Electromagnetic Field Analysis of a Microwave Oven by the FD-TD Method
- a Consideration on Steady State Analysis -

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I. INTRODUCTION

We must need uniform heating in microwave ovens. To remove unevenness, it is important to analyze the electromagnetic field distribution in the cavity of microwave ovens, and to optimize it.

Generally, we must use three-dimensional analysis in microwave ovens and often face the problem of exceeding computer resources available. So we adopt the FD-TD method, which has an advantage of using computer memories over other space dividing methods, such as FEM.

But the FD-TD method is mainly used for transient analysis, and not often for steady state analysis. So we first investigate in judgement on convergence to steady state, then compare the calculated electromagnetic energy distribution with experimental heating unevenness. We see that they fairly resemble each other.

II. MODEL FOR ANALYSIS

Figure 1 shows the model of a microwave oven which we analyze. We set frequency 2,464MHz, and assume that only TE_{10} mode can propagate in the exciting rectangular waveguide. The waveguide is matched at the source.

The observing plane is at 40.0mm above the bottom of the cavity. We use rectangular cells with the smallest cell size Δd=5mm and time step $\Delta t = 1/(2.464\times10^{9}\times50)$sec. which satisfies the Courant stability condition[1].

The operational memory is about 12Mbytes, and CPU times for calculating 30,000 time steps are 270 sec. by using our supercomputer.

III. CONVERGENCE TO STEADY STATE

Figure 2 shows the energy flow at a cross section of the waveguide as shown in figure 1. We calculate the sum of the Pointing's vector in this cross section and integrate over one period which corresponds to 50 time steps.

So this figure shows the relationship between energy flow and calculation times. Plus sign of energy flow denotes energy flowing into the cavity.

From this figure, it is expected that energy flow is almost balanced, and the electromagnetic field in the cavity is approximately steady over 30,000 time steps.

Then we calculate the correlation coefficient "r" and the regression coefficient "m" between electromagnetic energy distributed patterns with the different time steps.

The nearer the values of both "r" and "m" tend to 1, the more like the electromagnetic field patterns between the different time steps.

From table 1, it is concluded that the electromagnetic field in the cavity converges to steady state over 30,000 time steps (2.44×10^{-7}sec.).

Ⅳ.COMPARISON WITH EXPERIMENT

Both the cavity and the waveguide used in experiment have the same dimensions as shown in figure 1, and are made of copper. To observe the heating unevenness, we use the air guns' paint bullets which contain colored water.

In the cavity, we approprietly set the polystyrene foam stand of which surface holds the paint bullets at intervals of 15mm. We heat them 10~20sec. and then take out them and photograph the thermal distribution of the paint bullets with infra-red thermography camera.

Comparing the calculated electromagnetic energy distribution (see figure 3, 30,000 time steps after) with experimental heating unevenness (see figure 4, at 40.0mm above the bottom of the cavity), we see that they fairly resemble each other.

Ⅴ.CONCULUSION

We developed the simulation program for a model of a microwave oven with the FD-TD method. Both the numerical and the experimental results were similar.

We calculated the sum of the Poynting's vector in a cross section of the exciting waveguide and determined the convergence to the steady state from the energy flow balancing.

It was appeared that using the correlation coefficient and the regression coefficient, we can judge numerically the similarity on the electromagnetic field patterns between different time steps.

Ⅵ.REFERENCE

[1] K.S.Kuntz and R.J.Luebbers: The Finite Difference Time Domain Method for Electromagnetics, Boca Raton, Florida, CRC Press, 1993.

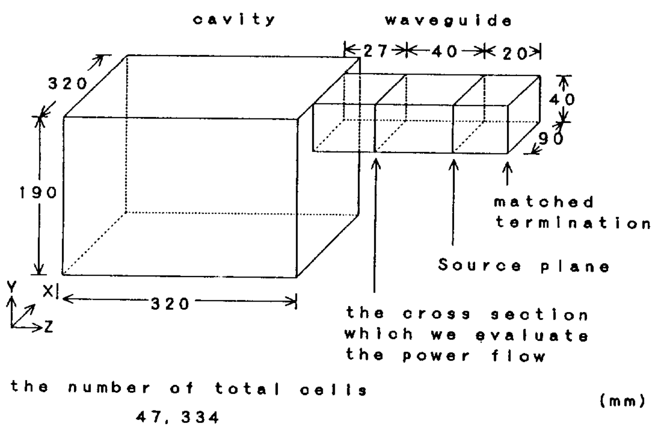

Fig. 1. Model of a Microwave Oven

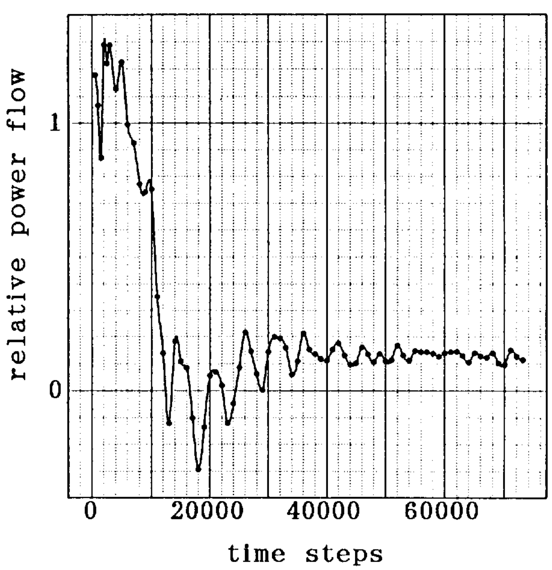

Fig. 2. Relative Power Flow

Table 1. The Correlation Coefficient and the Regression Coefficient

electromagnetic energy patterns	the correlation coefficient "r"	the regression coefficient "m"
30000T*−1000T	0.41796	0.02872
30000T −5000T	0.97310	0.71636
30000T −10000T	0.98094	1.3923
30000T −50000T	0.99569	1.0460
30000T −70000T	0.99662	0.94582

* a time step Δt=T

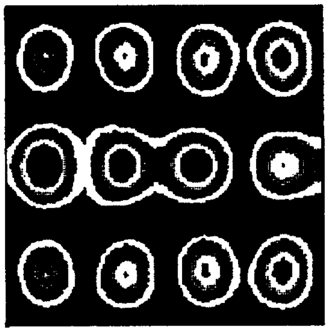

Fig. 3. Calculated Electromagnetic Energy Distribution

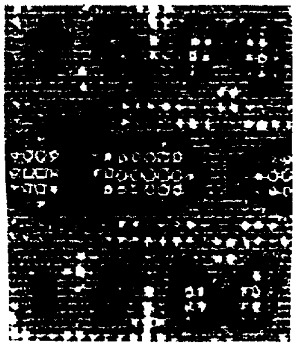

Fig. 4. Experimental Heating Unevenness