KANTHAL ALLOY BASED S-BAND COLLINEAR LOAD R&D FOR LINEAR ACCELERATORS*

Y. Sun, L.G. Shen#, Z. Shu, X.C. Wang, PMPI, USTC, Hefei, China
Y.J. Pei, NSRL, USTC, Hefei, China

Abstract

Collinear load is a substitute for waveguide load to miniaturize irradiation accelerators and make the system compact. The key technology is to design coaxial cavities coated inside with attenuating materials which will terminate the remnant power, meanwhile the operation frequency of 2856 MHz retains. For lossy materials such as Kanthal (25%Cr-5%Al-Fe) alloy, CST is used to simulate the effect of the coating on the load cavity properties like the operation frequency and attenuation. The frequency shifts caused by the coatings would be compensated by the strategy of cavity dimensions adjustment. Simulations revealed the compensation rules of the cavity inner radius *b*. Meanwhile the relationship between the attenuation and the coating area was also resolved. Based on a specified power allocation, a 15 kW collinear load consisting of six cavities at 2π/3 mode was designed with one-way attenuation of -18.8 dB. Two sets of prototype cavities have been manufactured and the experiment results are presented, compared with the CST simulations.

INTRODUCTION

Miniaturization and nice mobility are notably demanded for wider applications of civil LINAC, while common coupler structure of the waveguide load has turned into a bottleneck. Collinear load is advanced to deal with the problem. S-band disk-loaded collinear load is schematic as shown in Fig. 1. Several load cavities with efficient microwave-lossy material coated on the inner walls are extended coaxially at the termination of normal accelerator section. The arrived remnant power is absorbed by the material coatings, transformed into heat and then taken away by cooling water outside the tube. The collinear load was firstly proposed by J. Haimson [1]. He presented basic theory analysis as well as preliminary experiments, where Kanthal (Fe-Cr-Al) alloy was employed as the attenuating material. K. Jin developed "constant power-loss collinear load" for a X-band 1.6 MeV low power LINAC [2,3]. X. D. He measured electrical conductivity and permeability of Kanthal alloy by coaxial resonant cavity method and had a try on simulation design of S-band collinear load [4]. Previous researches about collinear load were conducted to lower power level and mainly based on experimental development. As the remnant power of irradiation accelerators increases to an average of 10~20 kW, systematical simulation analysis and design is necessary. In this paper, CST is utilized to analyze the load cavities and tests of prototype cavities have been performed. The Kanthal (Cr-25% wt.% Al-5% wt.% Fe) alloy used here has the electrical conductivity of σ = 8978.27 S/m and the permeability of μ = 2.58 [5]. The skin depth $\delta = \sqrt{2/\omega u \sigma}$ is 61.9 μm, where ω is the circular frequency of 2856 MHz. Considering the thermal spraying process, the thickness of the Kanthal coating is specified as 0.1 mm.

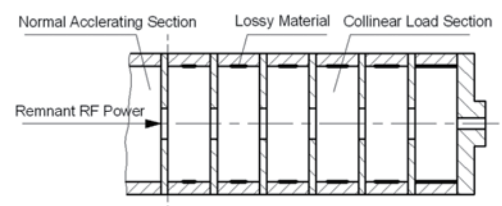


Figure 1: Schematic diagram of the collinear load.

SIMULATION ANALYSIS OF THE LOAD CAVITIES

The structure of a resonant cavity as shown in Fig. 2 is taken advantage of to study properties of the load cavities. Two cavities and two half cavities are assembled with three disks separating them and two shorting plates at the head and end faces. One of the shorting plates has a small thru hole centrally and a coaxial probe, which is connected to a VNA (Vector Network Analyzer), is inserted through it to feed the resonant cavity. By analyzing the electrical field pattern four modes of 0, π/3, 2π/3, π should be excited in the structure. Moreover the field pattern of the third mode is identical with that in the travelling wave accelerator tube which operates at the 2π/3 mode. To make the generated heat transfer to the outer cooling pipe easier, the Kanthal alloy is coated on the inner cavity walls rather than on the disk surfaces. Only when the coating could not supply sufficient attenuation, additional Kanthal alloy on the disk surfaces will be needed and it should be increased from the outer to the inner. The load cavity model as well as the coating dimensions of *m_l* and *m_r* is displayed in Fig. 3.

*Work supported by the NSFC (No. 10775128) and Innovation Funding for Graduates of USTC'09
#lgshen@ustc.edu.cn

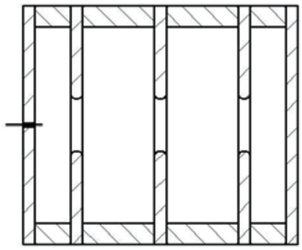


Figure 2: A resonant cavity for the 2π/3 mode simulation.

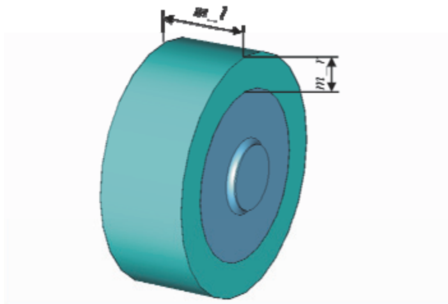


Figure 3: Dimensions of the Kanthal coatings.

There are two significant properties about a load cavity: the operation frequency at a specific mode and the corresponding attenuation coefficient, which is related to the quality factor. In order to ensure the cavity operating at 2856 MHz, the inner radius b of the cavity will be adjusted. Therefore it is necessary to analyze the relationship between the b and the coating area. The simulation results are presented in Fig. 4. The left eight points correspond to the circumferential coatings inside the cavity and the others represent the coatings on the disk surfaces with the cavity circumference fully filled. It can be seen that for compensating the frequency shifts, the b should increase linearly to the area of circumferential coating with a ratio of 3.97e-2 μm/mm^2, besides it should vary parabolically as the area of the longitudinal coating on the disks increases, with an inflexion, which corresponds to the location of about 29 mm away from the cavity axis.

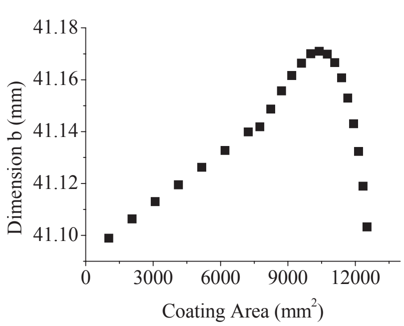


Figure 4: Dimension b vs coating area at 2856 MHz.

The quality factors of the load cavities could also be solved at 2856 MHz with the specific b values. Supposing the group velocity Vg constant, the attenuation coefficient

$$\alpha = \frac{\omega}{2V_g Q} \tag{1}$$

is inversely proportional to the quality factor. Hence the calculation results are recorded as the reciprocals of quality factors in Fig. 5. It can be concluded that the attenuation of a load cavity increases approximately linearly to the areas of both circumferential and longitudinal coatings, but with different ratios.

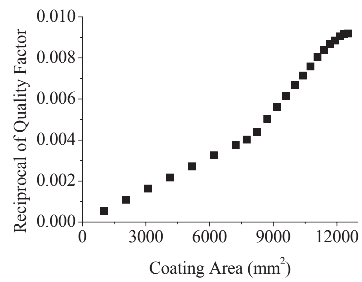


Figure 5: Reciprocal of Q vs coating area at 2856 MHz.

DESIGN OF THE COLLINEAR LOAD

A collinear load for 15 kW remnant power would be designed, with the total one-way attenuation above -15 dB. The collinear load consisted of six load cavities, which was two periods at the 2π/3 mode. From a specific power allocation among the cavities, the attenuation coefficient α could be calculated from

$$P_{out} = P_{in} \exp(-2\alpha D) \tag{2}$$

where P_{in} is the power into a cavity, P_{out} is the power out of a cavity and D is the cavity length. Then the Q-factor of each cavity would be solved through Eq. 1. Based on the data on Fig. 5, the parameters of the needed coating were determined. Correspondingly the compensating b values were derived from Fig. 4 to ensure the operation frequency.

At first, we tried to design the load cavities based on the principle of uniform power absorption. But the attempt failed, because the last cavity with its limited attenuation could not dissipate the residual power of 2.5 kW to the level of -15 dB. To guarantee sufficient attenuation, the power undertaken by the latter cavities should be migrated partly to the preceding ones. Considering both the recommendation from I-DEAS thermal simulation and the coating attenuation, a plan of 2.985 kW, 2.985 kW, 2.985 kW, 2.76 kW, 2.295 kW and 0.750 kW orderly for each cavity was proposed. The final parameters of the collinear load were listed in Table 1, as well as the actual power loss of each cavity. The copper losses were also considered. The final one-way attenuation achieved -18.8 dB.

Table 1: Cavity Parameters of A 15 kW Collinear Load

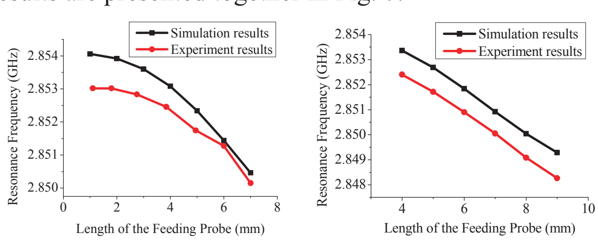
Cavity No.	*b* (mm)	*m_l* (mm)	*m_r* (mm)	Coating Losses (kW)	Copper Losses (kW)
1#	41.116	9.4	0	3.033	0.146
2#	41.119	11.8	0	2.907	0.108
3#	41.128	16.9	0	2.929	0.069
4#	41.144	26.4	0	2.681	0.034
5#	41.172	29.99	8.1	2.069	0.008
6#	41.134	29.99	24	0.818	-

EXPERIMENTS OF THE LOAD CAVITIES

According to previous load cavities analysis, two sets of load cavities were manufactured and then thermal sprayed with the Kanthal alloy, partially as shown in Fig. 6.

Figure 6: Cavities and disks with Kanthal coatings.

One set of cavities were designed with the circumferential coatings of *m_l* = 16.6 mm and without longitudinal coatings on the disks; the other set was designed with both the circumferential coatings of *m_l* = 16.6 mm and the longitudinal coatings of *m_r* = 24.0 mm. Subsequent measurement reveals that the thermal spraying process makes the cavity dimension *b* augment by about 5 µm, on the other hand the thicknesses of the coatings are measured as around 60 µm, much thinner than the designed value of 0.1 mm, therefore the resonance frequency would be lower than 2856 MHz. Models with the measured cavity and coating dimensions were created in CST and the simulations were performed, with different lengths of the feeding coaxial probe. The test results of the resonant cavity as well as the simulation results are presented together in Fig. 7.



(a) (b)

Figure 7: Resonance frequency vs probe length. (a) cavity set I; (b) cavity set II.

The data demonstrate that the measured frequencies are lower than that out of simulations, with average deviations of about 630 kHz for the first set and 880 kHz for the second set. The errors may be caused by the succeeding factors. Firstly, the simulation modeling of the Kanthal coating in CST is different from the actual coating because of its porous and faulty appearance, thinner coatings would lead to distinct decline of the frequency. Secondly, the air dielectric constants of 1.000589 with temperature of 20 ℃, humidity of 34 % and 1.0006 with temperature of 20 ℃, humidity of 44 % in the simulations may be different from the actual values in the experiments (variation of ± 0.0001 will lead to frequency deviation of about ∓ 143 kHz around 2853 MHz). Thirdly, the frequency is rather sensitive to the length of the probe, such as about -830 kHz/mm for the second set cavities, hence the errors of the probe valuing will affect the results seriously. At last, the oxidization of the oxygen-free copper surfaces will also result in frequency dropping.

SUMMARY AND CONCLUSION

In order to develop high power collinear load for irradiation LINAC, CST simulation is utilized for the analysis of Kanthal load cavities with the help of a resonant cavity structure. A strategy of changing the cavity inner radius *b* is proposed to compensate the frequency shift caused by the coating and the rule of the adjustment is discovered. Meanwhile the effect of the coating area and position on the cavity attenuation is analyzed by solving the *Q*-factor. On the basis of a scheduled power allocation, a collinear load for 15 kW remnant power was obtained, with the one-way attenuation of -18.8 dB. The actual power distribution as well as the copper losses was calculated afterwards. Finally, two sets of cavities, one with and the other without the disk coating, were fabricated and tested. The experiment results of the resonance frequency were compared with CST simulations and the frequency errors investigation has been carried out.

REFERENCES

[1] J. Haimson, Nucl. Instr. and Meth. 33 (1965) 93.
[2] K. Jin, Y.J. Pei, D.M. Jiang, Y.Z. Liu, Nucl. Instr. and Meth. A. 488 (2002) 473.
[3] K. Jin, Y.J. Pei, D.M. Jiang, et al. "X-Band Travelling Wave Accelerator Structure R&D", PAC'01, Chicago, September 2001, p. 4089 (2001).
[4] X.D. He, C.F. Wu, S. Dong, et al. "Measurement For the Kanthal Alloy Used for Collinear Load and the S-Band Design", PAC'07, Albuquerque, June 2007, p. 2146 (2007).
[5] X.D. He, "X-Band Hybrid Dielectric-iris-loaded Accelerator Investigations", Ph.D. Dissertation (in Chinese), 2009.