAC [1]. X. D. He simulated design for S-band collinear load [2,3] and contributed to the measurement of electrical conductivity and permeability of Kanthal alloy. Y. Sun and Z. Shu considered it a cross-discipline subject and tried to combine accelerator physics, microwave technology, heat transfer and mechanics to find out an optimization countermeasure. They have had a detailed study of the layout of the Kanthal coating and the structure of the collinear load. They aimed at minimum frequency drift of the cavities, developed some effective methods to increase the absorbing capability of the collinear load [4,5].

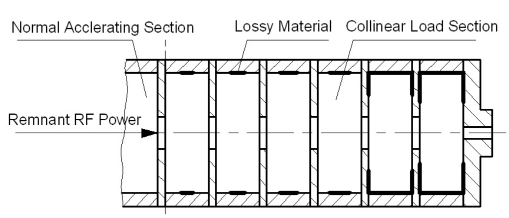

Figure 1: Collinear load section with Kanthal coating.

However, unfortunately their simulation and tests show that kanthal coating is hardly to absorb higher power more than 10kW, as its characters of skin effect. There is no enough area on the wall of the collinear load cavities to absorb more power.

FeSiAl (74%Fe-4%Si-22%Al) is a kind of dielectric microwave absorbing material. Its dielectric constant and permeability at 2856 MHz is ε=13.23-0.15i and μ=1.77-1.44i individually. Differing from Kanthal, its coating volume effects the absorbing capability directly. By means of CST Microwave Studio， FeSiAl coated collinear load is studied systematically.

SELECTION OF COATING ALLOCATION

Simulation Precision and Convergence

In order to guarantee the correctness of the simulation, the calculation precision of work frequency of the cavities must be controlled within a few kHz. The condition of the simulation precision and convergence are explored carefully. Discrete mesh dimension effects on the simulation accuracy seriously. Figure 2 shows the relationship. Accordingly， a mesh density of a single cavity should be controlled in 60~70 /λ. The number of the volume elements is adopted as 760 thousand in our model.

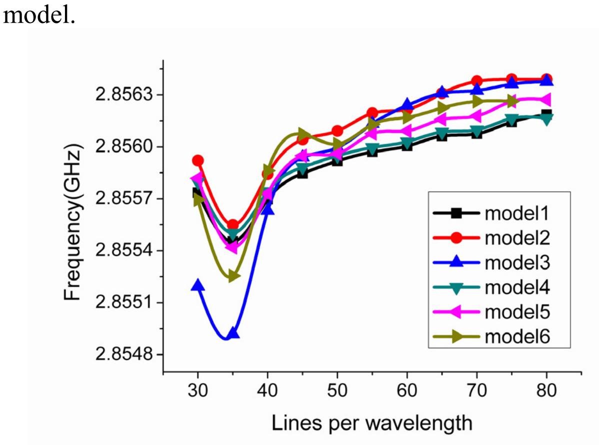

Figure 2: Operation frequency of FeSiAl load cavity changes with mesh density of the numerical analysis model.

Determination of Geometric Features and Location of Coating

The influences of coating allocation, geometric size and electromagnetic parameters of the coating on the working frequency f and quality factor Q of the cavities are investigated.

Allocation of the Coating

FeSiAl is a magnetic loss material. The magnetic loss is dominant and electric loss almost can be negligible. Calculation shows the strongest loss is located on the inner periphery wall of the cavities and on the rim of the

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disks. Therefore, if we want to ensure the coating a high absorptivity, the FeSiAl material must be coated at the position where magnetic field intensity is high. A strategy is drawn up to coat FeSiAl on the circumference wall of the cavity ring first, and then cover the material on the outside of disks if it is necessary to absorb excess power. Fortunately, simulation shows that just coating FeSiAl on the cavity inner circumstance wall of the cavities of load section is enough to absorb all 15kW and satisfy the requirements of the attenuation coefficient of cavities. The result shows in Figure 3, which is quite different from the situation of Kanthal in Figure 1, especially in the last several cavities.

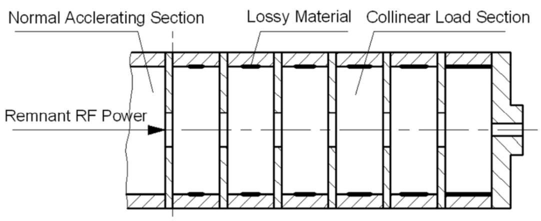

Figure 3: Allocation of FeSiAl coating in the cavities.

The result brings a very good prospect for the design of the cooling system round the accelerating tube, which is used for transfer the heat turned from the absorbed remnant power easier.

INFLUENCE OF COATING VOLUME ON THE RESONANCE FREQUENCY F AND QUALITY FACTOR Q

Embeding absorbing material would cause a small disturbance to the electromagnetic field patterns in the cavity and its resonant frequency. Meanwhile, the loss characteristics of every cavity will also be changed significantly, as shown in Figure 4.

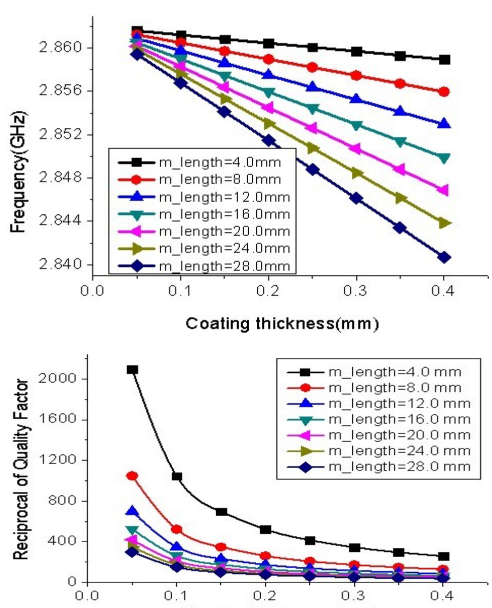

Figure 4: Coating volume effects on the f and Q.

Investigating the Sensitivity of Permittivity and Permeability to f and Q

Electromagnetic parameters of the microwave absorbing materials also act a significant role on the characteristics of the collinear load. Understanding the rule of influence and its working environment and condition is important to improve performance of the collinear load. The orthogonal experimental method is employed in simulation. Investigating focuses on the sensitivity of the electromagnetic parameters (real part and imaginary part respectively) to the work frequency f and quality factor Q (see Table 1).

Table 1: Orthogonal Experimental Table of $L_9(3^4)$

No.	ε'	ε''	u'	u''	f-2856 (MHz)	Q-factor
1	13.23	0.30	1.42	1.69	2.764	108.5
2	13.23	0.20	2.12	1.41	-2.697	129.8
3	13.23	0.25	1.77	1.13	0.029	162.1
4	10.58	0.30	2.12	1.13	-2.694	162.0
5	10.58	0.20	1.77	1.69	0.037	108.5
6	10.58	0.25	1.42	1.41	2.761	130.2
7	15.88	0.30	1.77	1.41	0.029	129.8
8	15.88	0.20	1.42	1.13	2.755	162.3
9	15.88	0.25	2.12	1.69	-2.697	108.2

Here, the electromagnetic parameter of FeSiAl coating ε=13.23-0.25i and μ=1.77-1.41i. Geometric dimensions of cavity are inner radius =40.972 mm; Width of coating =16 mm and its thickness=0.15 mm.

The calculation results show that the real part of magnetic permeability of FeSiAl coating acts on the frequency of cavity most sensitively. The influences of other parameters are weak. The sequence is *u' > e'> u'' > e''* from strong to weak. For Q the strongest influencing factor is imaginary part of magnetic permeability of FeSiAl and the sequence is *u'' > u' > e' > e''* from strong to weak. From the results we can deduce that FeSiAl material is a kind of absorbing materials which is dominated by magnetic loss.

PROTOTYPING COLLINEAR LOAD CAVITIES WITH FeSiAl COATING

FeSiAl material is consolidated on the inner wall of the cavities by special sintering process. In order to strengthen the binding force, roughening the surface is necessary. Some triangle grooves are turned out and the volume of coating can be accurately calculated.

Geometric Changes before and after Coating

Five prototyping cavities coated FeSiAl material are manufactured and tested. After coating, their dimension changed from before coating, as seen in Figure 5.

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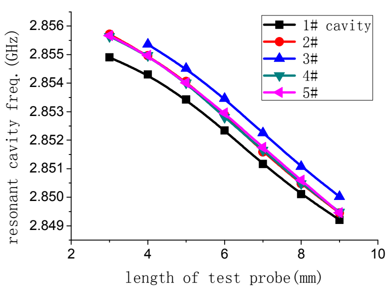
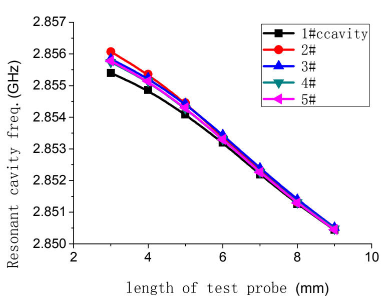
Figure 5: Five FeSiAl collinear load cavities ring.

Frequency f and Quality Factor Q of Experimentally Tested and Simulation Analysed

The maximum error between simulation and experiment is only about 0.03%. The measured frequency is lower than 2856 MHz. Comparing Fig. 6(a) and 6(b), the minimum deviation is 122.8 kHz and the maximum deviation is 854.7 kHz.



(a) Tested resonant frequency of cavities



(b) Simulated resonant frequency of cavities

Figure 6: Frequencies by simulation and test.

Error Analysis

Possible factors caused errors are as follows:

- The air permittivity (1.0006 ➔ -856.2 kHz).
- Inner radius *b* increment by thermal spraying method (5 μm ➔ -360 kHz).
- The actual coating thichness is not enough (average of about 60 μm, not 100μm ➔ +786 kHz).
- Slight oxidization of the oxygen-free copper surfaces makes the frequency drop.

COLLINEAR LOAD ABSORBING 15kW REMNANT POWER

The design of six cavities collinear load for absorbing 15kW remnant power and -30dB attenuation coefficient α is performed. The design cycle is as in Figure 7.

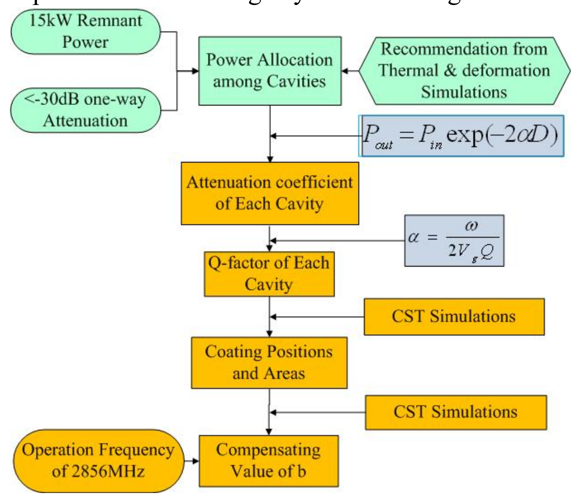


Figure 7: Design cycle of collinear load.

Usually, location scheme based on average power is better than the other method which is based on equal attenuation. But thermal analysis alarms that the thermal deformation of cavities is not uniform under the condition of every cavity absorbing same power. A recursive formula is developed to predict and optimize the power allocation program, then to design varies cooling system and find out an optimal solution. And then, calculate the cavity Q and the attenuation coefficient α value. Furthermore, determine the volume of the coating (length times thickness). Finally, radius b of cavity is defined.

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