DESIGN OF A 4-CAVITIES COLLINEAR LOAD COATED WITH FeSiAl ALLOY FOR 14MeV LINAC*

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Abstract

Collinear load is a substitute for waveguide load to miniaturize linear accelerator and make the beam quality better. Coating with a kind of high efficient microwave-absorbing material FeSiAl alloy, a collinear load section composed of 4 cavities (at 2 /3 mode) with different coating dimensions is designed to absorb 4kW remnant power. Cavity dimensions are adjusted to compensate the frequency shift from 2856 MHz respectively. Simulation shows the loss material FeSiAl only need to be coated on the inner surface of the ring. This makes the design and construction of the cooling system for the load segment easier. Coming with a specific water cooling system can makes the working frequency of the accelerator and the collinear load more close to the supposed. Eventually, based on optimized uniform power absorption principle concluded from the simulation of temperature field, a four-cavity collinear load is designed with one-way attenuation of 76.1 dB, while the largest shift from operation frequency is 35 kHz.

INTRODUCTION

Nowadays, electron linear accelerators are more and more employed in industry, agriculture, medical care, food security and so on. While the miniaturization and mobility of LINAC is expected to advance all these application. Replacing the waveguide type absorption load, collinear load coated with high loss materials, like FeSiAl and Kanthal, in its inner walls is found to be a good way to make it a reality. It can not only ensure the security of the accelerator, but also make the accelerating structure more compact. Collinear load was firstly proposed by J.Haimson [1]. Since then, the basic theory has been improving and different significant results have been produced. Kai Jin developed "constant power-loss collinear load" for an X-band 1.6 MeV low power linear accelerator [2]. Also, Yuan Sun summarized the relationship between Q-factor and parameter of the cavity and the researches were conducted to the high power collinear load of S-band linear accelerator [3]. In order to keep the LINAC working regularly, there is also a need of a cooling system with spiral water jacket. Based on the thermal performance of the collinear absorbing load with cooling system the coating can be adjusted to an optimized situation, according to Zhao Shu [4].

For 14 MeV LINAC, the desired collinear load is to be composed of only 4 cavities to shorten the LINAC. FeSiAl is taken into account as the effective microwave-

absorbing material，considering its high attenuation [5] and good machinability. Systematical simulation and analysis are required for the optimization of the collinear load.

THEORETICAL DESIGN OF THE COLLINEAR LOAD

Parameter simulation of the beam dynamics shows that the remnant power should be absorbed by the collinear load is 1.158kW when there is a beam through, while there is 2.972kW remains without the beam. In order to prevent the after power from interfering with the normal operation of the accelerator, the one-way attenuation must be above 20dB. Therefore, the collinear load should absorb enough power while the operating frequency is about 2856MHz. As the remnant power is only 1.158kW, four cavities are estimated enough so that the entire accelerator can be more compact. The dimensions of each load cavity are displayed in Fig.1. The principle of distribution of average power is firstly used in the simulation. Then more accurate data are calculated to find out a better distribution. Referring to the actual machining accuracy, a series of cavity is designed by CST based on the principle of distribution of average power.
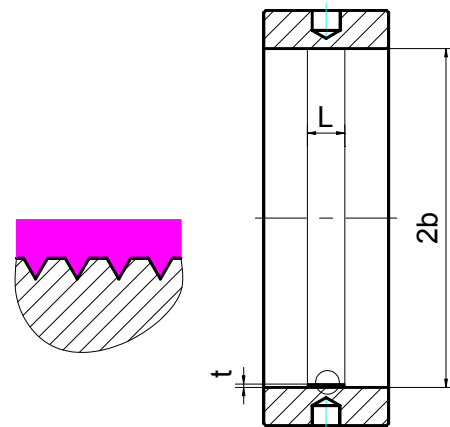

Figure 1: Dimensions of the FeSiAl coating.

It is known that the frequency deviates at lower mesh densities, while converge to certain value once the mesh density reaches enough high. Also, the trim sizes of the cavity and the coating are difficult to ensure because of the machining error. In order to reduce the error of the working frequency, the frequency shift from 2856MHz must be controlled fewer than 50 kHz in the simulation. The data are described in Table 1. The coating length (mm) and thickness (mm) are individually 8.3×0.05,

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11.9×0.05, 20.2×0.05 and 19.8×0.40. According to the final α value, the total attenuation reaches -50.4dB.

Table1: Parameters and Properties of Load Cavities

No.	b(mm)	△f (kHz)	Q_factor	α	Power loss(W)
1	40.812	-22	613.647	4.12	290.0
2	40.801	-13	433.596	5.83	290.8
3	40.776	17	258.852	9.76	285.8
4	40.595	13	48.3158	52.3	284.0

Because of the calculation error, the power losses are not the real equal. From this table, the maximum coating volume is enough without the material coating on the disk while the minimum Q is 48.3158. It shows that the attenuating ability of the FeSiAl is big enough. Simulations show that there is need to coat the disks with the material while the absorbing material is Kanthal and the Q is very small as Fig 2.

Figure 2: Disks coated with Kanthal.

Comparing with the average allocation method, design based on Newton's law of cooling was proposed by Zhao Shu in order to keep the mean surface temperature in the cavities the same. In this case, the power loss of each cavity could be 25.69%, 25.22%, 24.75% and 24.29% by the recurrence formula. Then a new data is designed which described in Table 2. The coating length (mm) and thickness (mm) are individually 8.6×0.05, 12.1×0.05, 20.8×0.05 and 24.6×0.55.

Table 2: Parameters and Properties of Load Cavities

No.	b(mm)	△f (kHz)	Q_factor	α	Power loss(W)
1	40.811	-12	593.122	4.26	298.6
2	40.800	18	426.688	5.92	291.6
3	40.774	17	251.526	10.0	286.7
4	40.434	4	28.5331	88.6	280.5

TEMPERATURE FIELD ANALYSIS OF THE COLLINEAR LOAD

All these two schemes in front are designed by estimation or theoretical equation, while a cooling water system are needed to keep the working temperature in the accelerator around 30 centigrade. Therefore,

simulation of the temperature field can provide the basis to access whether the scheme is appropriate or not. A large number of simulation works indicate that helical water channel method is more effective than other cooling systems. Double helical water channel ensure the temperature more uniform and can take more heat than single, but the structure is more complicated. Double helical water is firstly adopted in the simulation, as to ensure the working temperature is the primary goal in this case. Existing research results prove that the pitch of the helical water channel and the height of the clapboard have little effect on the distribution of temperature, while great influences on the water pressure. Water flow has significant influences on both the distribution of temperature and the water pressure when the structure has been confirmed. Also, the centre temperature can be adjusted through the linear relationship between it and the start temperature, according to the function of

$$T_{in}^{'} = T_{in} + (T_{aim} - \frac{T_{max} + T_{min}}{2})$$
(1)

where T_{max} and T_{min} are the maximum and minimum temperature when the start temperature is T_{in} in the simulation. Based on these theories, the temperature simulation results are displayed in Table 3. The pitch of the partition is 50 mm and the water flow is totally 3kg/s in both of the cooling systems. The inlet temperature is adjusted to 29.2 ℃ to ensure the accelerator working around 30±0.5 ℃, while the outlet temperature is 29.3 ℃, the start temperature of the collinear load.

Table 3: Temperature Field in the Accelerator

No.	Water T_out (℃)	T_min (℃)	T_max (℃)	Pressure (MPa)
Double	29.25	29.6	30.2	0.10071
Single	29.25	29.6	30.2	0.02745

It can be concluded from Table 3 that single helical water channel can achieve the same cooling effect as the double while the water pressure is lower. Follow-up simulation shows that double helical water channel can provide better temperature environment than the single when the load power is big enough. Therefore, single helical water channel cooling system is a better choice, because the water pressure in the double is about twice as much, although it can keep the collinear load working in a more appropriate temperature environment. The maximum and the minimum temperatures of each cavity are displayed in the Fig. 3. The water pressure differences are all 0.04298 MPa in both schemes.
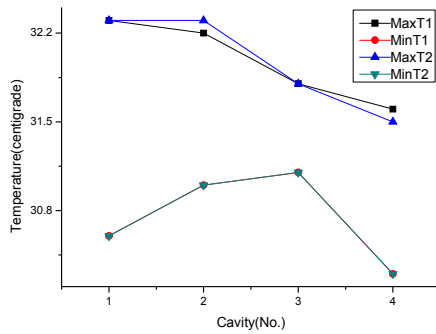
Figure 3: Temperature of the collinear load.

It could be clear that the more power the cavity absorbs, the higher the maximum temperature is in these two cases. Because the inlet water temperature of the collinear load is restricted to 29.3 ℃, the minimum temperature in it is above 30 ℃, the target temperature. Therefore, there is only the maximum temperatures in each cavity could be considered about to deal with the temperature field.

OPTIMIZATION DESIGN OF THE COLLINEAR LOAD

Comparing these front two schemes, the maximum temperature in the first two cavities is higher than in the last two cavities. In order to reduce the maximum temperate difference, part of the power absorbed in the first two cavities should be distributed to the last two. Here is a scenario that making the maximum temperature in each cavity approximately equal by adjusting the distribution of the coaxial cavity is a way to minimize the maximum temperature difference. Also, comparing the first two cavities in the average scheme, the increase of the length of the coating can reduce the heat concentration. According to these, series of cavities are designed by successive adjustment and the best scheme (the third one) is found out as in the Fig 4.
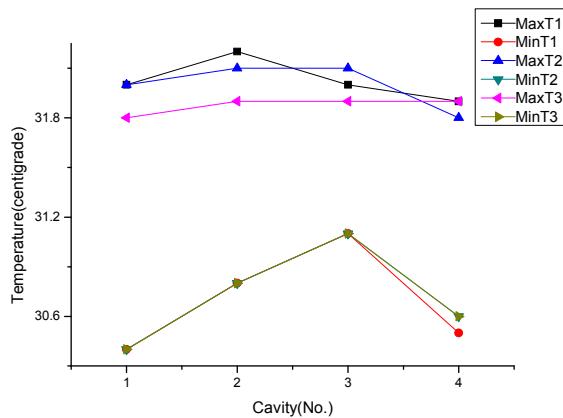

Figure 4: Temperature field of the collinear load.

Table 4 displays the dimensions and properties of the final design. In the fourth cavity, the coating covers the

whole internal surface of it. And the final temperature field in the collinear load is presented in Fig. 5.

Table 4: Dimensions and Properties of Collinear Load

No.	b/mm	m_l/mm	m_t/mm	$\triangle$f/ kHz	Power loss/W
1	40.814	9.0	0.03	22	243.0
2	40.804	13.0	0.03	26	260.3
3	40.778	23.6	0.03	36	294.2
4	40.409	29.9898	0.47	-10	259.9

The simulation of the temperature field shows the highest temperature is 32.0 centigrade and the difference of the highest temperature in each cavity is below 0.1 centigrade.
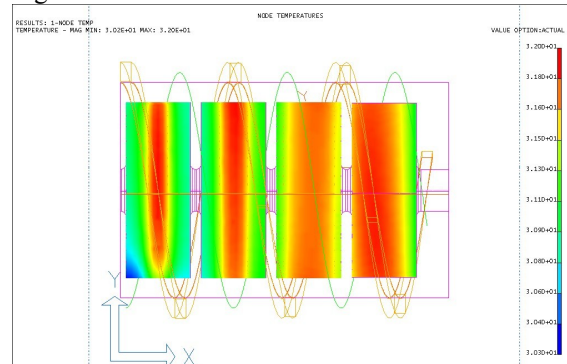

Figure 5: Temperature field of the collinear load.

SUMMARY AND CONCLUSION

In order to develop a kind of collinear load suitable for the current accelerator, several regular rules are summarized. Strategies of simulation analysis and design were proposed accordingly. The dimension b is used by approximate -72 kHz/um for the frequency compensation to 2856MHz. Different power distributions are adopted and new scheme are designed on the basis of the previous temperature field by adjusting the highest temperature and reducing the thickness of the coating. A four-cavity 4 kW collinear load was designed with specific power-assignment finally. The one-way attenuation reaches -76.1 dB. And a cooling system was devised that ensures the temperature range in the accelerator is 29.6-30.2 ℃ and the maximum offset in the collinear load is 2 ℃.

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