THE SIMULATION CALCULATIONS AND DIELECTRIC CHARACTERISTICS INVESTIGATION OF AN X-BAND HYBRID DIELECTRIC-IRIS-LOADED TRAVELING ACCELERATING STRUCTURE

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Abstract

Mafia code has been used to calculate the RF properties versus the geometric parameters and dielectric permittivity for the X-band (f=9.37GHz) hybrid dielectric-iris-loaded traveling accelerating structure. The simulation results show that when the range of the permittivity is about 5-9, the new structure may have lower ratio of peak surface electric field at the iris to axial accelerating electric field by optimizing the geometric parameters, while r/Q of the new structure being comparable to iris-loaded accelerating structure and r, Q being a little lower. The experimental investigations of the permittivity for selection about the dielectric (ceramics) have been made at the X-band by using the cavity perturbation technique. The measured results are consistent with the simulation results by Microwave Studio. Furthermore, the permittivity stability of the certain ceramic with varying frequency is examined. The experimental results show that the certain ceramic with permittivity of 5.81 is applied to the design of the new accelerating structure.

INTRODUCTION

X-band high-gradient accelerator development has gained great momentum in recent years, motivated by the need for the future linear colliders in high energy physics research and for the industrial and medical application. By developing X-band high gradient accelerating structure, one can use a shorter length for a given power to achieve a certain electron beam energy. There are obvious advantages for using X-band range than S-band one. First, the shunt impedance per unit length of X-band is higher than that of S-band. Second, the maximum permissible electric field strength is also higher.

The most commonly studied structure is a conventional iris-loaded copper structure. Our lab has also developed the x-band iris-loaded structure [1]. However, in all the iris-loaded structures, the peak surface electric field Es at the iris is in general at least a factor 2 larger than the axial acceleration field E_a [2]. If the peak surface electric field exceeds the breakdown limit at the operating frequency, it can cause damage to the irises through arcing and detune the structure. Such phenomena was observed in the high acceleration gradient testing of NLC-type structures, with the axial acceleration gradient up to 50 MV/m[3-4].

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The use of uniform dielectric-lined circular waveguides as accelerating structures has been discussed in many studies. One distinct advantage is that axial accelerating electric field is the maximum field in this class of structures[2]. Another advantage is that the higher-order modes in the structure are attenuated swiftly[5]. But the quality factor Q of a dielectric-lined circular waveguides is degraded much comparing to an iris-loaded structure with the same group velocity[2].

A X-band (f=11.424GHz) hybrid dielectric and iris loaded acceleration structure was proposed [2]. The calculation results show that when ε_r is equal to 6, the ratio of E_s to E_a may be reduced to 1.01.

In this paper, Mafia code has been used to calculate the RF properties versus the geometric parameters and dielectric permittivity for the X-band (f=9.37GHz) hybrid dielectric-iris-loaded traveling accelerating structure. The experimental investigations of the permittivity for selection about the ceramics have been made by using the cavity perturbation technique. The measured results are compared with the simulation results of Microwave Studio. Furthermore, the permittivity stability of the certain ceramic is examined.

NUMERICAL CALCULATION RESULTS

The RF properties of pure iris-loaded traveling wave structure (a=3mm, b=12.447mm, t=1.5mm,d=10.67mm), whose operation frequency is 9.37GHz, in the reference [1] are calculated again by Mafia code. The results of RF properties are: Es/Ea=2.1, r=119MΩ/m, Q=7689, r/Q=15496Ω/m.

Figure 1 shows the hybrid dielectric-iris-loaded travelling-wave structure. In figure 1, a is the iris radius, b is the outer radius, and h is the beam hole radius, t is the thickness of the iris (t=1.2mm), and d is the length of one cell (d=10.67mm). The operation mode is $2\pi/3$. The outer radius of the cylinder b is adjusted accordingly to have the phase velocity of TM01 mode equal to c.

First, we describe self-consistent calculations of hybrid structures with a fixed beam hole radius and also varying the iris radius. From figure 2 to figure 5, Es/E_a , r, Q, r/Q as the functions of iris aperture radius are shown respectively. The inspections of these figures show that the values of E_s/E_a decrease with increment of a and ε_r. The values of r, Q and r/Q increase by increment of a .

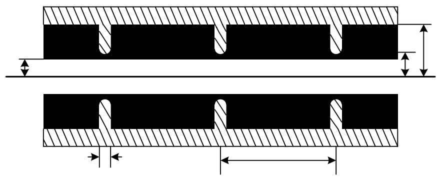

Figure 1: Schematic drawing of a hybrid dielectric-iris-loaded accelerating structure.

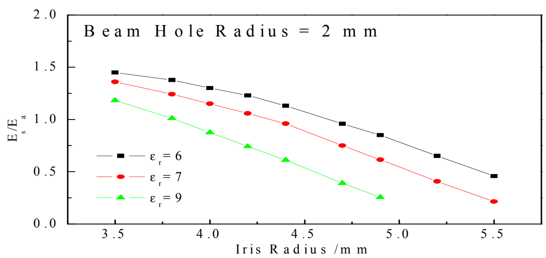

Figure 2: The E_s / E_a as a Function of a and ε_r.

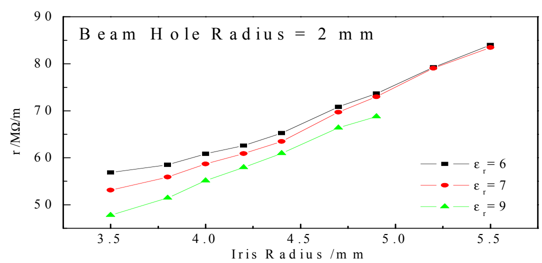

Figure 3: The r as a Function of a and ε_r.

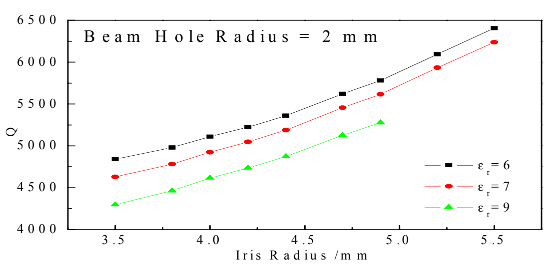

Figure 4: The Q as a Function of a and ε_r.

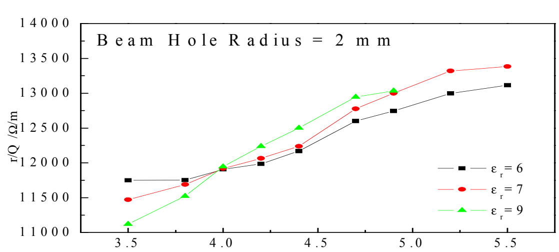

Figure 5: The r/Q as a Function of a and ε_r.

Second, the relations among the Rf properties, the structure sizes and ε_r are given in table 1.Comparing with the above results of the iris-loaded structure, we observe that when the range of ε_r is about 5-9, under optimum design, E_s/E_a can be reduced to about 1 without diminishing to any great extent r, Q, and r/Q.

Table 1: RF Properties of some Hybrid Dielectric-Iris-loaded Periodic Structures.

t=1.2mm, d=10.67mm, λ = 32.017 mm

a (mm)	b (mm)	h (mm)	ε_r	E_s / E_a	r MΩ/m	Q	r/Q Ω/m
5.9	7.290	2.7	5.0	1.119	69.77	6322.64	11034.95
5.5	6.825	2.5	5.6	1.060	69.07	6001.56	11508.67
5.2	6.565	2.7	6.5	1.147	57.94	5379.42	10770.68
5.2	6.400	2.9	7.5	1.032	51.05	5022.13	10165.01
5.2	6.275	2.9	8.0	0.890	50.05	4931.50	10149.04
5.2	6.160	2.9	8.5	0.822	49.06	4842.98	10130.13
5.2	6.050	2.9	9.0	0.759	48.09	4753.13	10117.54

THE EXPERIMENTAL INVESTIGATIONS OF DIELECTRIC

The waveguide cavity developed is shown in figure 6. The cross-section dimensions are 22.86mm x 10 mm. The length is varied from 104mm to 120mm. The slot width is 3mm. The ceramic samples, whose diameters are 3mm, under test are fabricated in the form of a cylinder and inserted into the resonator. The real part of the permitivity can then be calculated from the shift in the resonance frequency. The s_{21} parameter vs frequency is measured with Network Analyzer Hp8722D.We have found that the permittivity consistency of the certain ceramic is good by the measurements of some different ceramic samples. The measured results are shown in figure7.

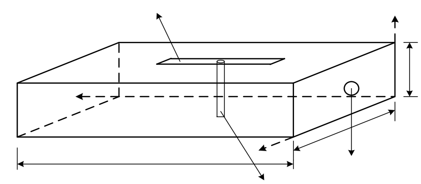

Figure 6: The waveguide resonator and its dimensions

Cavity perturbation theory is expressed approximately as follows [6]:

$$\frac{\Delta f_0}{f_0} = \frac{-(\varepsilon_r - 1)\int_V E_1^2 dv - (\mu_r - 1)\int_{V_s} H_1^2 dv}{\int_V (E_1^2 + H_1^2) dv} \quad (1)$$

where $\vec{E}_1$, $\vec{H}_1$ are the electromagnetic fields. V_s is the sample volume , V is the cavity volume. For TE_{10p} mode, p=3. The components of $\vec{E}_1$ and $\vec{H}_1$ are:

$$\begin{cases} E_z = E_x = H_y = 0 \\ E_y = \frac{2}{\sqrt{V}} \sin\frac{\pi x}{a} \sin\frac{p\pi z}{l} \\ H_x = \frac{2}{\sqrt{V}} \frac{pa}{l} \frac{1}{\sqrt{1+(\frac{pa}{l})^2}} \sin\frac{\pi x}{a} \cos\frac{p\pi z}{l} \\ H_z = \frac{2}{\sqrt{V}} \frac{1}{\sqrt{1+(\frac{pa}{l})^2}} \cos\frac{\pi x}{a} \sin\frac{p\pi z}{l} \end{cases} \quad (2)$$

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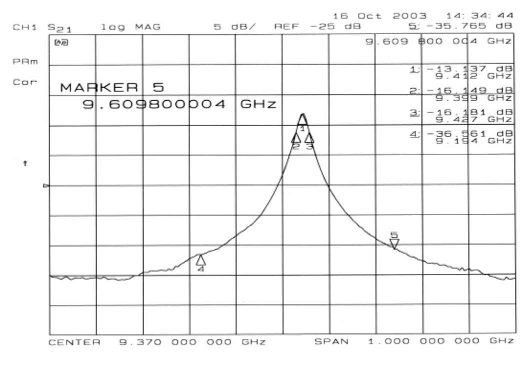
Thus:

$$\varepsilon_r = \frac{f_0 - f}{f_0} \bullet \frac{al}{2\pi r^2} + 1 \tag{3}$$

Form the figure 7, the resonance frequencies of the cavity at the l=112mm are f_0=9.412GHz and f=9.163GHz under the case without and with the dielectric sample respectively. The measured resonance frequencies are good agreement with the ones simulated with Microwave Studio in figure 8. The calculated value of ε_r is about 5.8129. Varying the length of the cavity, the values of ε_r at the other frequencies are obtained in table 2. The results show that the values of permittivity vary slowly with frequency at X-band.

Table 2: The Dielectric Constant as a Function of the Frequency.

F	9.1199	9.2740	9.4120	9.6108	9.8055
ε_r	5.8046	5.8117	5.8129	5.8177	5.7977



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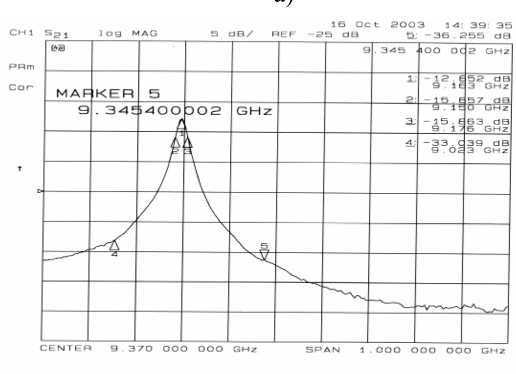
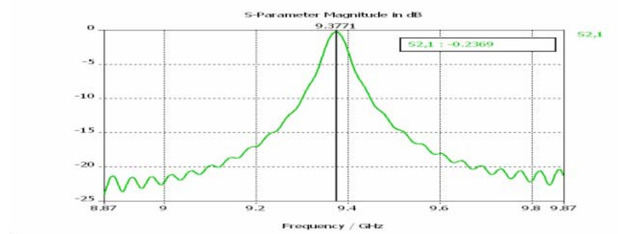


b)

Figure 7: The measurement results of S_{21} vs frequency. a) without the dielectric sample. b) with the dielectric sample.

CONCLUSION

The simulation results show that when the range of the permittivity is about 5-9, the new structure may have lower ratio (about 1) of peak surface electric field at the iris to axial accelerating electric field by optimizing the



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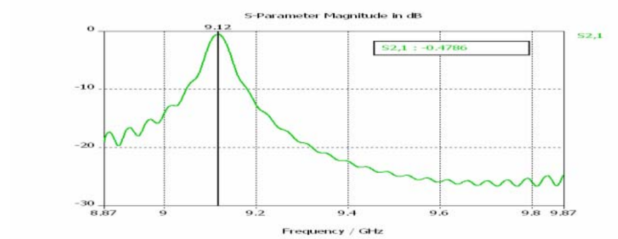

b)

Figure 8: The simulation results of S_{21} vs freqeency using the Microwave Studio. a) without the dielectric sample. b) with the dielectric sample

geometric parameters, while r, Q, r/Q of the new structure being comparable to iris-loaded accelerating structure. The experimental investigations of the permittivity for selection about ceramics have been made at the X-band by using the cavity perturbation technique. The measured results are consistent with the simulation results of Microwave Studio. Furthermore, the permittivity stability of the certain ceramic with varying frequency is examined. The experimental results show that the certain ceramic with permittivity of 5.81 is applied to the design of the new accelerating structure.

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