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

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Abstract
The dispersion property and the propagation characteristic of the accelerating mode (TM01 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 HEM11 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 TM01). 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.

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 TM01 mode can be expressed approximately in different regions as follows:

At region I (r < h):
\[ E_z^{(0)} = \sum_{n=0}^{\infty} A_n \cdot J(k_n r) e^{-\beta z}; \]  
\[ H_{\phi}^{(0)} = \sum_{n=0}^{\infty} \frac{i}{k_n} A_n \cdot e^i \cdot J(k_n r) e^{-\beta z}; \]

At region II (h < r < a):
\[ E_z^{(2)} = \sum_{n=0}^{\infty} \left[A_n \cdot J(k_n r) + A_n \cdot i \cdot \phi \cdot J(k_n r) + e^{-\beta z}; \right. \]  
\[ H_{\phi}^{(2)} = \sum_{n=0}^{\infty} \frac{i}{k_n} \cdot e^i \cdot A_n \cdot \phi \cdot J(k_n r) + A_n \cdot Y(k_n r) e^{-\beta z}; \]

At region III (a < r < b):
\[ E_z^{(4)} = \sum_{n=0}^{\infty} A_n \cdot \phi \cdot J(k_n r) \cdot \left[ \cos(\eta z) \right] \]  
\[ H_{\phi}^{(4)} = \sum_{n=0}^{\infty} \frac{i}{k_n} \cdot A_n \cdot \phi \cdot \frac{F_n(k_n r)}{Y(k_n r)} \cdot \left[ \sin(\eta z) \right] \]

Where,
\[ F_n = J(k_n r) - \frac{J(k_n b)}{Y(k_n b)} \cdot Y(k_n r) \]

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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.

\[
U(A^{(1)}_n, A^{(2)}_n, A^{(3)}_n)^T = 0
\]  

(7)

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

\[
\text{Det}(U) = 0
\]  

(8)

The determinant equation (8) defines the dispersion relation. The dispersion curve of phase (\(\phi\)) versus frequency for TM01 mode about a hybrid dielectric-iris-loaded accelerating structure with \(d=10.67\text{mm}, a=5.5\text{mm}, b=6.764\text{mm}, t=1.5\text{mm}, h=2.5\text{mm}, \lambda=5.812\) is shown in figure 2. Figure 2 shows also the dispersion curves calculated by MAFIA code for TM01 mode and HEM11 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 TM01 mode). Moreover, it is shown in figure 2 that the cutoff frequency of HEM11 mode is lower than that of TM01 mode. The intersections of the dispersion curves with the speed of light line indicate that the propagation constant of HEM11 mode is less than that of TM01 mode, at the locations where these two modes have the same phase velocity as the speed of light c.

**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.

<table>
<thead>
<tr>
<th>a (mm)</th>
<th>b (mm)</th>
<th>h (mm)</th>
<th>(\varepsilon_r)</th>
<th>(E_i/E_s)</th>
<th>r (M(\Omega)/m)</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>6.764</td>
<td>2.5</td>
<td>5.812</td>
<td>0.9902</td>
<td>68.71</td>
<td>6011.81</td>
</tr>
</tbody>
</table>

Figure 2. The phase (\(\phi\)) of the TM01 mode and the HEM11 mode versus frequency.

![Figure 2: The phase (\(\phi\)) of the TM01 mode and the HEM11 mode versus frequency.](image)

**Figure 3:** the components of the model cavities

**Figure 4:** Low-Power testing for the model cavities

![Figure 4: Low-Power testing for the model cavities.](image)
According to the sizes in table 1, the model cavities (figure 3) have been developed. The S21 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 S21 vs frequency with two model cavities.](image)

Because the frequency is an even function of $\phi$, whose period is $2\pi$. Thus, the frequency can be expressed as follows:

$$f = c_0 + \sum_{n=1}^{\infty} c_n \cos(n\phi)$$  \hspace{1cm} (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:

$$f_{2,3}=9.3735\text{GHz}$$  \hspace{1cm} (10)

The measured result of (10) is consistent nearly with the design value $f=9.37\text{GHz}$

**CONCLUSION**

The dispersion property and the propagation characteristic of the accelerating mode (TM01 mode) about a X-band ($f=9.37\text{GHz}$) hybrid dielectric-iris-loaded accelerating structure has been analysed and discussed by the field matching method and MAFIA code respectively. The ones of the HEM11 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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**REFERENCES**


