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FLEXIBLE PRINTED STRUCTURES QUALITY MODELS FOR MOBILE ROBOT PLATFORM

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ABSTRACT

The main factors influencing on quality of the flexible printed structures for mobile robot platform are analyzed. Requirements for the bases materials characteristics of such structures are considered. Models of mechanical, electrical and electromagnetic processes in electronic devices based on flexible printed structures are proposed. The developed models allow to predicate flexible printed structures quality level for use in the mobile robot platform design.

To automate the flexible printed structures design based on the proposed models, the software "Flexible PCB Designer" was developed, with the use of which it is possible to determine many design, technological and electrical flexible printed structures parameters.

Keywords: mobile robot platform, flexible printed structures; quality model, design, production technology.

1. INTRODUCTION

The flexible printed structures (FPS) using is an actual trend for the development of highly reliable electronic devices with a high density of printed circuit elements layout. Such structures include elements of flexible electronics, flexible electronic components, printed circuits and interconnection elements [1-3].

Particularly useful is the use of FPS for portable telecommunication devices, for terrestrial and satellite communication systems, military, household, and medical equipment, as well as for MEMS devices design.

The replacement of rigid hardware components of mobile robot platform (MRP) with flexible ones to improve their quality, functionality, reliability and reduce weight-size parameters, manufacturing labor intensity, cost, as well as the development of tooling based on flexible structures, are currently relevant.

Requirements for such products are constantly increasing due to the toughening of their operating conditions. At the same time, there is a serious problem of providing quality indicators of flexible components, since they can be exposed to a lot of destabilizing factors at all stages of the life cycle. For example, modules installed on mobile objects such as cars, airplanes, missiles, etc., during operation can be exposed to intensive mechanical influences such as impacts, vibrations, linear overloads [4-5].

One of the important directions in this area is the automation design of the main FPS elements and determining the technological process parameters for such structures manufacturing, as well as analyzing and predicting the state of FPS during their operation [6]. Therefore, the goal of the work was the development of a complex models of FPS parameters, as well as its software implementation.

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2. MATERIALS AND METHODS

2.1. Analysis of the FPS Requirements and Parameters

The important task for manufacturing is development of methods of quality technological support for electronic products based on FPS. One of such methods is forecasting of devices failures at the design, manufacturing and operation phases based on the analysis of the product operating conditions and modes, the parameters of technological process of its fabrication, and its output parameters.

FPS are widely used for a long time for intra- and interblock commutation of electronic devices (ED). Compared with traditional rigid printed circuit boards they have several advantages:
– compact dimensions achieved due to the thinner dielectric base,
– ergonomics, depending on the degree of FPS rigidity, flexible components can take various shape without loss of functional parameters,
– weight reduction that achievement also due to a thinner base, on average FPS are lighter than rigid boards by 75%,
– reduction of time and cost of assembly, due to the group methods of assembly and components mount.

Requirements for the FPS bases materials characteristics are the following.

a) Stability of dimensions: A flexible foiled dielectric must have exceptional dimensional stability. Shrinkage or expansion of the FPS base material during its processing can cause problem for electronic products fabrication and assembly and during it using.

b) Heat resistance: Since most high-temperature group heating processes, such as reflow soldering, are used at most electronic equipment manufacturers for components mount, it is extremely important that the material chosen for FPS fabrication also be able to withstand the soldering temperature without deforming.

c) Mechanical reliability: Many FPS designs are based on thin and not reinforced films, so they tend to break. So, the base material for FPS fabrication must have a high breaking resistance.

d) Electrical characteristics: As the signal transmission rate increases, the requirements to dielectric properties of FPS base increase. At high signal transmission rates (more than 100 MHz), the insulating material must have a small dielectric constant and a low loss tangent. In addition, for various high-energy problems it is desirable to have an average insulation resistance.

e) Flexibility: Depending on the application, FPS can be exposed to extreme temperatures. Therefore, flexibility over a wide range of temperatures is extremely important. Of particular importance is flexibility at low temperatures when most materials tend to be fragile.

f) Moisture absorption: Moisture absorption is not desirable for any flexible substrate. Moisture can adversely affect both the production process, causing stratification during processing or assembly, and on the characteristics of the finished product, changing the value of the dielectric constant and increasing the signal loss.

g) Resistance to chemical effects: The material of the FPS must withstand the effects of a number of reagents that accompany it during the manufacture and operation. The substrate must be compatible with various chemical reagents and typical solvents used in assembly and cleaning processes.

h) Repeatability of characteristics from batch to batch: The variability of the material parameters has an extremely negative effect on the FPS production, so the repeatability of the characteristics is important for good fabrication process control. Although the requirements for quality indicators may not be achieved in real production, the high repeatability of all material characteristics, including physical, mechanical, and electrical, is a key factor during technological processes. This property ensures that flexible structure will be processed well at manufacturing stages and will operate well during it using.

i) Cost: Standing for inexpensive solutions is a common practice in the field of electronics. As a rule, in the calculation of the product cost price, the base material price is the main parameter.

One of the important tasks of ensuring the necessary quality indicators of technical products, in particular, ED with the use of flexible components, is task of predicting their parameters and automation of this process.

It is possible to use the following description types of flexible structures in the ED structure:
– functional – represents the basic principles of operation and the physical and information processes taking place in ED based on FPS,
– design – represents the physical implementation of ED based on FPS, its geometric shapes, location in space, as well as used materials and components,
– technological – refers to the methods and means of manufacturing FPS and ED on their base.

There is a concept of stability of ED based on FPS, that can be characterized by normal functioning of the equipment under mechanical influences. The reasons for the disturbance of the electronic device stability are following:
– resistance value changing in the contact groups of connectors,
– changing the parameters of ED passive elements,
– changing the parameters of ED active elements,
– appearance of noise voltages in conductors, that are oscillating in magnetic fields,
– noise voltages appearance in oscillations due to the arising electric charges during mechanical actions in high-quality dielectrics.

The output parameters of the ED based on FPS can be influenced by mechanical, electrical, and technological parameters (or, according to the systemological terminology, input variables) [6].

The mechanical characteristics are stiffness, natural oscillations frequency, dynamic flexibility of the FPS base, wear out.

The electrical characteristics are parasitic parameters of the conductor system, electromagnetic compatibility, etc. [7-31].

The technological parameters include materials of the printed substrate (most often used type is polyimide) and conductive layers (aluminum, copper), number of FPS layers, width of the conductors and the gap between them, interlayer connection type (ultrasonic welding, gluing, etc.).

2.2. FPS Quality Models Development

The experiment implementation plan for FPS quality analysis includes:
– study of mechanical processes in the FPS,
– study of electrical processes in flexible structures,
– modeling of FPS reliability and quality,
– analysis of simulation results.
Applying the system analysis apparatus, the interaction of dissimilar physical processes in the FPS can be represented by a system of equations:

$$W\{X(\psi), Y(\psi), B(Z)\} = 0, \quad (1)$$

where W are the model operators connecting the input actions $X(\psi)$, the output characteristics $Y(\psi)$ and the internal model parameters $B(Z)$; Z is set of external influences; ψ is an independent argument (time, frequency, spatial coordinate).

Write down expression (1) for the model of mechanical processes in FPS (2), model of electrical processes (3), model of electromagnetic processes (4):

$$W_{mech}\{[\alpha_{in}(\psi)], [\alpha_e(\psi), \tau_d], [B_e(\psi), B_k]\} = 0, \tag{2}$$

$$W_{el}\{[L_{in}(\psi), R_{in}(\psi)], [Q_{out}(\psi), K_{out}(\psi)], [B_k]\} = 0, \tag{3}$$

$$W_{em}\{[Y_e(\psi), I_n(\psi), U_n(\psi), E_n(\psi)], [I_i(\psi), U_i(\psi), E_e(\psi)], [B_{em}(B_n(\psi)), B_k]\} = 0. \tag{4}$$

Here: $\alpha_{in}(\psi)$ are sets of vibrations (harmonic and random) acting on the object under study, impacts, linear accelerations; $\alpha_e(\psi)$ are sets of electronic components accelerations; τ_d are sets of time values before the electronic components pins destruction; $B_e(\psi)$ are sets of internal electrical parameters characterizing a definite physical process; B_k is the set of FPS geometric parameters; $L_{in}(\psi)$ are sets of input inductances; $R_{in}(\psi)$ is set of input resistances for the model of electrical processes in the FPS; $Q_{out}(\psi)$ is set of output Q-factors of the circuit; $K_{out}(\psi)$ are sets of output coefficients characterizing the filter capacity; $Y_e(\psi)$ are sets of electrical characteristics of electronic components; $I_n(\psi)$, $U_n(\psi)$, $E_n(\psi)$ are sets of currents, voltages and intensities of electromagnetic interferences; $I_i(\psi)$, $U_i(\psi)$ are sets of currents and voltages induced by noises in electrical circuits; $E_e(\psi)$ are sets of electromagnetic field intensities emitted by the ED; B_{em} is a set of internal model electromagnetic radiations; B_n is the set of internal model interferences caused by electromagnetic radiation.

Also, in the complex model structure developed for the ED on the FPS basis we introduce the sub model of reliability and quality

$$W_{RQ}\{[X_{RQ}(\psi), Y_{RQ}(\psi), B_{RQ}((Y_{el}(\psi), Y_T(\psi), \alpha_a(\psi), F_{TP}, F_t)]\} = 0, \tag{5}$$

where $X_{RQ}(\psi)$ are input indicators of reliability and quality; $Y_{RQ}(\psi)$ are output values of reliability and quality; B_{RQ} are internal model parameters, depending on: $Y_{el}(\psi)$ – the set of electrical characteristics of electronic components; $Y_T(\psi)$ – sets of thermal characteristics of electronic components; $\alpha_a(\psi)$ – sets of electronic components accelerations; technological factors F_{TP} and time factors F_t.

Internal model characteristics depend on the ED operation modes, obtained because of modeling various physical processes, technological factors (dispersion of parameters during FPS manufacture) F_{TP}, time factor (gradual change of parameters due to FPS aging and wear out) F_t.

Thus, the output parameter $Y(\psi)$, considering the destabilizing factors, will have the form (10):

$$Y(\psi) = \{Y_e(\psi), Y_{em}(\psi), Y_m(\psi), Y_{RQ}(\psi)\}, \tag{6}$$

where $Y_e(\psi)$ is the output parameter of the electrical processes model; $Y_{em}(\psi)$ is the output parameter of the electromagnetic processes model; $Y_m(\psi)$ is the output parameter of the mechanical process model; $Y_{RQ}(\psi)$ is the output parameter of the reliability and quality model.

Thus set of FPS parameters includes design D, electrical E, mechanical M, operational O and technological T parameters [6]

$$F = \{D, E, M, O, T\}. \tag{7}$$

In turn, the set of FPS design parameters includes the design parameters of the insulating and conducting layers:

$$D = \{w, l, t_b, t_f, a, p, b, l_p, D_m, N\}. \quad (8)$$

where w is the FPS width; l is the FPS length; t_b is the thickness of the FPS base; t_f is the thickness of the foil; a is the height of the adhesive layer, p is the length of the conductor, and b is its width; l_p is the distance between two conductors; D_m is the diameter of the metallized hole; N is the number of layers.

The electrical parameters are determined by the properties of the base and the conducting layer materials, as well as by the FPS operating conditions:

$$E = \{\varepsilon, \rho, tg\delta, E_p, L, C, C_p, U, U_p, I, R, f, P_p, Q, R_x\}. \quad (9)$$

Here ε is the permittivity of the FPS base; ρ is the electrical resistivity of the conductor material; $tg\delta$ is the loss tangent and E_p is the breakdown strength of the insulating material; L is inductance; C is FPS self-capacitance; C_p is stray capacitance between two adjacent printed conductors located on one FPS side; U is working voltage; U_p is allowable voltage drop on the conductor; I is current in the conductor; R is resistance of the printed conductor; f is the frequency of the current; P_p is the loss power; Q is the quality factor; R_x is the reactance.

Mechanical parameters characterize the properties of FPS materials and their resistance to mechanical effects, to which FPS can be exposed during their operation:

$$M = \{\sigma_y, \sigma_B, \delta, \varphi, H, E_m, G, P, \mu, r, n_l\}, \quad (10)$$

where σ_y is the yield strength; σ_B is ultimate tensile strength; δ is breakdown elongation; φ is relative breakdown necking; H is hardness; E_m is the modulus of elasticity; G is the shear modulus; P is plasticity; μ is the Poisson ratio; r is the permissible bend radius, n_l is the value of the neutral line of the FPS.

3. RESULTS

To automate the FPS design based on the proposed models, the software "Flexible PCB Designer" was developed. The software interface is shown on the Figure 1.

With the use of "Flexible PCB Designer" it is possible to determine many design, technological and electrical FPS parameters, in particular, the minimum allowable FPS bending radius, position of the FPS neutral line, allowable voltage drop in the printed conductor, parasitic capacitance of two parallel conductors, FPS self-capacitance and loss power, FPS interlayer capacitance, resistance of the printed conductor and others.

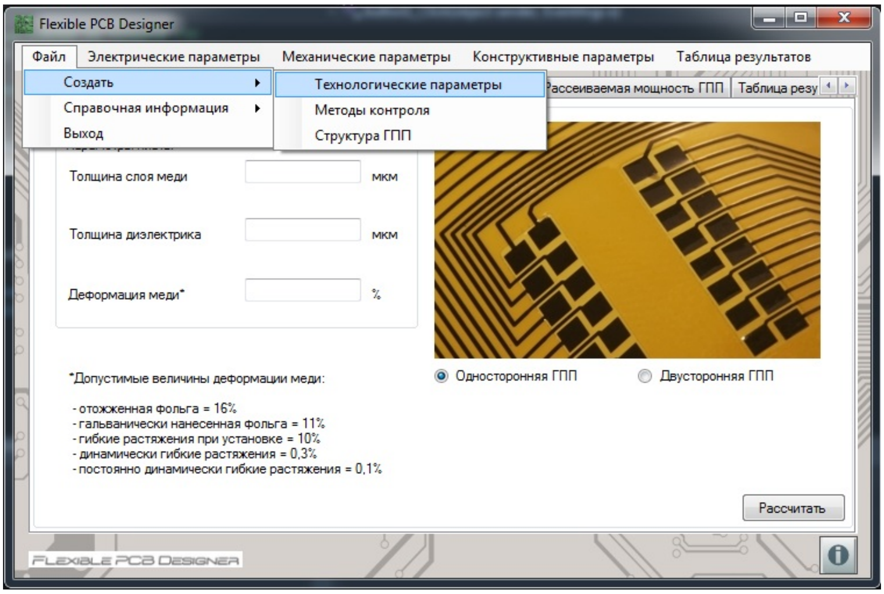

Figure 1. The main software window

In addition to the listed functions, the program includes the implementation of the possibility of filling design documentation (technological manufacturing parameters, recommended testing methods), and allows to build and visualize the FPS structure

4. CONCLUSİONS

Thus, the quality models of FPS in the ED design for MRP are developed based on analysis of mechanical, electrical, and electromagnetic processes in such structures. The software "Flexible PCB Designer" was developed to automate the FPS design, their mechanical and electrical parameters calculation.

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