THE STUDIES OF X-BAND HYBRID DIELECTRIC-IRIS-LOADED ACCELERATING STRUCTURE

Cong-Feng Wu, Lin Hui, Sai Dong
National Synchrotron Radiation Lab, USTC, Hefei, Anhui, 230029, P. R. China

Abstract

The dispersion property and the propagation characteristic of the accelerating mode (TM_{01} mode) about a X-band (f=9.37GHz) hybrid dielectric-iris-loaded accelerating structure has been analysed and discussed by the field matching method and Mafia code respectively. The ones of the HEM_{11} mode have also been calculated by MAFIA code. Based on the experimental results of the used dielectric (ceramic). Mafia code has been used to make the optimization design for the new structure. Some model cavities have been developed and measured. The experimental investigations show that the results are nearly agreement with the theory design.

INTRODUCTION

An extremely small accelerator has found wider and wider applications in high energy physics research, industrial and medical fields. The many advantages of using higher RF frequencies (X-band) for electron linear accelerators include higher shunt impedance, higher breakdown threshold level, smaller size and short fill time etc. The most commonly studied structure is a conventional iris-loaded copper structure. However, in all the iris-loaded structures, the peak surface electric field Es can be an important constraint in high-energy accelerating structure design because it is in general found to be a factor of 2 larger than the axial acceleration field Ea [1, 2]. Because the peak surface electric field causes breakdown of the structure, it represents a direct limitation on the maximum acceleration gradient.

. The use of uniform dielectric-lined circular waveguides as accelerating structures has been discussed in many previous studies [3, 4]. One distinct advantage is that the axial accelerating electric field is the maximum field in this class of structure. (The acceleration mode used here is the TM_{01}). But the quality factor Q of a dielectric-lined waveguides is degraded much compared to an iris-loaded structure with the same group velocity.

Based on these observations, a hybrid dielectric and iris loaded structure is a device which balances high Q and reduced surface electric fields. This device is shown in Figure 1. In the paper, the dispersion property of the accelerating mode about a X-band (f=9.37GHz) hybrid dielectric-iris-loaded accelerating structure have been analysed and discussed by the field matching method and Mafia code respectively.

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# cfwu@ustc.edu.cn

In terms of the experimental results of the used dielectric (ceramic), Mafia code has been used to make the structure optimization. Some model cavities have been developed and the experimental studies have been carried on. The above results will provide some beneficial data for the design and manufacture of X-band hybrid dielectric-iris-loaded traveling-wave accelerating structure.

ANALYSIS

The schematic of the hybrid dielectric-iris-loaded accelerating structure, as shown in Figure 1, can be divided into three regions. From Maxwell's equations and the Eloquet theorem, the electromagnetic fields for TM_{01} mode can be expressed approximately in different regions as follows:

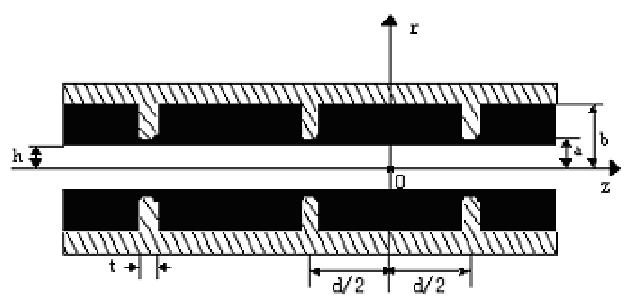

Figure 1: Schematic drawing of a hybrid dielectric-iris-loaded accelerating structure.

At region Ⅰ ($r \le h$):

$$E_z^{(1)} = \sum_{n=-\infty}^{n=\infty} A_n^{(1)} J_0(k_{rn}^{(1)} r) e^{-i\beta_n z} \tag{1}$$

$$H_\theta^{(1)} = \sum_{n=-\infty}^{n=\infty} \frac{i}{k_{rn}^{(1)}} A_n^{(1)} \omega\varepsilon_0 J_1(k_{rn}^{(1)} r) e^{-i\beta_n z} \tag{2}$$

At region Ⅱ ($h \le r \le a$):

$$E_z^{(2)} = \sum_{n=-\infty}^{n=\infty} \left[A_{1n}^{(2)} J_0(k_{rn}^{(2)} r) + A_{2n}^{(2)} Y_0(k_{rn}^{(2)} r) \right] e^{-i\beta_n z} \tag{3}$$

$$H_\theta^{(2)} = \sum_{n=-\infty}^{n=\infty} \frac{i}{k_{rn}^{(2)}} \omega\varepsilon_r\varepsilon_0 [A_{1n}^{(2)} J_1(k_{rn}^{(2)} r) + A_{2n}^{(2)} Y_1(k_{rn}^{(2)} r)] e^{-i\beta_n z} \tag{4}$$

At region Ⅲ ($a \le r \le b$):

$$E_z^{(3)} = \sum_{s=0}^{s=\infty} A_s^{(3)} F_0(k_{rs}^{(3)} r) \begin{Bmatrix} \cos(\eta_s z) \\ i\sin(\eta_s z) \end{Bmatrix} \tag{5}$$

$$H_\theta^{(3)} = \sum_{s=0}^{s=\infty} \frac{i\omega\varepsilon_0\varepsilon_r}{k_{rs}^{(3)}} A_s^{(3)} F_1(k_{rs}^{(3)} r) \begin{Bmatrix} \cos(\eta_s z) \\ i\sin(\eta_s z) \end{Bmatrix} \tag{6}$$

Where,

$$F_0 = J_0(k_{rs}^{(3)} r) - \frac{J_0(k_{rs}^{(3)} b)}{Y_0(k_{rs}^{(3)} b)} Y_0(k_{rs}^{(3)} r)$$

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$$F_1 = J_1(k_{rs}^{(3)}r) - \frac{J_0(k_{rs}^{(3)}b)}{Y_0(k_{rs}^{(3)}b)} Y_1(k_{rs}^{(3)}r)$$

$$(k_{rn}^{(1)})^2 = k^2 - \beta_n^2,\ (k_{rn}^{(2)})^2 = \varepsilon_r k^2 - \beta_n^2,\ (k_{rn}^{(3)})^2 = \varepsilon_r k^2 - \eta_s^2$$

$$\beta_n = \beta_0 + \frac{2n\pi}{d}\ ,\ \eta_s = \frac{s\pi}{d_0},\ d_0 = d - t$$

At the two interfaces of the structure(r=h,r=a), the tangential field components must be continuous. Utilizing the general solutions of the three regions to the boundary conditions at the related interfaces results in a system of homogeneous linear equations.

$$U(A_n^{(1)}, A_{1n}^{(2)}, A_{2n}^{(2)}, A_s^{(3)})^T = 0 \qquad (7)$$

The existence of a nontrivial solution for (7) requires that the coefficient determinant vanish:

$$\mathrm{Det}(U)=0 \qquad (8)$$

The determinant equation (8) defines the dispersion relation. The dispersion curve of phase (Φ) versus frequency for TM_{01} mode about a hybrid dielectric-iris-loaded accelerating structure with d=10.67mm, a=5.5mm, b=6.764mm, t=1.5mm, h=2.5mm, ε r=5.812 is shown in figure 2. Figure 2 shows also the dispersion curves calculated by MAFIA code for TM_{01} mode and HEM_{11} mode respectively about the structure. From figure 2, the agreement between the dispersion curve calculated by field matching method and the one calculated by Mafia code is seen to be very good over all mode range (for TM_{01} mode). Moreover, it is shown in figure 2 that the cutoff frequency of HEM_{11} mode is lower than that of TM_{01} mode. The intersections of the dispersion curves with the speed of light line indicate that the propagation constant of HEM_{11} mode is less than that of TM_{01} mode, at the locations where these two modes have the same phase velocity as the speed of light c.

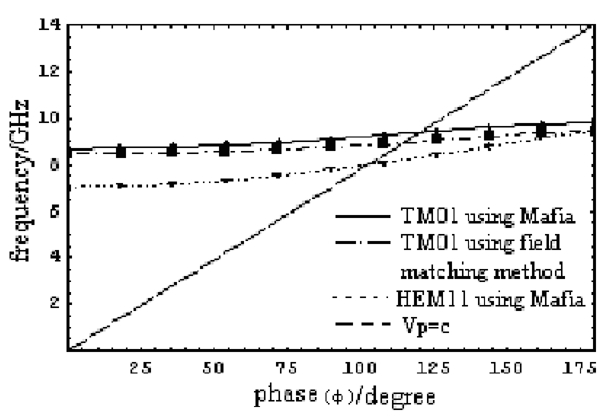

Figure 2. the phase (Φ) of the TM_{01} mode and the HEM_{11} mode versus frequency.

OPTIMIZATION DESIGN AND MEASUREMENT

Based on the measurement result [5] of the permittivity the used dielectric, optimization design has been made by Mafia code. The RF properties vs geometric sizes are shown in table 1.

Table 1: RF Properties of a Hybrid Dielectric-Iris-loaded Periodic Structure.

t=1.5mm, d=10.67mm, λ = 32.017 mm

a (mm)	b (mm)	h (mm)	ε_r	E_s / E_a	r (MΩ/m)	Q
5.5	6.764	2.5	5.812	0.9902	68.71	6011.81

Figure 3: the components of the model cavities

Figure 4. Low-Power testing for the model cavities

According to the sizes in table 1, the model cavities (figure 3) have been developed. The S_{21} parameter vs frequency is measured with Network Analyzer Hp8722D (figure 4). The measured result of two cavities is shown in figure 5.

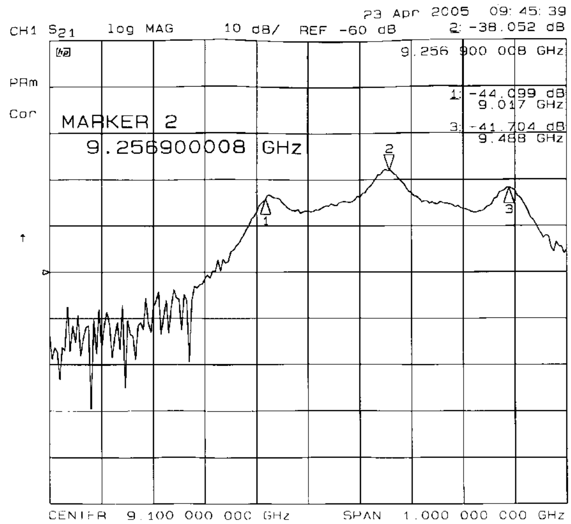

Figure 5: The measurement results of S_{21} vs frequency with two model cavities.

Because the frequency is an even function of Φ, whose period is 2π. Thus, the frequency can be expressed as follows:

$$f = c_0 + \sum_{n=1}^{n=\infty} c_n \cos(n\Phi) \tag{9}$$

From the data in figure 5, we can obtain the coefficients:

c_0=9.2547 , c_1=-0.2355, c_2=-0.0022

As a result, the operation frequency is:

$$f_{2\pi/3}=9.3735(\mathrm{GHz}) \tag{10}$$

The measured result of (10) is consistent nearly with the design value f=9.37GHZ

CONCLUSION

The dispersion property and the propagation characteristic of the accelerating mode (TM_{01} mode) about a X-band (f=9.37GHz) hybrid dielectric-iris-loaded accelerating structure has been analysed and discussed by the field matching method and Mafia code respectively. The ones of the HEM_{11} mode have also been calculated by MAFIA code. Based on the experimental results of the used dielectric (ceramic), Mafia code has been used to make the structure optimization. Some model cavities have been developed, and experimental investigations show that the results are nearly agreement with the theory design. The above results will provide some beneficial data for the design and manufacture of X-band hybrid dielectric-iris-loaded traveling-wave accelerating structure. Further studies of the new structure are in progress.

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