New Paper Feed Mechanism Utilizing Electrostatic Force

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Abstract

A new paper separation and feed mechanism is proposed to realize a highly reliable paper handling system for printers. A prototype mechanism consisted of a roller-type separation electrode coated with an insulating film, a ground electrode, and a paper pile between the electrodes. When electrostatic field was applied between the electrodes, it was confirmed that only the top paper was separated. However the applied voltage had to be increased to separate subsequent papers, because charge on the insulating film was cancelled by the attached paper. Then a biased charger roller was settled in contact with the separation electrode to charge the insulating film on the separation electrode. In this system, reliable paper separation and feed was realized and a feed speed over 600 mm/s was demonstrated.

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- or multi-feed of paper sometimes takes place when the friction roller is deteriorated. Although many studies have been conducted and some improvements have been realized for this mechanical paper handling system,[1-3] a system that completely solves the problems has not been proposed yet.

On the other hand, many paper separation and feed mechanisms without friction roller were proposed and investigated. One of them utilizes the electrostatic traveling field generated by the application of alternative voltage to comb electrodes.[4] Another idea based on aerodynamic transport of paper.[5,6] That is, paper motion was controlled by air jet from matrix of micro nozzles manufactured by the MEMS technology. However, these have not been in practical use due to complexity of the mechanisms.

We propose a new paper separation and feed mechanism utilizing the electrostatic force to realize highly reliable and simple system based on the former fundamental investigation on the electrostatic paper separation.[7]

Paper-Separation Utilizing Electrostatic Force

It has been already reported that a top sheet of paper was separated from a paper pile by the electrostatic force.[7] The essence of this former investigation is summarized in this section.

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

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.

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

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 and the conservation of charge by the Finite Element Method.

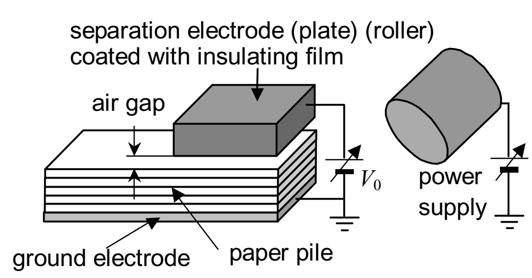


Figure 1. Experimental set-up of prototype electrostatic paper separation mechanism.

Table 1. Dimensions and properties of paper used for experiment.(temp: 25℃, humidity: 45 %)

	thickness mm	*weight* $\mu N/mm^2$	*conductivity S/m*	*relative permittivity* ε_r
PPC	*0.10*	*0.58*	3.9×10^{-10}	1.70
pasteboard	*0.32*	*1.75*	5.8×10^{-10}	1.82
tracing	*0.05*	*0.42*	1.5×10^{-10}	2.86
glassine	*0.03*	*0.25*	7.6×10^{-11}	3.52
double-side coated	*0.12*	*1.34*	3.3×10^{-10}	1.48

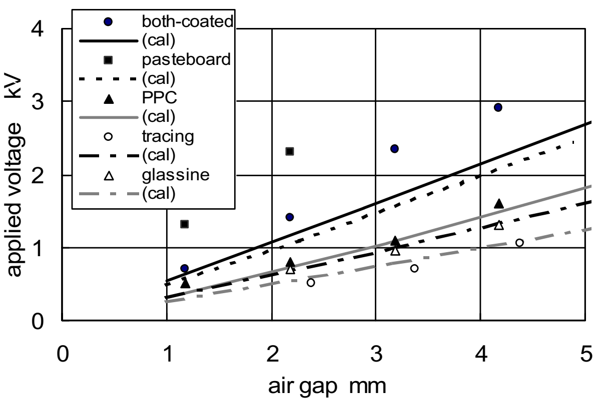


Figure 2. Comparison of measured and calculated threshold voltage of paper separation.

Figure 2 shows the calculated and measured threshold voltage of the electrostatic paper separation. The calculated results 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.

Paper-Feed Mechanism

Experimental Set-up

A paper-feed mechanism is necessary after the paper-separation. We tried to feed a sheet of paper by rotation of a roller-type separation electrode in Fig. 1. Figure 3 shows separating voltage of paper in series from the paper pile in the case that continuous separation and feed were conducted. The calculated was based on the same method described in the former session but the air gap was increased in each time due to the decrease of papers from the paper pile. The result indicated that the measured separating voltage was increased in accordance with the increase of the paper feed, i. e the increase of air gap. Although the separation voltage of the first sheet agreed with the calculated, the demonstrated separation voltage of succeeded papers was much higher than the calculated. The reason of the large increase of the separation voltage is assumed that the applied voltage must be increased to supply charge, because some portion of charge on the separation roller was cancelled by the attached paper.

An improved system as shown in Fig. 4 has been invented. In this system a biased charger roller was used to charge the separation roller. The charger roller consists of a center shaft made of steel and elastmer bulk rubber (11.5 mm outer diameter). The roller was in contact with the separation roller (30.0 mm outer diameter) and micro-discharge near the nip controlled the charge of surface insulating film on the separation roller after charge cancellation by attached paper, repeatedly. A speed control motor and a gear head (Oriental Motor, US425-401, 4GN3.6K) were connected to the separation roller and the rotation was controlled by a speed control unit (Oriental Motor, US425-01T).

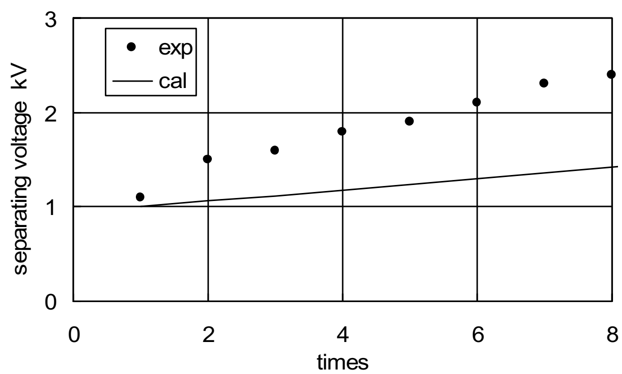


Figure 3. Separation voltage utilizing prototype electrostatic paper feed mechanism without charger roller (PPC, 3 mm initial air gap).

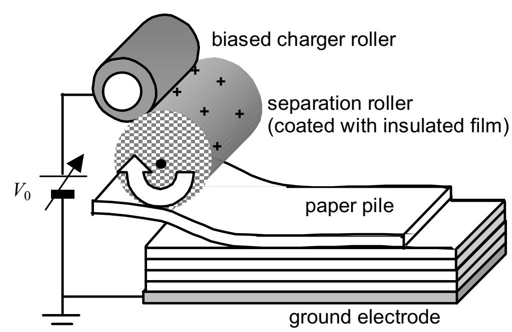


Figure 4. Experimental set-up of new electrostatic paper feed mechanism with charger roller.

Figure 5 shows measured voltage on the separation roller (a) just after the roller was charged by the biased charger roller and (b) after the paper was attached to the roller. Voltage was measured by an electrostatic voltmeter (Trek, 344-F-JX). The broken and solid lines in the figure were theoretical values of the surface charged voltage of roller due to micro-discharge determined by the Paschen's law.[8]

$$V = (\sqrt{6.2d/\varepsilon_r} + \sqrt{312})^2, \quad (2)$$

where d is the thickness, 110 µm, and ε_r is the relative dielectric constant, 3.0, of the insulator film on the separation roller. This figure clearly indicated that the separation roller was charged when applied voltage was larger than the threshold, 1,072 V in this case, and the surface voltage was increased linearly with the applied. After the paper was attached to the roller, the surface voltage was also increased linearly with the applied voltage but it was saturated to the threshold, 1,072 V in this case, because micro-discharge took place between the separation roller and paper over the threshold voltage. The experimental results roughly agreed with the calculated.

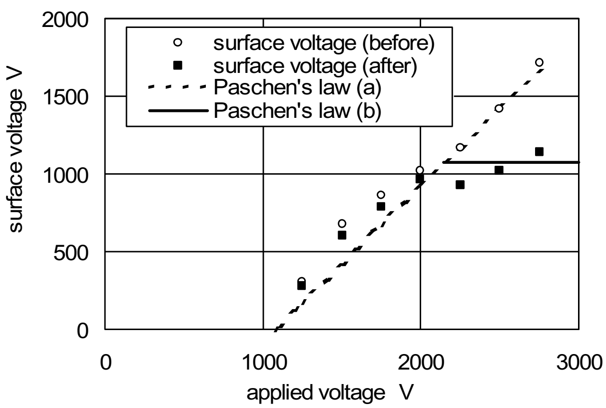
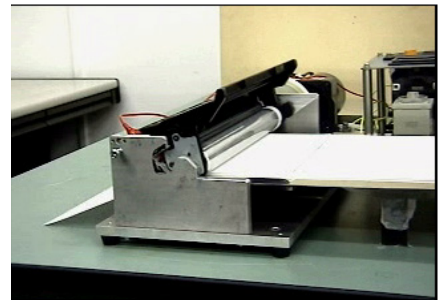
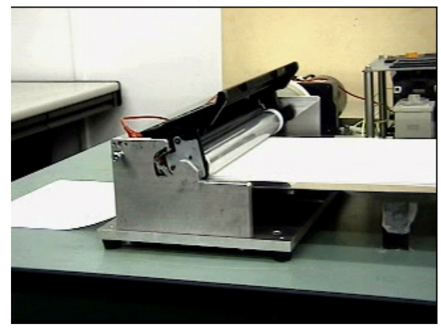


Figure 5. Voltage on separation roller vs. applied voltage.

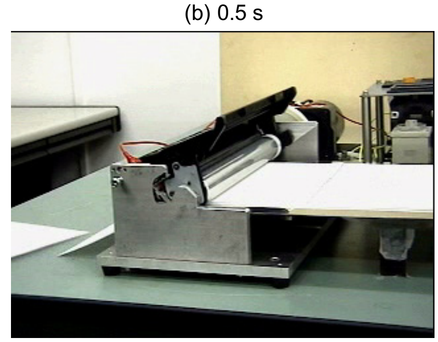
Succeeded separations and feeds were demonstrated with the improved set-up. The initially settled papers were 200 sheets of A4. Figure 6 shows a demonstration of succeeded paper separation and feed. This figure indicated that paper attached to the separation roller was not peeled off but successfully fed by the rotation of the roller. Figure 7 shows the demonstrated paper feed speed. The feed speed over 600 mm/s was achieved. The threshold voltage of demonstrated paper-feed was around 1,100 V and it agreed well with the calculated, 1,030 V, which was the summation of the threshold voltage of discharge 830 V in the condition that the thickness of the insulator was 55 µm and the relative dielectric constant was 3.0 and the calculated separation voltage at 0.5 mm air gap 200 V. As stated in the previous report,[7] paper must be conductive to guarantee the paper separation. The electrostatic paper feed was also preferable at the high-humidity condition.



(a) 0 s



(b) 0.5 s



(c) 1.0 s

Figure 6. Motion of electrostatic paper-feed after electrostatic paper separation in experimental observation. (initial air gap: 0.5 mm, 1.3 kV applied voltage, paper feed speed: 30 A4-prints per minute).

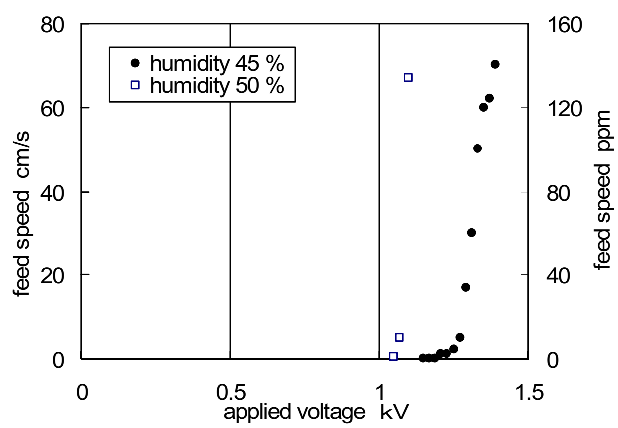


Figure 7. Paper feed speed of electrostatic paper feed mechanism (PPC, initial air gap: 0.5 mm).

Concluding Remarks

A new electrostatic paper separation and feed system was proposed. The system consisted of a charger roller, a roller-type separation electrode coated with an insulating film, a ground electrode, and paper pile on the ground electrode with an air gap to the separation electrode. High voltage was applied to the charger roller to charge the film on the separation electrode by virtue of the micro-discharge. It was demonstrated that stable and continuous paper separation and feed was possible with the speed over 600 mm/s (100 A4 print per minute). The present system is expected to be utilized for a reliable high-speed paper handling system in copiers and laser printers.

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References

1. E. M. Williams, The Physics and Technology of Xerographic Process, Krieger Publishing Co. (1993).
2. K. Yoshida, N. Hagiwara and M. Aida, Sheet Sticking and Jamming Caused by Creases and Curling, J. Robotics and Mechatronics, 10-3 (1998) pp.214-220.
3. S. Yanabe, Y. Hosokawa and T. Maeda, FEM Simulation of Paper Feed Mechanism with Reverse Roller, Proc of. International Conference on Micromechatronics for Information and Precision Equipment (2003) pp.311-312.
4. 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.
5. D. Biegelsen, W. Jackson, A. Berlin and P. Cheung, Air Jet Arrays for Precision Positional Control of Flexible, Proc. of International Conference on Micromechatronics for Information and Precision Equipment: (1997) pp.631-634.
6. A. Berlin, et al, Paper Transport Using Modulated Airjet Arrays, IS&T's NIP 15: International Conference on Digital Printing Technologies (1999) pp.285-288.
7. S. Umezu, J. Shiraishi, H. Nishimura, and H. Kawamoto, Paper Separation and Feed Mechanisms Utilizing Electrostatic Force, IS&T's NIP 19: International Conference on Digital Printing Technologies (2003) pp.559-564.
8. H. Kawamoto and H. Satoh, Numerical Simulation of the Charging Process Using a Contact Charger Roller, J. Imaging Sci. Technol, 38-4 (1994) pp.383-388.

Biography

Shinjiro Umezu received the BE (2001) and MS (2003) degrees in Mechanical Engineering from Waseda University, Tokyo, Japan. He is now a doctor student and a research associate in Mechanical Engineering at Waseda University, since September 2003. He awarded Best Presentation Award of the Japan Society of Mechanical Engineers in 2004. His research interests include imaging technology and MEMS technology utilizing electrostatic and gas discharge phenomena.