DESIGN OF OVERSIZED SINGLE MODE CORRUGATED APPLICATORS FOR MICROWAVE HEATING.

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Abstract. The Finite Element Method (FEM) has been applied to the design of single mode TM$_{101}$ applicator for microwave heating applications. The basic idea is to control the resonant frequency of the cavity using a set of corrugations on the cavity walls, instead of modifying the cavity dimensions.
1 INTRODUCTION

Heating is a very important part of many industrial processes. Electromagnetic fields in the microwave band represent a rather interesting alternative to traditional heat sources (fossil fuels). Microwave heating (or in a more general sense, microwave processing) is faster (since it is a volume heating source), cleaner (reduces the wastes), easier to control (microwave sources can be easily controlled by a computer) and even produces a more friendly working environment.

A microwave heating system is usually formed by a microwave source and an applicator. Normally, the power source is a 2.45 GHz magnetron protected from power reflections in not matched loads by some circuitry (a circulator and a water load is a typical example). The applicator is a resonant cavity where the material to be processed is placed to be exposed to the electromagnetic energy. The connection between the power source and the applicator is made using rectangular waveguides (WR340) and the cavity is fed via a resonant iris (a circular or rectangular hole in the cavity wall).

Basically, there are two kinds of applicators: single mode applicators and multimode applicators. Single mode applicators are smaller than multimode applicators, and inside them only one resonant mode is excited, yielding a known field pattern. On the other hand, inside multimode applicators, due to its big size, many modes are excited yielding a more uniform field pattern.

A very common single mode applicator is the TM$_{010}$ cylindrical applicator, where the material to be processed is a dielectric cylinder placed in the middle of the cavity. The resonant frequency and field pattern of the TM$_{010}$ mode of a cylindrical cavity are well known and they can be obtained analytically. However, the resonant frequency and the quality factor of a partly filled resonant cavity strongly depend on the dielectric properties of the material sample. Anyway, we can use a standard cavity of fixed dimensions if we can adjust the resonant frequency to 2.45 GHz. To do so we can use a resonant cavity designed to have a resonant frequency for the TM$_{010}$ mode greater than 2.45 GHz. When the cylindrical sample of dielectric material is placed in the centre of the applicator, the resonant frequency will drop. Afterwards, the cavity can be tuned using a set of radial corrugations that allow the resonant frequency to be shifted to 2.45 GHz.

The design of complex structures is seldom possible using analytic techniques, so the designer needs to use numerical methods. The Finite Element Method (FEM) has been widely used to solve these kind of electromagnetic problems in recent years. In the work that we will present here, we have used one commercial FEM package (ANSYS) to design a corrugated cylindrical cavity for microwave heating cylindrical samples of dielectric materials. The cavity has been built and the numerical and experimental results have been compared, showing a very good agreement.
2 DESCRIPTION OF THE PROBLEM

The TM$_{010}$ is a well-known single mode applicator for microwave heating systems. The resonant frequency of this mode depends on the cavity radius, and is given by:

$$f_r = \frac{150 \, \chi_{01}}{\pi \, R}$$

(1)

This formula is only valid for an empty cavity, and $\chi_{01}$ stands for the first root of the Bessel function of the first kind and $R$ is the cavity radius. The field pattern is shown in figure 1:

![Electric field for the TM$_{010}$ resonant mode in a cylindrical cavity.](image)

Figure 1: Electric field for the TM$_{010}$ resonant mode in a cylindrical cavity.

When the cavity is coaxially loaded using a 12 mm radius dielectric cylinder made of teflon ($\varepsilon_r = 2.0$ and $tg\delta = 10^{-4}$) both the resonant frequency and the field pattern are modified, as can be seen in figure 2:
It can be appreciated that the field is concentrated around the cylinder, which is a positive effect from the microwave processing point of view. However, the resonant frequency drops below 2 GHz, far away from the nominal frequency of the magnetrons used as power sources (2.45 GHz). To increase to resonant frequency the radius must be reduced, thus it is necessary to use a new cavity. In the next section we will present a different alternative.

3 CORRUGATED CAVITY

It is a well-known fact that smaller cavities usually yield higher resonant frequencies. So, an alternative to the reduction of the cavity radius is to corrugate the cavity. The corrugated cavity cross-section is that of figure 3.

In table 1 we present the resonant frequencies obtained for different corrugations. In general, it can be noted that the resonant frequency rises when the corrugation dimensions are increased. There is, however, an unexpected behavior for the 20 mm deep corrugation. In this case, the resonant frequency is almost constant, no matted the corrugation width. This fact can
be explained using figure 4. In can be appreciated in figures 4.a to 4.c how the electric field changes as the corrugations are made deeper. Finally, in figure 4.d it can be noted that the modal shape of the field for the deepest corrugation ($d = 20$ mm) has been essentially modified and is very different of that of the $TM_{010}$ mode (the maximum field is not yet in the middle of the cavity).

![Figure 3: General geometry of the corrugated cavity used in this work.](image)

<table>
<thead>
<tr>
<th>$w$</th>
<th>$d = 5$ mm</th>
<th>$d = 10$ mm</th>
<th>$d = 15$ mm</th>
<th>$d = 20$ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm</td>
<td>2.379</td>
<td>2.497</td>
<td>2.686</td>
<td>2.940</td>
</tr>
<tr>
<td>12 mm</td>
<td>2.384</td>
<td>2.508</td>
<td>2.708</td>
<td>2.940</td>
</tr>
<tr>
<td>15 mm</td>
<td>2.389</td>
<td>2.524</td>
<td>2.738</td>
<td>2.940</td>
</tr>
</tbody>
</table>

Table 1: Resonant frequencies (in GHz) of an empty cavity for different corrugations
Based on the previous analysis, it is possible to find values of $w$ and $d$ that force the resonant frequency to fall within the limits of the magnetrons (2.45 GHz ± 12.5 MHz). Table 2 shows some of these results. It should be noted that in this case and due to the effect of the cylinder the field distribution does not change dramatically, as it happened in the empty cavity case. This late phenomenon can be observed in figure 5, where the corrugations are the same than in figure 4.d.
Table 2: Resonant frequencies (in GHz) of a corrugated cavity loaded with a 12 mm diameter dielectric cylinder of teflon for different corrugations

<table>
<thead>
<tr>
<th>w (mm)</th>
<th>d (mm)</th>
<th>f_r (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>22</td>
<td>2.435</td>
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<tr>
<td>10</td>
<td>23</td>
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<tr>
<td>12</td>
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<td>2.408</td>
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<td>12</td>
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<td>2.460</td>
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<tr>
<td>15</td>
<td>21</td>
<td>2.439</td>
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<tr>
<td>15</td>
<td>22</td>
<td>2.493</td>
</tr>
</tbody>
</table>

Figure 5: Electric field for the TM_{010} mode of a corrugated cavity loaded with a 12 mm diameter dielectric cylinder of teflon with w = 10 mm and d = 20 mm.
CONCLUSIONS

An alternative solution to tune a TM$_{010}$ cylindrical applicator for Microwave Heating systems has been presented. This solution does not require to modify the cavity dimensions but to add some tuning elements (corrugations). The FEM can be used to accurately design this kind of devices. A special attention must be paid to the “degeneration” of the desired field profile due to the effect of the corrugations.

REFERENCES