

Implementation of Algorithm of Thermal Quadrupoles for Filament Defect Detection

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Abstract— The report is devoted to implementation of algorithm of thermal quadrupoles for filament defect detection. The purpose of this research is the thermal quadrupoles model and algorithm of filament defect detection implementation with the FPGA.

Keywords— Thermal Quadrupoles, Multiprobe Microwave Multimeter, Analogy Method, Implementation, FPGA

I. INTRODUCTION

3D printing filament defects can cause poor print quality, failed prints, or even damage of printer. The common filament defects are inconsistent diameter, moisture absorption, cross-wound spools, brittle or snapping filament, clogged or dirty filament, color or material contamination, outgassing/bubbling, uneven coloring or pigment streaks.

3D printing filament with defects belong to multi-layer dielectric. One of model of multi-layered dielectric is thermal quadrupoles [1,2,3]. The defects are defined by its electro-physical parameters, thickness and depth of location.

The purpose of this research is the thermal quadrupoles model and algorithm of defect definition implementation with the FPGA.

II. EXPRESSION FOR DEFECT PARAMETERS

The method of thermal quadrupoles is an approach based on electrothermal analogies, originating from the heat conduction equation [1].

The equations for temperature and heat flux are combined into a system that can be represented in matrix form. This system matrix can be viewed as a four-port or thermal quadrupole with two inputs and two outputs. The cascaded four-ports are used to determine the overall gain by multiplying the gains of individual four-ports, thermal quadrupoles can be connected in a cascading manner to model the multi-layer structure of a sample with a defect. In the case of multilayer systems, the model is represented by the product of the matrices for each layer, analogous to the wave-transmission matrices used in electronics.

Algorithm for obtaining a solution to the inverse problem for three layers under the conditions that the total thickness of the multi-layer sample, temperatures, and heat fluxes included in the coefficients t_1 , t_2 , t_3 , and t_4 are known. The algorithm of inverse task of parameter defect definition is

multiply three matrices to get the matrix of the middle layer, i.e. the defect. The first matrix in the product is the inverse matrix of the transfer of the third layer. The second matrix in the product is composed of the coefficients t_1 , t_2 , t_3 and t_4 , with the coefficients arranged as follows: top left t_1 , bottom left t_2 , bottom right t_3 , top right t_4 . This second matrix is obtained either by measurement or during modeling by multiplying the matrices of all three layers in a direct problem. The third matrix in the product is the inverse matrix of the first layer. Matrices that multiply the matrix have dimensions two by two and the resulting matrix has the same dimension. Multiplication is performed in MathCAD using the Symbolic toolbar and the Simplify command.

Element by element equating the left and right sides of the product of the inverse transfer matrices of each of the three layers, each layer has its own transfer matrix, we obtain for the sine of the argument of the thickness of the middle layer multiplied by the coefficient and the cosine of the same argument expressions, and in double quantity, because the heat flow is inversely proportional to the temperature.

The sums and differences of sines and cosines in pairs are then determined. For the difference of cosines and the sum of sines, we obtain the equality of the expressions to zero and this allows us to transfer one of the terms through the equal sign. So we can obtain the tangent as the ratio of sine to cosine and determine the difference of the thicknesses of the first and last layer as the inverse.

The difference of the sines of an expression, if written out, gives, taking into account the signs of the original expressions, the doubled sine, which we square and obtain the inverse.

The thickness of the defect is determined using the trigonometric method of the supplementary angle.

From [1] expression for sinus of defect thickness in thermal quadrupoles model is

$$\sin(k_d \delta) = \frac{\sqrt{(t_1 + t_3)^2 + (t_2 - t_4)^2}}{2}, \quad (1)$$

where t_1 , t_2 , t_3 , t_4 are results of measurements.

It is known simplified formula for calculating load reflection coefficient in multiprobe microwave multimeter[2]

$$|\Gamma| = \left(1 + |\Gamma|^2\right)^{\frac{1}{2}} \frac{\sqrt{(U_1 - U_3)^2 + (U_2 - U_4)^2}}{\sum_{i=1}^4 U_i}, \quad (2)$$

where Γ is reflection coefficient, $U_1 \dots U_4$ are sensor signals. The physical meaning of formula (1) and (2) completely another, but it is similarity between expression (1) and (2) in root of sum of squares. For expression (2) exists ready solution. That solution could be apply for expression (1).

III. ALGORITHM REALIZATION

As to realization algorithm (1) on FPGA it is useful transform the algorithm as close as possible to apparatus description.

The method of implementing the formula is the use of a special analog-digital computer with processing according to simplified equations and based on FPGA. In particular, the operation of squaring the values $(t_1 + t_3)$ and $(t_2 - t_4)$ and extracting the square root are eliminated by the operation of finding the maximum of the voltages $|t_1 + t_3|$ and $|t_2 - t_4|$ and adding to 1/3 the minimum of these voltages. This operation gives a reading with an additional error of no more than 5,5% [2].

The analog-digital computer consists of selectors, addition blocks, digital-to-analog converter (DAC), switch, analog-to-digital converter (ADC) and indicator. The selectors, which are voltage comparators with controlled switches, select the maximum of the four input voltages and feed it to the input of the summing block. The voltage $\min\{\max(t_1, t_3), \max(t_2, t_4)\}$ is fed to the input of the summing block.

As a result, the voltages are proportional to $\max(|t_1 + t_3|, |t_2 - t_4|)$ and $\min(|t_1 + t_3|, |t_2 - t_4|)$ are sent to the inputs of the summing block, where they are summed in a ratio of 3:1. This voltage is supplied to the input of DAC. As a result, switch receives a signal proportional to $|t_1 + t_3|$ and $|t_2 - t_4|$. This processing technique gives the high speed of performance due to use of FPGA.

As compare with [5] algorithm and its implementation with FPGA proposed processing is more suitable for FPGA realization.

IV. CONCLUSION

The report is devoted to implementation of algorithm of thermal quadrupoles for filament defect detection. The purpose of this research is the thermal quadrupoles model and algorithm implementation with the FPGA.

Despite different physical meaning of expressions (1) and (2) there was used ready apparatus realization of expression (2) with modification for expression (1) for further implementation with on base of FPGA.

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