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The Technology of Constructing of Cylindrical Photoreceptor

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A Photoreceptor is the main element for electrostatic image formation in xerographic machines, which is usually a cylinder with three layers.

By considering the result of theoretical studies (Solving the Laplace equation, for Fourier transform of potential) a three-layered photoreceptor with conductive layer Al, photoconductive layer Se and intermediate layer Al_2O_3 was designed and made. The deposition of Al and formation of Al_2O_3 were carried out at $5\cdot10^{-5}$ – 10^{-6} mbar pressure. Coating of high purity Se was carried out under $2\cdot10^{-7}$ mbar pressure, 220°C boat temperature, and 105°C substrate temperature in 110 min. After electrostatic measurements, the function of the sample was tested by mounting it in a Xerox machine with successful results.

Key words: Photoreceptor – Latent Electrostatic Image – Vacuum Coating – Amorphous Selenium.

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I. Introduction

A photoreceptor used in imaging systems, e.g. copier machines, printers, etc., is in a cylindrical shape and consists of a cylindrical substrate, photoconductor and a barrier between these. For imaging from a document, initially the cylindrical photoreceptor-photoconductor layer is charged in a dark medium and then illuminated with opto-image of the original document. The result of interaction between opto-image and charged surface of the cylindrical photoreceptor reduces surface potential in illuminated area; leading to the formation of electrostatic latent image. This latent electrostatic image could be developed or transported to any other location. Cylindrical photoreceptor in the many imaging machines used, since suitable geometrical properties of cylindrical photoreceptors easily provides all steps of xerographic process in the limited space of imaging machine:

II. Theoretical bases

Based on results obtained from the studying different xerographic processes and an actual photoreceptor, a three layered-model in the general state was considered.

Assuming thickness t_j and permeability ε_{rj} (j=1,2,3), and σ, is the surface charge density that exists between first and second layer.

Where:

$$\nabla^2 V(x, y, z) = 0$$

Using Fourier transform of potential in two dimensions to solve the equation, the results for potential is:

$$\bar{V} = A_j e^{kz} + B_j e^{-kz}$$

consequently Fourier transform of electric field equals:

$$\bar{E} = -k\left(A_j e^{kz} - B_j e^{-kz}\right)$$

Where A_j and B_j are constant values and obtained from boundary conditions as bellow.

$V_1(x,y,z)=0$ at $z=0$
$V_1=V_2$, $\varepsilon_{r2}E_{2z} - \varepsilon_{r1}E_{1z} = \sigma$ at $z=t_1$
$V_2=V_3$, $\varepsilon_{r3}E_{3z} - \varepsilon_{r2}E_{2z} = 0$ at $z=t_1+t_2$
$V_3=V_0$ at $z=t_1+t_2+t_3$

By taking the distribution of charge equal to 1 c/m^2, the A_j and B_j can be derived and then the Fourier transform of electric field or transfer function will be as following:

$$\bar{E}(k,z) = \left\{2\varepsilon_{r2} \; e^{-k(t_2+h)}\left[1+e^{\;-2k(t_3-h)}\right]\tanh kt_1\right\}/$$
$$/\left\{(\varepsilon_{r2}+\varepsilon_{r3})\left[\varepsilon_{r2}\tanh kt_1+\varepsilon_{r1}\tanh \; k(t_2+t_3)\right]\left[1 \; +e^{-2k(t_3+t_2)}\right]+\right.$$
$$\left.+(\varepsilon_{r3}-\varepsilon_{r2})\left[\varepsilon_{r2}\tanh \; kt_1 \; - \; \varepsilon_{r1} \; \tanh \; k(t_3-t_2)\right]\left[e^{-2kt_1}+e^{-2kt_3}\right]\right\}.$$

Where K is spatial frequency and h is the height of considered point, and it is observed that transfer function only depends on spatial frequency (K). Therefore to obtain suitable variation of spatial frequency at which transfer function is not zero, exponentially-decreasing behavior of transfer function $\bar{E}(k,z)$ versus spatial frequency in a specific state with t_1=50 μ, t_2=50 μ, t_3=100 μ, ε_r =6.3, ε_{r2}=2.3, ε_{r3}=1, and h=0,5,10 were studied.

From this figure we observed at first, that the field increased with increasing the spatial frequency, but after a period of time it decreased exponentially as expected. The reason for this behavior could be justified as follows:

In the beginning of increasing the spatial frequency, because of the absorption of light pulse by photoconductor layer, some charges were injected to it. But after a period of time, arisen currents from generated electrons (due to the absorption of light pulse) and their movement to surface caused $\bar{E}(k,z)$ to decrease exponentially.

The results of these studies determine the ranges of limits of spatial frequency variations at which $\bar{E}(k,z)$ is not zero.

To obtain distribution of electric field or spread function, we must take inverse Fourier transform. Therefore by taking inverse Fourier transform and using the cylindrical coordinates (r,θ,z) the spread function is obtained as equation bellow:

$$E(r,z)=\frac{1}{2\pi}\int_0^{\infty} kJ_0(kr)\bar{E}(k,z)dk\,.$$

Where $J_0(kr)$ is zero Bessel function with kr argument. Exponential decrease of the behavior of spread function E(r,z) in the area which transfer function $\bar{E}(k,z)$ prevail over Bessel function $J_0(kr)$, is proportional to behavior of decreasing the surface potential of photoconductor in opto-image interaction with charged surface of photoconductor (that forms the latent electrostatic image). Now, by having the domain of suitable variations of spatial frequency the behavior of spread function could be investigated. The behavior of spread function E(r,z) versus r with spatial frequency obtained from figure (1) and the same values ε_{rj} , t_j were studied which resulted in figure (2) .

Decreasing of E is exponential for r-values as long as $\bar{E}(k,z)$ prevails over Bessel function. However in higher values of r, the Bessel function prevails over $\bar{E}(k,z)$ that is not desirable.

Also by studying limit cases where $k \to 0$ or $k \to \infty$, $t_j \to 0$ or $t_j \to \infty$ the optimum behavior of function was determined. A thin film of a:Se with 20μ thickness as the photoconductor layer, Al as the conductor layer, and Al_2O_3 with 10μ thickness as the intermediate layer were chosen. By optimizing behavior of E(r,z) obtained results from the analysis of an actual photoreceptor, resultant conditions and constraints from theoretical considerations, by considering applied remarks and testing of the already made sample in an actual machine.

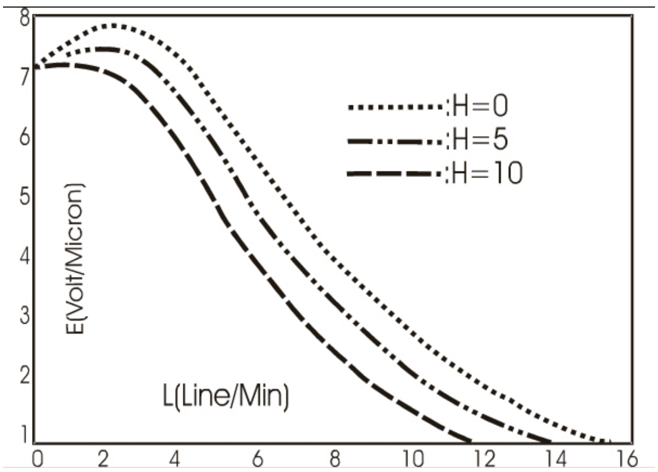

Fig. 1. Drawing the electric field versus spatial frequency by using of the Matlab Softer and determination of permissible spatial frequency range

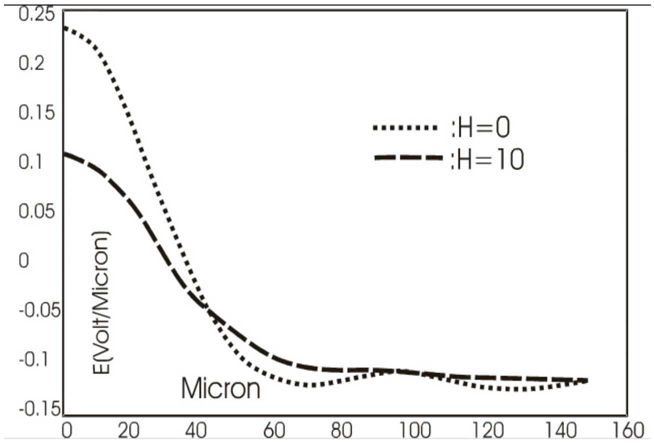

Fig. 2. Reduction of photoconductor electric field in Permissible spatial frequency range

Fig. 3. Substrate rotator and holder system.

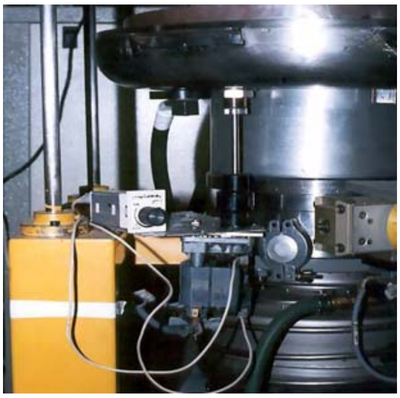

Fig. 4. Control rotation speed system.

Fig. 5. The coating system and its subsystems.

Fig. 6. Al deposition and Al_2O_3 formation.

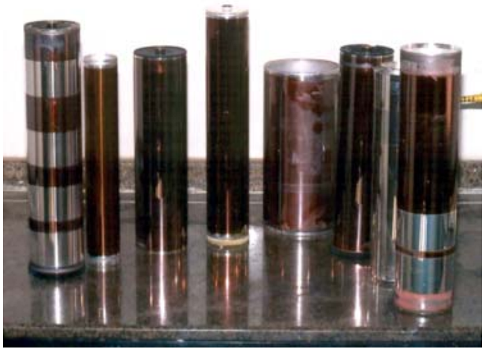

Fig. 7. Se deposition on the Al_2O_3.

Fig. 8. Photoreceptor resistance measurement upon exposure to light.

Fig. 9. Photoreceptor resistance measurement in dark.

III. Experimental methods

A cylindrical photoreceptor substrate is an Al cylinder where is external surface has been polished with center less method. Conditions for constructing cylindrical photoreceptor, in order to form a complete electrostatic image of cylindrical photoreceptor ,were:

1 – The tube must be cut with suitable dimensions.

2 – In polishing the cylindrical photoreceptor, the formation of oxide layer do to the hot should be prevent surface from polishing should be kept free from any dust that can deposited during the polishing fraction.

3 – The curvature of tube is very negligible, thus after polishing and then coating no defects are to be observed.

4 – It has a suitable mechanical stability.

5 – No cracking or spotting in the surface of the tube is produced due to tension.

6 – Surface is polished in center less method with suitable depth.

And finally the required conditions of construction of photoconductor in xerographic processes, determines the method making of its layers.

The amorphous selenium structure is suitable for photoreceptor. This structure is formed in temperatures bellow Se Melting point, whereas for forming Se thin film, we must evaporate it in vacuum on a proper substrate.

This technology was already available in our laboratory. We had to design and make substrate holder and rotator (Fig. 3), rotation speed controller (Fig. 4), special boat, boat and substrate temperature controller system, vapor rising angle controller and etc. (Fig. 5).

By installing the subsystems on the coating system, their function was tested and optimum conditions were obtained. After preparing of cylindrical substrate, it was mounted on the holder and rotator. Al deposition and Al_2O_3 formation were carried out in $5\cdot10^{-5}$ –10^{-6} mbar pressure (Fig. 6).

Then deposition of Se on the Al_2O_3 was carried out under conditions as bellow: 220ºC boat temperature, 105ºC substrate temperature, $2\cdot10^{-7}$mbar pressure, in 110 minutes. Se layer was formed amorphous, without any crystallization and with the desired thickness.

IV. Electrical measurements

For electrical measurements, the prepared photoreceptor was held in dark for 72 h, then it was exposed to a light source with a determined intensity. The sample resistance with the mentioned conditions was measured zero. This result indicated that the photoreceptor, upon exposure to light, would become photoconductor and charge generation and transport were of charge were carried out correctly (Fig. 8). This phenomenon is very important in xerography process, since surface discharge and latent electrostatic image formation occur in these conditions.

In the next step, the sample was put in a completely dark medium and its resistance was measure, which was over 10^{12} Ω (Fig. 9).

High resistance in dark medium for xerographic photoreceptor is very essential, because the low conductivity for the development and transfer of electrostatic image is necessary.

V. Testing function of the actual machine on a sample

For testing operation of the photoreceptor, it was placed in a Sharp 7200 Xerox machine. The results of this test indicated that all the xerographic processes including surface charging, generation and transport of charge, surface discharge (corresponding to opto-image) and consequently latent electrostatic image formation, development, toner image formation and its transfer and fixing on a paper were achieved successfully.

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Технологія конструювання циліндричних фоторецепторів

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Фоторецептор є основним елементом для утворення електростатичного зображення в копіювалій машині, що являє собою циліндр з трьома пластами.

Результати теоретичних досліджень (розв'язання рівняння Лапласа через Фур'є перетворення потенціалу) дали змогу розробити та виготовити трьох-пластовий фоторецептор з провідним пластом Al, фотопровідним пластом Se та проміжним пластом Al_2O_3. Залишки Al та утворення Al_2O_3 отримано при тиску $5{\cdot}10^{-5}$-10^{-6} мбар. Покриття високо-чистим Se відбувалося при тиску $2{\cdot}10^{-7}$ мбар, температурі корпусу 220°C та температурі підкладки 105°C впродовж 110 хв. Після електростатичних вимірювань зразок піддали випробуванню на апараті Xerox і було отримано чудові результати.