Method of calculating the dosing device of the ink machine of the stencil machine

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Abstract. One of the ways of increasing accuracy of printed electronics elements produced with the use of stencil screen printing is the use of doctor rollers with a resilient cellular packing. The amount of paste in cells is regulated by a metering doctor blade and depends on the hydrodynamic pressure in paste. This paper presents a method of determining the thickness of the paste layer with a viscosity of 400 Pa·s on a print. The experiments showed that the pressure in the layer of paste in front of a moving doctor roller is 30000-130000 Pa. For the preliminary gap between the doctor blade and doctor roller of 0-0.3 mm, thickness of the paste layer on the print is 8-12.9 µm.

1. Introduction
Stencil screen printing is being increasingly used in manufacturing and research aimed at improving components in electronics [1–4]. The requirements for image accuracy obtained by stencil screen printing are also continuously growing. However, a screen printing method itself implies distortion of the reproduced images. This is due to the presence of the technological gap and the impact of the doctor blade on the printing plate. To improve the accuracy of stencil screen printing it is necessary to modify the design of a printing system. One of the ways of printing equipment development is the use of the printing system with a doctor in the form of a glazed roller. Attempts to use such a doctor and study its technological capabilities are known [5–8]. The range of doctor rollers applicability, the thickness of the applied layer of paint, the amount of dot gain for halftone images depending on the density of the net base of the printing plate, the pressure in the strip of printed contact, printing speed are defined in the papers.

Among the advantages for the smooth doctor roller one can make a note of the minimum net base strain during the printing process. The disadvantages include the limitation in the density of a net base, which should be not less than 150 nit/cm, as well as a greater possibility of dot gain, which is unacceptable in the manufacture of high-precision products.

As the development of doctor roller application it is proposed to use a doctor roller with the resilient cellular packing [9]. In the paper [10] the process of paste transfer on the surface of the LTCC-circuit workpiece when using a roller with a resilient cellular surface was considered. The amount of paint on the print is directly dependent on its amount in the cells of the resilient packing. Ink dispensing is done with a special metering doctor blade, which is a flat plate, being pressed against the surface of the resilient packing (Figure 1).

The pressure of the metering doctor blade on the resilient packing depends on the clamping pressure, its elasticity, roller doctor blade speed, and ink viscosity. The paper outlines the technique of determining the amount of paste on the print. The technique is based on the computational and full-scale experiments to determine the amount of paste in the cells of the doctor roller depending on specified parameters.

2. Task description
The object of research is the amount of ink in the cells of a resilient packing depending on various factors. Among them are resilient properties of packing and doctor roller material, paste viscosity with completely destroyed structure, the size of the initial gap between the metering doctor blade and resilient packing, rotation speed of the doctor roller. When the doctor roller rotates, the resilient packing is deformed due to hydrodynamic pressure. Thus, the objective of the study is to develop the technique for determining the amount of ink in the cells of a resilient packing. To achieve this it is necessary to solve the following tasks: to determine the value of hydrodynamic pressure in paste by calculation and experimental methods with different parameters; to define resilient packing deformation due to hydrodynamic pressure.

Figure 1. Schematic representation of the printing system with the doctor roller.

3. Experimental procedure
The metering doctor blade is made of steel, and the resilient packing is made of photopolymer. In addition, the modulus of elasticity of steel is 5...6 orders greater than that of a resilient packing. Therefore, the deformation of a doctor blade can be neglected. Printing is carried out with paste with a completely destroyed structure, so we take viscosity as constant and being equal to 400 Pa s, which corresponds to the viscosity of the paste for chip conductors manufactured on LTCC technology. Making the task more formal, we introduce the following assumptions:
− the pressure generated in the paste layer allows the paste to be considered as an incompressible fluid,
− the flow of paste is stationary and is considered in the plane to be perpendicular to the axis of the doctor roller.
To calculate hydrodynamic pressure a particularly designed program was applied, which uses the coordinates "vortex – stream function". Figure 2 represents the example of calculation in the form of a velocity field, and Figure 3 shows the distribution of pressure in paste at the rotation speed 0.2 rps of the doctor roller of 42 mm in diameter, which corresponds to a linear speed of approximately 2.5 cm/s. Photopolymer material NFS of Toyobo Co., Ltd. (Japan) of 2.85 mm thick was used for manufacturing flexo plates. The cells have a hexagonal form in the hexagonal packing (4). The lineature of cells is 20 lcm, the depth of cells is 0.156 mm. Cells are obtained by the photomechanical method adopted in the manufacture of flexo printing plates. A laboratory model of a doctor blade system was used for the experimental determination of pressure (Figure 5).
Figure 2. Velocity field during paste flowing. The broken line shows the segment of the doctor roller.

Figure 3. Pressure distribution in the paste: The broken line shows the segment of the doctor roller and paste.

Figure 4. Surface appearance of elastic shell with cells.

The measurements were conducted by the method of strain gauging. The sensors were placed according to the diagram shown in Figure 6. A flat doctor blade was installed at an angle of 30° to the
tangent to the circle at the point of doctor roller contact. At this angle doctor blades are installed in serial printing presses. The linear speed of the doctor roller was 2, 4, 6 and 8 cm/s. These values are recommended by the manufacturer of screen process equipment for applying the paste in production of LTCC chips.

Figure 5. Surface appearance of the laboratory model for measuring pressure in the paste. Cylinder diameter is 42 mm.

A strain-gauge was connected to the amplifier; amplifier signals were recorded with the digital oscilloscope PCS500 and processed in the program MS EXEL. Figure 7 shows the example of pressure distribution in the paste obtained on the oscilloscope screen.

Figure 6. Installation diagram of the pressure sensor.

Figure 7. Pressure distribution in the paste when the doctor roller moves.
Measurement of deformation of the doctor roller under hydrodynamic pressure was modeled with mechanical static pressure according to the diagram in Figure 8. Figure 9 represents the results of static load deformation measurement of the material NFS.

Measurement of the ink-film thickness was conducted using the universal stage microscope УИМ 21 according to the standard technique as the difference of the measured dimension of the glazed roller surface and the roller surface covered with a paste layer after exposure to a flat doctor blade.

4. Experimental results

The main results of the research are presented in the form of the dependence of the pressure in the paste layer placed in front of a moving doctor roller (Figure 10) on the speed of movement of the latter. Also rated and experimental dependence of the pressure in the paste layer on the motion speed of a doctor roller with a zero initial gap was obtained (Figure 11). In addition, Figure 12 shows the dependence of the thickness of the paste layer on the print on the motion speed of the doctor roller.

It is clear from Figure 10 that the pressure in the paste is higher if the initial gap between the metering doctor and doctor roller is less. So, for the initial gap of 0 mm the pressure at the minimum speed (0.2 cm/s) is 60,000 Pa, for the initial gap of 0.2 mm it is 40000 Pa, and for the initial gap of 0.3 mm it is 30000 Pa. With the increase of the doctor roller speed, the pressure in the paste grows nonlinearly. So, for the initial gap of 0 mm at the at the roller doctor motion speed of 0.8 cm/s, the pressure is 128000 Pa, for the initial gap of 0.2 mm it is 120000 Pa, and for the initial gap of 0.3 mm it is 116000 Pa. That
is, with the increase of the doctor roller motion speed, the difference between the pressures for different initial gaps is decreased, and the line dependency graphs converge. This is due to the fact that by increasing the doctor roller motion speed, the speed growth of the paste in the gap between a flat doctor blade and roller is slower than in the rest of the paste, which leads to the growth slowdown of pressure. Under further increase in the doctor roller motion speed, the pressure with different initial gaps will be identical.

![Figure 10](image)

**Figure 10.** Dependence of calculated pressure in paste on the doctor roller speed.

It is seen from Figure 11 that the calculated and measured values of pressure are different. However, the differences are small. Thus, at the minimum doctor roller motion speed (2 cm/s), the calculated and measured pressures are 52000 and 54000 Pa respectively, which is about 3%. This difference is within limits of measurement uncertainty. It should be noted that generally the type of calculated and measured dependencies agrees.

To define the thickness of the paste layer on the roller surface, for the pressure calculated for the corresponding speed, for the graph of the resilient packing deformation it is necessary to determine its deformation. Since the thickness of the resilient packing material is known, it is possible to determine the deformation in micrometers, which will determine the thickness of the paste layer.

![Figure 11](image)

**Figure 11.** Dependence of calculated and measured pressure on the speed of the doctor roller with zero initial gap.
Figure 12 shows that the thickness of the paste layer on the print in direct proportion to the pressure in paste, located in front of the moving doctor roller and to the initial gap between the metering doctor blade and doctor roller. Thus, when the speed of the doctor roller is 2 cm/s and initial gap is 0 mm, the layer thickness is 8.4 µm, and when the maximum speed is 8 cm/s, the thickness is 12.9 µm. In this case, the difference of thicknesses for different initial gaps increases when the speed increases. At the minimum motion speed of the doctor roller the difference of thicknesses is approximately 0.1 μm, and with the maximum speed it is 0.5-1 μm.

5. Results discussion
The thickness of a paste layer on the print depends on the pressure in the paste in front of the moving doctor roller. This pressure largely depends on the doctor roller motion speed. The pressure can be increased by increasing the speed of rotation of the doctor roller. However, the best version is when the doctor roller rolls on the surface of the printing plate without slipping. This is due to the fact that with the increase of internal shear the temperature of the paste and its viscosity vary nonlinearly, resulting in decreased predictability result. On this basis, when making calculations, the doctor roller was assumed to roll on the plate surface without slipping. The doctor roller motion speed was chosen based on the parameters of available equipment.

The data shown in Figure 11 allow us to draw a conclusion about the adequacy of the developed model of paste flow. The graphic dependences obtained for other parameters of the printing process are of a similar nature. The pressure in the layer of paste is from 30000 to 130000 Pa for different doctor roller motion speeds and the preliminary gap between the metering doctor and doctor roller. The graphic dependences in Figure 12 allow one to determine the amount of paste on the print in the range of 8-12.9 µm.

Thus, the sequence of mode selection for the printing process consists of the following steps. Based on the requirements for conductors from the point of view of their electric properties, at the stage of development of an electronic device, the conductor thickness which is necessary to obtain on the print is selected. The width of the conductor is assigned by the width of the printing element of the screen stencil. The mechanical properties of the resilient packing of the doctor roller are determined from experiments or data sheets. The pressure in the paste is determined from the obtained model of the paste flow, this paste being placed in front of the moving doctor roller. From the obtained graphic dependencies the speed of doctor roller motion and a preliminary gap between the flat doctor blade and resilient packing is chosen, which allows one to achieve the desired thickness of the paste layer on the print.

6. Conclusion
The proposed method allows determining the amount of paste on the print, which is important in the manufacture of electronic components. To use the techniques it is appropriate to determine the
deformation of the resilient packing by making calculations on the pressure in the layer of paste, which moves due to the doctor roller in the ink mechanism. Comparison of the calculated and experimental data has shown their good agreement, and that allows one to use the computational method without experiments. To determine the pressure in the paste it is necessary to know its rheological characteristics that normally are given in supporting documentation of the manufacturer. In addition, it is necessary to know the mechanical properties of the elastic shell, which are also available in the documentation on the material, or are measured by certain methods. As a result of data processing, a characteristic curve of the amount of paste on the surface of the cylinder is formed. The obtained dependences determine the settings of the printing process (the doctor roller speed and a preliminary gap between the flat doctor blade and resilient packing) depending on the required amount of paste on the print. The experiments showed that with the speed of the doctor roller in the range of 2-8 cm/s for preliminary gap of 0-0.3 mm between the metering doctor blade and doctor roller, the thickness of the paste layer on the print is in the range of 8-12.9 µm. The pressure in the paste is changed in the range of 30000-130000 Pa.

7. References

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