Paper Separation and Feed Mechanisms Utilizing Electrostatic Force

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Abstract

New mechanisms of paper separation and feed systems were proposed to realize a highly reliable paper-handling system for printers. The new paper-separation system consisted of a pair of parallel electrodes and a paper pile between the electrodes. In this system, electrostatic separation of a piece of paper was realized always at the top of the pile when the applied voltage exceeded a threshold to generate electrostatic force larger than the weight of a paper. The threshold voltage was about some hundred volts, and it agreed with the numerical value calculated by the FEM for the electrostatic field. Additionally, lateral pull-off force of a paper from the attached electrode was measured to confirm the required force to feed the separated paper. The value was some μN/mm^2 that was also in the same order as the calculated pull-off force estimated from the friction coefficient between them and the electrostatic force between the plate electrode and the adhered paper. Two kinds of new paper-feed systems have been also developed. One consisted of a pair of parallel plate electrodes and two sheets with slanted fibers. In this system, vertical vibration of the electrodes was realized when the alternating electric field was applied between the electrodes. Paper attached between the sheets was fed in the horizontal direction in the order of 1 mm/s utilizing the vibration and anisotropic feature of the friction of slanted fibers. Another system consisted of an electrostatic particle conveyer with parallel electrodes, particles, and a sheet of paper on them. The paper is fed about 100 mm/s almost synchronized with the linear motion of particles driven by traveling electrostatic field.

Introduction

A friction roller is being used for a paper separation and feed system in printers. However, because friction depends on paper characteristics and environmental conditions, miss-feeds sometimes take place when the friction roller is deteriorated. In this study, a new paper separation and feed systems are proposed to realize a highly reliable paper-handling system for printers.[1]

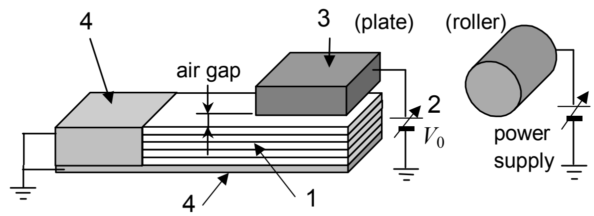

Figure 1. Experimental set-up of electrostatic paper-separation system. (1: paper pile (five sheets of paper), 2: power supply, 3: applied electrode, 4: ground electrode)

Table 1. Properties of Papers Used for Experiments.

	thickness mm	weight μN/mm^2	conductivity σ S/m	relative permittivity ε_r
PPC	0.10	0.68	3.9×10^{-10}	1.70
pasteboard	0.32	2.04	5.8×10^{-10}	1.82
tracing	0.05	0.49	1.5×10^{-10}	2.86
glassine	0.03	0.29	7.6×10^{-11}	3.52
double-side coated	0.12	1.56	3.3×10^{-10}	1.48

Paper-Separation Mechanism

System Configuration and Experimental Procedure

An experimental set-up shown in Fig. 1 was constructed to demonstrate the separation of a sheet of paper on the top of a paper pile. The set-up consisted of a pair of parallel electrodes and the paper pile between the electrodes. High voltage was applied between the electrodes by a DC power supply (Matsusada Precision Inc., HVR-10P, 0~+10 kV). Properties of papers (L90/W30 mm) used for experiments are summarized in Table 1.

Modeling

In this system, electrostatic separation of a sheet of paper was realized when the applied voltage exceeded the threshold to generate electrostatic force larger than the paper weight. A numerical calculation was conducted to determine the threshold voltage and to confirm that only the top paper is separated with this system. The electrostatic force per unit area f applied to the paper was calculated from the difference of the Maxwell's stress between the upper and lower surfaces of the paper.

$$f = \frac{1}{2}\varepsilon_0\varepsilon_r(\boldsymbol{n}\cdot\boldsymbol{E})^2 , \tag{1}$$

where ε_0 is permittivity of free space, ε_r is the relative permittivity, $\boldsymbol{n}$ is a unit normal vector to the boundary, and $\boldsymbol{E}$ is the electric field ($= -\nabla\phi$, ϕ : potential). The electric field was calculated with the Poisson's equation (2) and the conservation of charge (3).

$$\nabla\cdot(-\varepsilon_0\varepsilon_r\nabla\phi) = \rho , \tag{2}$$

$$\nabla\cdot(-\sigma\nabla\phi) + \frac{\partial\rho}{\partial t} = 0 , \tag{3}$$

where ρ is the charge density and σ is the conductivity of the paper. Boundary and initial conditions are as follows.

$\phi = V_0$	*on the applied electrode, where V_0 is the applied voltage.*
$\phi = 0$	*on the ground electrode.*
$\boldsymbol{n}\cdot\nabla\phi = 0$	*on other insulated boundaries.*
$\rho = 0$	*at $t = 0$.*

Distributions of the potential and the charge density were numerically calculated with the Finite Element Method. Figure 2 shows the geometries and linear triangular mesh patterns for the FEM calculation.

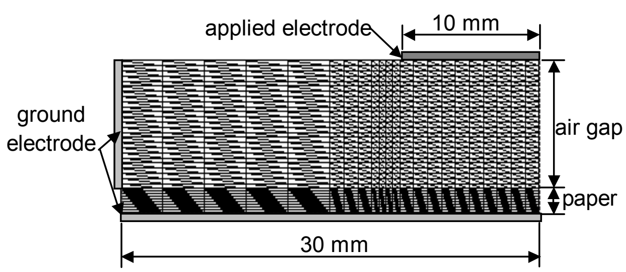

Figure 2. Geometries and linear triangular mesh patterns for FEM calculation.

Results and Discussion

Figure 3 shows an example of the calculated time response of the electrostatic force on the top and second papers and the charge density in the top paper. Because the time constant was about 0.03 seconds, the force applied to the paper was almost constant and it was applied only to the top paper at the time 0.1 second after the step voltage application. This is confirmed by Fig. 4 that shows the time response of the potential distribution around the paper pile. The electrostatic field in the paper was gradually decreased and it almost vanished at the time 0.1 second after the step voltage application. Thus the electrostatic field, the gradient of the potential, was large at the upper face of the top paper but almost no field was generated in the paper pile. This feature means only the top paper is separated from the pile.

Figure 5 shows the calculated electrostatic force on the top paper. It is assumed that the paper separates from the pile and adheres to the applied electrode when the applied voltage exceeds the threshold that the electrostatic force is equal to the paper weight. Figure 6 shows the calculated and measured threshold voltage. The calculated roughly agreed with experimental results. Although the time constant is determined by the conductivity and permittivity of the paper, the threshold voltage based on the saturated force is solely dependent on the paper weight.

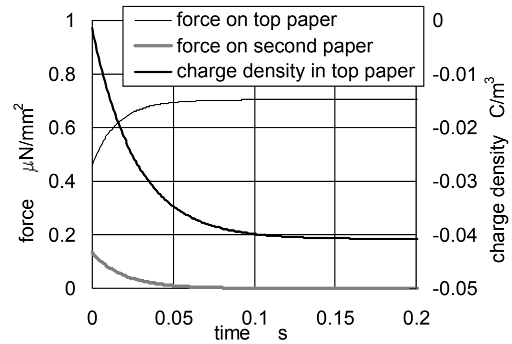

Figure 3. Time response of electrostatic force and charge density. (PPC, 5mm gap, V_0 = 2,000 V)

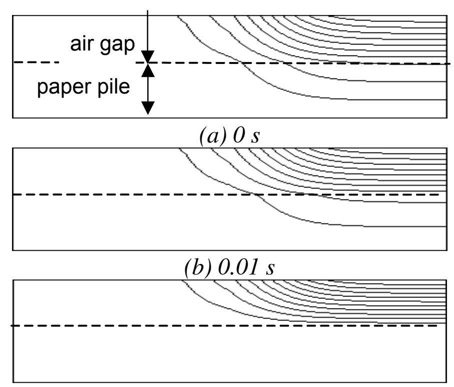

Figure 4. Potential distributions in the vicinity of paper at the designated time after step voltage application. (PPC, 5 mm gap, V_0 = 2,000 V)

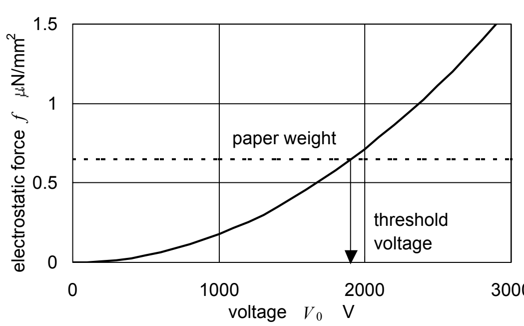

Figure 5. Calculated electrostatic stress on the right end of the top paper and paper weight one second after application of step voltage. (PPC, 5.0 mm gap)

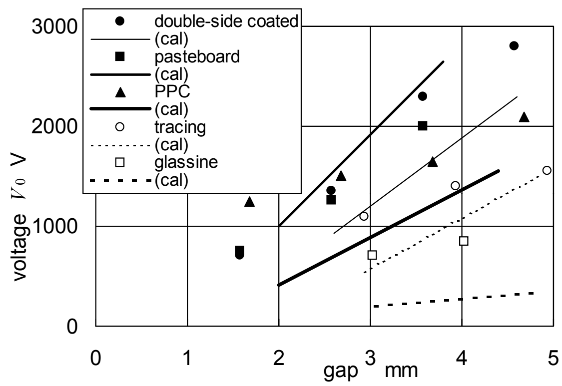

Figure 6. Comparison of measured and calculated threshold voltage of paper separation.

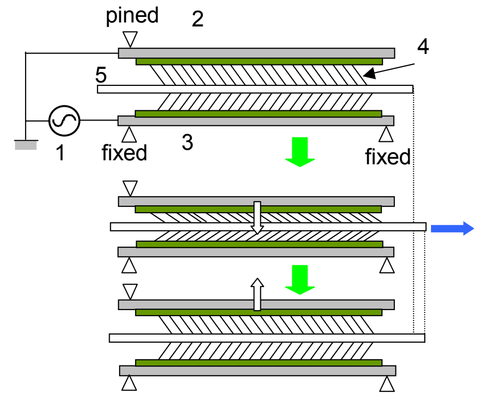

Figure 8. Schematic diagram of paper-feed system utilizing sheets with slanted fibers. (1: AC power supply, 2: upper plate electrode, 3: lower plate electrode, 4: sheets with slanted fibers, 5: paper)

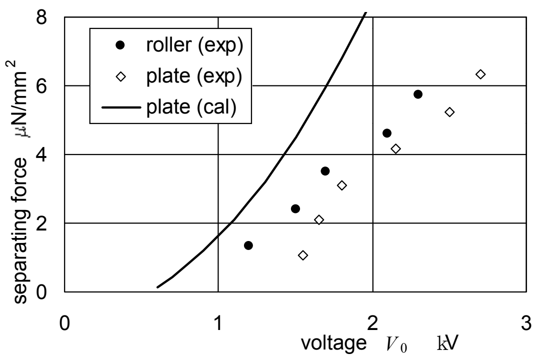

Figure 7. Lateral separating force of paper from separating electrode. (paper: PPC)

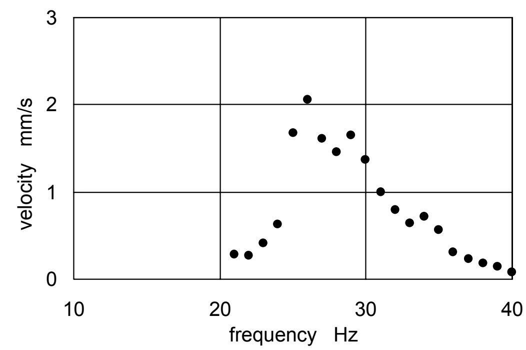

Figure 9. Speed of paper feed in paper-feed mechanism with slanted fiber sheets (1,000 $V_{0\text{-}p}$)

The lateral pull-off force of a paper from the attached electrode was measured to determine a required force to feed the separated paper. The result is shown in Fig. 7. Force from the plate electrode was almost same with that from the roller electrode, because the paper was wrapped up around the electrode due to the electrostatic adhesion force. The force was in the order of μN/mm^2 that was also in the same order as the calculated pull-off force estimated from the Maxwell's stress and the measured friction coefficient between the applied electrode and the adhered paper.

Paper-Feed Mechanisms

Paper-Feed Mechanism with Slanted Fiber Sheets

Figure 8 shows the paper-feed mechanism with slanted fiber sheets. It consisted of a pair of parallel plate electrodes and two sheets (L20/W20/T3 mm) with slanted fibers. The bottom electrode was fixed and the left end of the upper electrode was pined. AC voltage of rectangular wave was applied between the electrodes to generate vertical vibration of the electrodes. The paper attached between the sheets in contact with fibers was fed in the horizontal direction utilizing the vibration and anisotropic feature of the friction between slanted fibers and the paper.

Figure 9 shows the measured paper-feed speed. The speed was increased with the increase of the frequency but it decreased if the frequency exceeded 26 Hz that coincided with the critical frequency of the system. Because the realized velocity was only the order of mm/s, the system is not suitable for the principal paper feeder but for a precise secondary positioning of the paper.

Paper Feed Utilizing Traveling Wave

Figure 10 shows another new paper-feed system utilizing traveling wave transport of particles. Spherical particles (ϕ 100 μm, 0.005 g) were set on an electrostatic particle conveyer.[3] The conveyer consists of parallel electrodes and four-phase traveling electrostatic wave was applied to the electrodes to transport particles on the conveyer. Traveling wave propagation was achieved utilizing four amplifiers (Matsusada Precision Inc, Tokyo, HOPS-1B3) and five function generators (IWATSU, Tokyo, SG-4105), one of which was used to control phase-differences of the other four generators. By virtue of friction force, a sheet of paper on particles was linearly driven with the linear motion of particles.

Figure 10 shows demonstrated paper-feed speed. At low frequency paper feed was synchronized with the frequency of the traveling wave, however at higher frequency it delayed to the wave speed. Demonstrated maximum speed was about 0.1 m/s at about 200 Hz.

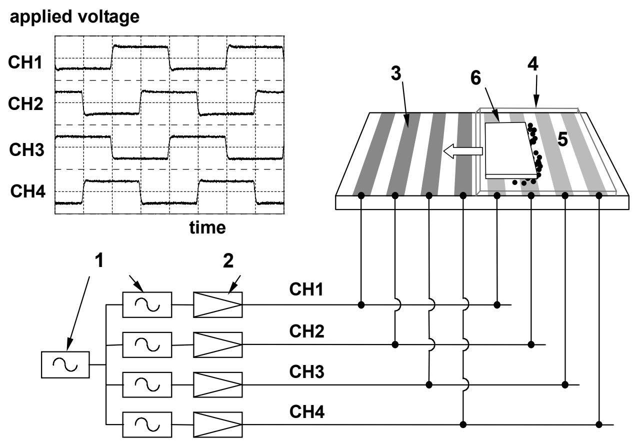

Figure 10. Experimental set-up of paper-feed system utilizing electrostatic particle conveyer. (1: function generators, 2: amplifiers, 3: parallel electrodes on plastic substrate, 120 mm width and 250 mm length, 4: insulation film, 5: particles, 6: paper)

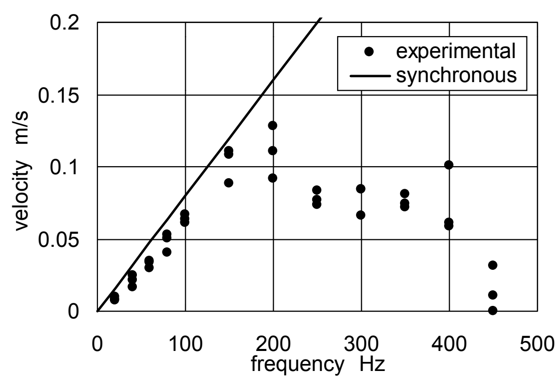

Figure 11. Paper speed of paper-feed system utilizing electrostatic particle conveyer. (applied voltage: 800 V_{0-p}).

Concluding Remarks

The following new electrostatic paper separation and feed systems were proposed and demonstrated.

(1) system to separate a top paper from a paper pile
(2) system for a precise positioning of a paper by virtue of anisotropic feature of the friction of slanted fibers
(3) system to feed a paper with an electrostatic particle conveyer

These systems are expected to realize a highly reliable and precise paper handling for laser printers.

Acknowledgement

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References

1. E. M. Williams, The Physics and Technology of Xerographic Process, Krieger Publishing Co. (1993).
2. S. Egawa, T. Niino and T. Higuchi, Film Actuators: Planar, Electrostatic Surface-Drive Actuators, Proc. IEEE Workshop on Micro Electro Mechanical Systems (1991) pp.9-14.
3. H. Kawamoto, N. Hasegawa and K. Seki, Traveling Wave Transport of Particles and Particle Size Classification, IS&T's NIP19: Int. Conf. on Digital Printing Technologies, New Orleans (2003).

Biography

Shinjiro Umezu received the BE (2001) and MS (2003) degrees in Mechanical Engineering from Waseda University, Tokyo, Japan. He is now a doctor course student in Mechanical Engineering at Waseda University, since April 2003.