Electrical Characterization of the Transfer Belt

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Abstract

The electrically equivalent circuit of a transfer belt is expressed as a parallel circuit of resistance and capacitance. Using this equivalent circuit, we determined the dependence of relaxation time on voltage from the attenuation characteristics. In addition, we proposed and evaluated a method of measuring a dielectric constant under a high voltage to obtain a dielectric constant. From this result, we demonstrated that the dependence of relaxation time on voltage is caused by volume resistivity and determined the dependence of volume resistivity on voltage. Furthermore, to check whether the obtained dielectric constant and volume resistivity reflects the behavior in the transfer phenomenon, we made both theoretical calculations and experiments based on the step response characteristic and verified that the results are in good agreement.

Introduction

In any type of electrophotographic color printer, a transfer belt is an important functional part.[1] A transfer belt is usually made of insulating materials such as polyimide, polycarbonate, and ETFE mixed with carbon and kneaded to adjust the resistance to a relevant provide suitable transfer process properties. This electrical equivalent circuit is expressed as a parallel circuit of equivalent resistance and equivalent capacity. However, semi-insulative polymer, whose volume resistivity is has highly dependence on the electric field strength,[2] cannot be simply handled as an equivalent resistance. The equivalent capacity measured by a general-purpose measuring test device instrument is about from 1 to 5 volts. However, the dielectric constant at 1,000 to 2,000 volts that are used as a transfer voltage is still unknown.

This report attempts to provide the elucidation on describe the electrical characteristics of a transfer belt in terms of its behavior during the transfer process.

Relaxation Time

Method of Measuring Relaxation Time

The relaxation time of a semiconductive polymer can be generally expressed as follows:

$$V(t) = V_0 \mathrm{E} e^{(-t/\tau)} \tag{1}$$

where $V(t)$ denotes potential after time t passes. V_0, t and τ are initial potential, time and relaxation time.

Relaxation time τ is defined as the time in which the potential attenuates to 1/e of the initial value. However, if the relaxation time depends on the electric field, the relaxation time cannot be obtained by measuring the time in which the potential attenuates to 1/e. Consequently, we needed to obtain a relaxation time that depends on the electricfield.

The relaxation time $\tau(V_n)$ is obtained from Eq.(1) approximately .

$$\tau(V_n) = -\Delta t / \ln\{V(t_n + \Delta t) - V(t_n)\} \tag{2}$$

$$n = 0, 1, 2, \cdots\cdots$$

where $V(t_n)$ and $V(t_n + \Delta t)$ are potentials at time t_n and $t_n + \Delta t$ respectively.

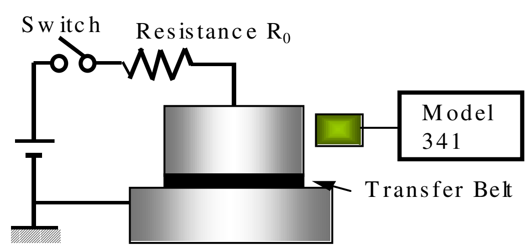

Figure 1. Experimental equipment

Figure 1 shows the experimental equipment. The transfer belt with a diameter of 49 mm and a depth of 144 μ m is sandwiched between aluminum electrodes and put under a pressure of 2 kg. The potential of the transfer belt is measured by placing a high-speed type surface potentiometer (Trek Model 341) on the upper aluminum electrode. The waveform was read with a digital oscilloscope. Using this equipment, we closed the switch to instantaneously apply a high voltage (for about 0.2 to 0.5 second), and then opened the switch to measure the attenuation characteristic of the transfer belt. The resistor R0(1MΩ) had been inserted to regulate the initial current to the transfer belt.

Figure 2 shows the results of measuring the attenuation characteristics of the transfer belt. The initial potentials used for the measurement were 250 V, 500 V, 750 V, and 1000 V. Figure 3 shows the dependence of relaxation time on voltage. The relaxation time was calculated at each of the potentials.

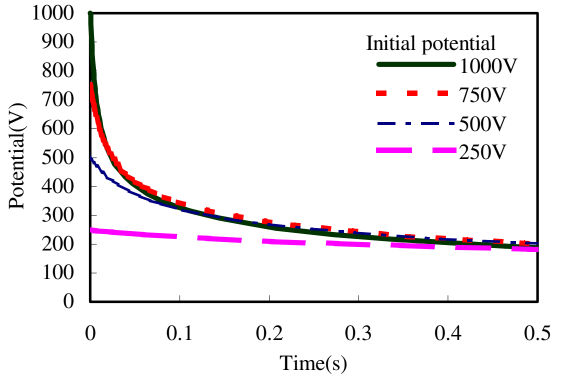

Figure 2. The attenuation characteristics of the transfer belt

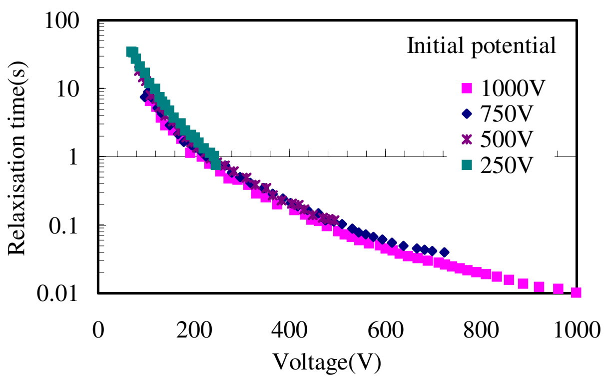

Figure 3.Relaxation time

Dielectric Constant

Since the volume resistivity is high, the influence of the probe impedance (a resistance of 100 MΩ and a capacitance of 3 pF) cannot be ignored. Thus, the equivalent circuit can be expressed as shown in Fig. 4, considering resistance R_0 and the transfer belt's resistance r_b and capacitance c_b as well as the probe's resistance r_p and capacitance c_p.

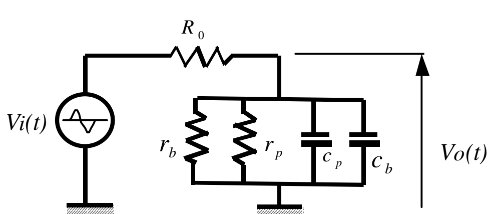

Figure 4. Equivalent circuit of measuring frequency characteristics

In Fig. 4, input voltage $v_i(t)$ and output voltage $v_0(t)$ have the following relationship:

$$v_i(t) = V_i \sin(2\pi f t) \tag{3}$$

$$v_o(t) = V_o \sin(2\pi f t + \varphi) \tag{4}$$

Here, f is frequency, t is time, and φ is the phase difference from the input waveform.

From this, we can obtain gain G and phase difference φ as follows:

$$\varphi = \tan^{-1}\left(2\pi f c_0 \frac{r_0 R_0}{R_0 + r_0}\right) \tag{5}$$

$$G = \frac{V_o}{V_i} = \frac{r_0}{R_0 + r_0} \frac{1}{\sqrt{1 + \left(2\pi f c_0 \frac{r_0 R_0}{R_0 + r_0}\right)^2}} \tag{6}$$

$$r_0 = \frac{r_b r_p}{r_b + r_p} \tag{7}$$

$$c_0 = c_b + c_p \tag{8}$$

From expression (6), if we measure gains G_1 and G_2 at frequencies f_1 and f_2, we can obtain the combined resistance r_0 using the following expressions:

$$r_0 = \frac{-k_2 + \sqrt{k_2^2 - 4k_1 k_3}}{2k_1} \tag{9}$$

$$k_1 = G_2^2\left\{1 - \left(\frac{f_2}{f_1}\right)^2\right\} + \left(\frac{G_2 f_2}{G_1 f_1}\right)^2 - 1 \tag{10}$$

$$k_2 = 2G_2^2 R_0\left\{1 - \left(\frac{f_2}{f_1}\right)^2\right\} \tag{11}$$

$$k_3 = G_2^2 R_0^2\left\{1 - \left(\frac{f_2}{f_1}\right)^2\right\} \tag{12}$$

Additionally, we can obtain the combined capacitance c_0 from the combined resistance r_0 using the following expression:

$$c_0 = \frac{\sqrt{1 - G_1^2\left(\frac{R_0}{r_0} + 1\right)^2}}{2\pi f_1 G_1 R_0} \tag{13}$$

Accordingly, we can obtain the relative dielectric constant $\varepsilon_b{}^*$ of the transfer belt as follows:

$$\varepsilon_b{}^* = \frac{c_b \cdot d}{\varepsilon_0 S} \tag{14}$$

where ε_0 is dielectric constant in a vacuum, S is the area, d is the thickness, respectively.

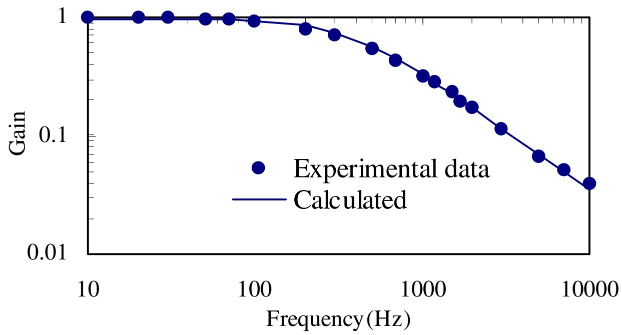

Figure 5. Frequency characteristics

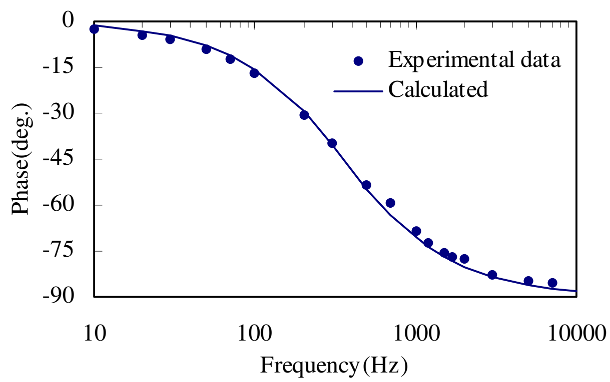

Figure 6. Phase characteristics

Figures 5 and 6 show the gain and phase characteristics when input voltage V_i is 500 V. We made the measurement using serial resistance R_0 of 500 KΩ and a frequency of 10 Hz to 10 kHz.

Figure 6 shows that the phase difference becomes -45 degrees around 370 Hz. Centered on 370 Hz, we obtained the equivalent capacitance using expressions (5) to (13) at combinations of frequencies, 200 Hz and 500 Hz, 100 Hz and 700 Hz, 70 Hz and 1 kHz, 50 Hz and 2 kHz, 30 Hz and 3 kHz, 20 Hz and 5 kHz, 10 Hz and 7 kHz, assuming the frequencies as f1 and f2 and the gains as G1 and G2. We then averaged the obtained seven values to obtain the dielectric constant of the measured transfer belt.

For transfer belt, we obtained a relative dielectric constant of 7.66. We assigned this value to expressions (5) and (6) to calculate the gain and the phase difference. Figs. 5 and 6 show the results.

Next, we performed experiments set the peak-to-peak value of the input waveform (2*Vi*) to 100 V, 500 V, 1500 V, and 2000 V, and calculated the relative dielectric constant from the obtained data in the same way. Figure 7 shows the result. From this diagram, we learned that the dielectric constant is a constant value scarcely dependent on voltage.

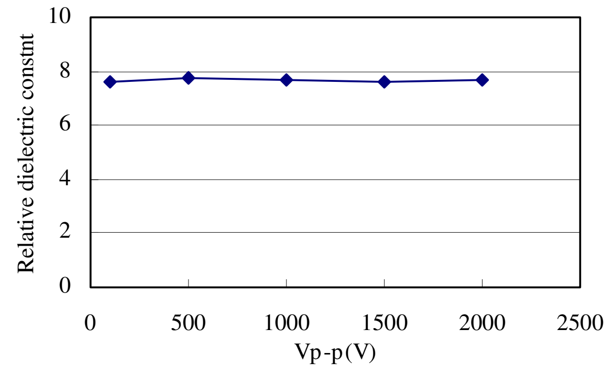

Figure 7. Dependence of the relative dielectric constant on the voltage

Volume Resistivity

As observed in the measurement of the dielectric constant of the previous section, the dielectric constant of the transfer belt is scarcely dependent on the voltage. Thus, we can obtain the dependence of the volume resistivity on the voltage using the expression:

$$\rho_v(V) = \frac{\tau(V)}{\varepsilon^* \varepsilon_0} \tag{15}$$

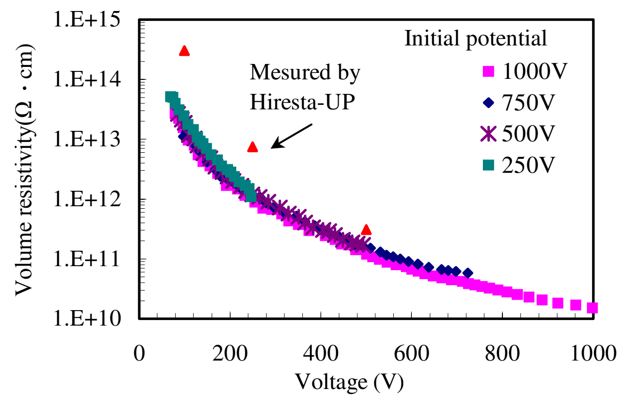

Figure 8. Volume resistivity

Figure 8 shows the result of obtaining volume resistivity by assigning the relaxation time obtained in previous section and the dielectric constant of 7.66. From this data, we determined the approximate expression of volume resistivity as follows:

$$\rho(V) = 9 \times 10^{18} V^{-2.925} \Omega \cdot cm \tag{16}$$

Volume resistivity can be expressed roughly as an approximate exponential curve with little dependency on voltage at the initial potential. Figure 9 shows the volume resistivity measured using a commercial test device (Yuka Electronics Hiresta-UP MCP-HT480). The measurements were made ten seconds after voltage application.

Dependence on the voltage has a roughly equal inclination but the volume resistivity has somewhat higher values than the method described above, in which the volume resistivity was obtained from the relaxation time.

Step Response

Equivalent resistance and equivalent capacitance in the equivalent circuit model were obtained in the previous sections. To check the validity of these values, i.e., whether the circuit can operate under these values during actual transfer, we compared the theoretical and experimental values through step response.

The experimental equipment is the same as Figure 1. We measured the input voltage using a high-voltage probe and the output waveform of the transfer belt using a high-speed surface potentiometer. Since the measurement of the rise time is limited by the response performance of the surface potentiometer, we inserted a serial resistor of 32 MΩ so the rising waveform is not distorted. The rising characteristic of the input waveform, dependent on the performance of the high-voltage power source, is not a complete step waveform but a slow rising waveform. Thus, assuming that a voltage is applied to the measurement circuit via the low pass filter, to the equivalent circuit we added a primary low pass filter consisting of capacitance c_i and resistance R_i and provided time constant τ_i ($=c_i R_i$) to adjust to the actually measured waveform. The electrically equivalent circuit of the measuring equipment is as shown in Fig. 9.

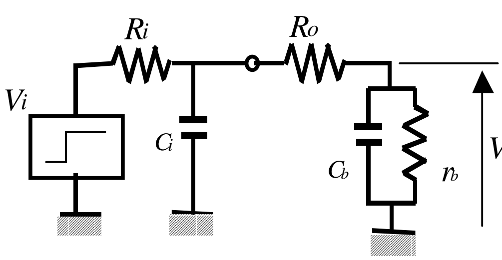

Figure 9. Equivalent circuit of step response

The output waveforms of this equivalent circuit can be expressed as:

$$v_{out}(t)=V_i\frac{K}{R_1}\left\{1+\frac{1}{\tau_1-\tau_0}\left(\tau_0 e^{-\frac{t}{\tau_0}}-\tau_1 e^{\frac{t}{\tau_1}}\right)\right\} \tag{17}$$

Here,

$$K=\frac{R_1 r_b(V)}{R_1+r_b(V)} \tag{18}$$

$$\tau_1=c_b K \tag{19}$$

t (≧0) *is time and* V *is a voltage value.*

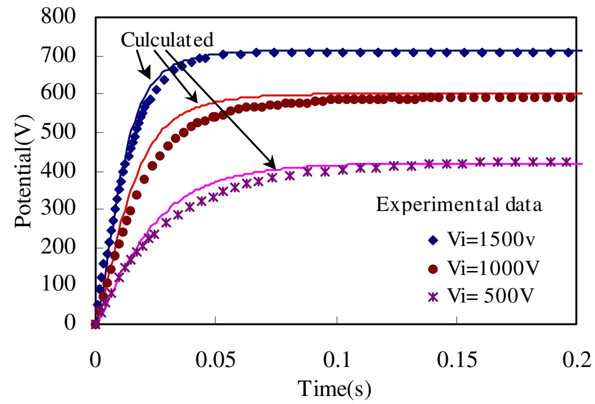

Figure 10. Step response

Figure 10 shows the measurement results of the output waveform. The measurement data and calculation values for input voltages 500 V, 1000 V, and 1500 V are shown. The calculated values were obtained using expression (18), the volume resistivity was obtained using expression (16), and the dielectric constant was 7.66. As the figure shows, the experimental data and the calculated values are in good agreement. These results indicate that we are now able to accurately express the characteristics of a transfer belt in actual transfer operation, using the equivalent circuit's volume resistivity and dielectric constant obtained using the measurement method proposed in this report.

Conclusion

The characteristics of a transfer belt used in a color printer, despite being an important functional component, have not yet been sufficiently evaluated. No quantitative assessment has been made on the basic properties or on behavior during transfer. Thus, we examined a transfer belt in a state close to the transfer phenomenon.

The electrically equivalent circuit of a transfer belt is expressed as a parallel circuit of resistance and capacitance. Using this equivalent circuit, we determined the dependence of relaxation time on voltage from the attenuation characteristics with different initial potentials. In addition, we proposed and evaluated a method of measuring a dielectric constant under a high voltage to obtain a dielectric constant. We also demonstrated that the dielectric constant of a transfer belt does not depend on the voltage. From this result, we demonstrated that the dependence of relaxation time on voltage is caused by volume resistivity and determined the dependence of volume resistivity on voltage. Furthermore, to check whether the obtained dielectric constant and volume resistivity reflects the behavior in the transfer phenomenon, we made both theoretical calculations and experiments based on the step response characteristic and verified that the results are in good agreement.

References

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Biography

Tsuneo Mizuno received his B.S. degree in electronic engineering from the Shinshu University in 1974, and a M.S. degree in electric engineering from the Shinshu University in 1976. Since 1976, he has worked in the Fujitsu Limited. He engages in development of non-impact printing techniques. His work has primarily focused on the development electro photographic process. He is a student of graduate school of Tokyo institute of technology from 1999, too. E-mail: GDC02173@nifty.ne.jp