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Sheet sticking caused by charge flow in a buried conducting layer

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ABSTRACT

Electrostatic charge causes sheets to misfeed from the input stacks in inkjet and laser printers. Conductive layers within sheets that suppress discharges and reduce particulate contamination also aggravate sheet sticking. The surface potential of sheet media is a direct measure of the charge in the buried conducting layer. Our experiments find that the times characterizing the voltage transients range from 10 to 1000 s for conductive layers with sheet resistivities in the range from 10^{+9} to 10^{+11} Ω/□. Our models predict that charge flowing in the conducting layer increases the electrostatic sticking force. Model predictions are in agreement with our experimental measurements.

1. Introduction

As shown in Fig. 1, electrostatic charge causes sheets of media to stick to each other. Initially, these sheets slide apart easily. However, when the contact area becomes small, the attractive force increases and causes the sheets to stick together. Fig. 2 depicts a simple printer, scanner, or other device that feeds a sheet from an input stack, transports it through the device, and collects the finished sheet in an output bin. Even with excessive static charge on the top sheet of the input stack, the sheet initially slides easily when a feeding sequence begins. During the feeding sequence, the static charge may cause the sheet to stick to the input stack, which reduces the reliability of sheet feeding. As the sheet is transported through the device, charge also may cause the sheet to stick to rollers, guides, and other objects in the transport path, which results in jams, reducing the overall reliability of sheet transport.

Preventing electrostatic problems during the transport of flexible media has been extensively studied. Improving static performance by providing a conductive layer on the surface of flexible media dates back to at least 1938 [1]. There are several disadvantages to using a conductive layer on the surface of films or sheets. The layer is exposed to the ambient environment and its properties may change with the relative humidity. Also, the components in the conductive layer may wear or change over time, limiting product shelf life. And, if the media must undergo processing, such as photographic development, the surface layer may cause undesirable foaming and be washed away, which compromises future static performance.

Burying the conductive layer within the media eliminates many of these problems and maintains good performance over time. Burying a layer specifically formulated for conductivity beneath a protective overcoat dates back to at least 1980 [2]. In the same way, resin-coated paper for photographic printing has benefited from the conductivity of the paper core.

However, buried conductive layers aggravate sheet-sticking problems. Buried layers are electrically isolated, so charge within the layer cannot flow easily to ground. As the sheet is fed from the input stack and transported through the device, charge flows through the conductive layer.

Understanding this flow of charge within the buried conductive layer is fundamental to predicting static performance. Because it is difficult to directly measure the charge flowing in the buried conductive layer, we measured the surface potential of a sheet that was lying flat on a grounded plate. The standard size of a medical imaging film sheet is 14 × 17 in., which is commonly designated 35 × 43 cm. Voltage was applied to an electrode that was clamped to one end of the surface of the sheet to electrically excite the system. The surface potential over the length of the sheet varied as charge flowed through the conductive layer.

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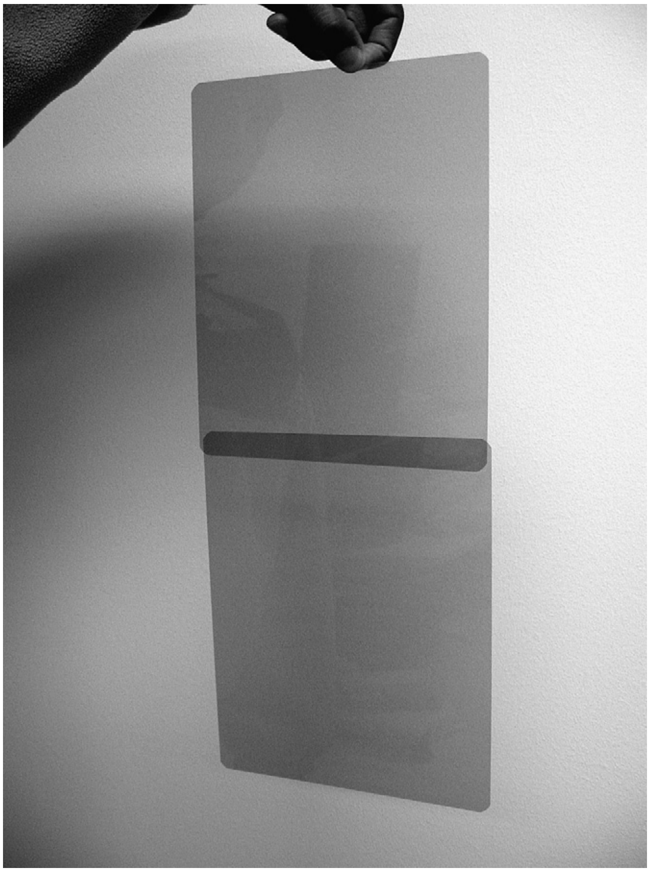

Fig. 1. Electrostatic charge causes sheets to stick. Each sheet has a buried conducting layer.

We measured the time characterizing the transient voltage to be in the range from 10 to 1000 s for conductive layers with sheet resistivities in the range from 10^{+9} to 10^{+11} $\Omega/\square$. The voltage transient is expected to be much faster for the area of the sheet that is separated from the stack. When the duration of the voltage transient is on the same order of magnitude as the mechanical time for feeding and sheet transport, there is a strong coupling between sheet motion and electrical forces [3].

We report the results of three models that predict the charge flow in a conductive layer that is buried within a sheet. The first is a lumped-parameter electromechanical model that predicts electrostatic sticking caused by charge flowing during sheet feeding, which accumulates in the area of the sheet that is in contact with the stack. The next is a first-principles model based on an equivalent circuit that includes the resistivity of the conductive layer. Finally, a finite element analysis includes the effects of fringing electric fields. The key results are that charge flows, causing sheet sticking, and the surface potential is governed by the diffusion equation. The sheet resistivity and capacitive coupling to the grounded plate determine the diffusion constant.

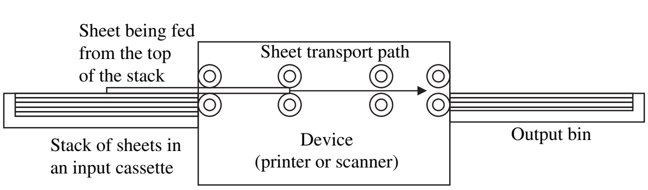

Fig. 2. Electrostatic charge on the sheet causes it to stick to the top of the input stack (misfeed), or jam as the sheet is transported through the equipment.

2. Theory

2.1. Lumped-parameter electromechanical model

Lumped-parameter electromechanical models are useful when analyzing coupling between electrical networks and mechanical systems [3]. To analyze a sheet being fed from a stack, the electrical network shown in Fig. 3 is a capacitor with a fixed, grounded electrode, which represents the stack of sheets, and an electrode that can move horizontally, which represents the sheet being fed. The mechanical system is the sheet being fed approximated as a rigid plate with a known mass. The sheet is under tension so it is effectively rigid. The buried conducting layer is distance d above the lower surface and is distance h below the upper surface. A "virtual air gap" of height δ exists between the sheet and the top of the stack. The electric field across this air gap causes the sticking force.

Four state variables characterize this electromechanical system. The electrical variables are the charge Q_0 on the sheet and the voltage V of the conductive layer. The mechanical variables are position x of the sheet and the electrical force F_e acting on the sheet. Feeding failures have been experimentally observed when F_e is on the order of 1 Nt.

An initial charge Q_0 on the upper surface of the sheet is represented by five positive charges. The conducting layer has an image charge – Q_0 represented by five negative charges. Because the conducting layer is electrically isolated, charge is conserved by adding five positive charges that are mobile and will move, as the sheet is fed, to maintain the conducting layer at a uniform potential.

The voltage of the conductive layer as a function of initial charge and position x is given in (1).

$$V_0 = \frac{Q_0}{C_{\text{eff}}} = \left[\frac{\frac{d}{\kappa_r} + \delta}{\varepsilon_0 (L - x) W}\right] Q_0 \tag{1}$$

The voltage of the conductive layer increases as the sheet is pulled from the top of the stack (increasing x) and charge concentrates where the top sheet remains in contact with the stack. Voltage also increases with increasing air gap δ. The electric field across the virtual air gap is given in (2).

$$E_z = \frac{\sigma_0}{\varepsilon_0} = \frac{Q_0}{\varepsilon_0 (L - x) W} \tag{2}$$

The electric field is independent of the air gap height δ and increases as the sheet is pulled from the top of the stack. The electrical energy W_e stored in the system is given in (3).

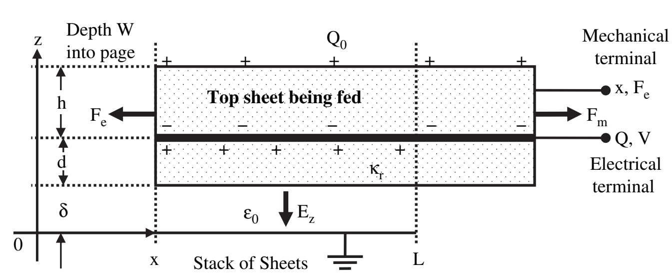

Fig. 3. A lumped-parameter, electromechanical model for a sheet being fed from a stack shows that sticking occurs when the mechanical force F_m feeding the sheet is dominated by the opposing electric force F_e.