Charge Relaxation Due to Surface Conduction on an Insulating Sheet Near a Grounded Conducting Plane

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***Abstract*—Electrostatic charges are responsible for a variety of problems in industrial processes and customer equipment that use webs or sheets. Problems include particle contamination from attracting dust, sheets that stick to each other, and electrical discharges resulting in logic resets or damage to electrical components. These problems can be mitigated by increasing the surface conductivity of the insulating sheets by coating the surface with a conductive layer or by increasing the relative humidity. To mitigate problems, electrostatic charge must dissipate quickly compared with the mechanical transport time of the process. Reported here are the results of a model calculation of the charge relaxation time showing explicitly that the charge relaxation time depends on both surface conductivity and geometry. The charge relaxation time is found to increase as the distance to a nearby, grounded conducting plane decreases. Charge relaxation is slowed because the tangential electric field needed to drive surface current becomes smaller as the distance to the grounded plane decreases. Inferred from this analysis is the dependence of charging on the electric Reynolds number (ratio of the electrical charge relaxation time to the mechanical transport time). Web charging can be divided into three regimes: dissipation ($R_e < 0.1$), transition ($0.1 < R_e < 10$), and charging ($10 < R_e$). Only in the transition regime does charging depend strongly on surface conductivity and speed.**

***Index Terms*—Boundary condition, charge relaxation, electric field, electric potential, electric Reynolds number, insulating sheet, insulating web, Laplace equation, surface conductivity.**

NOMENCLATURE

A	Constant coefficient in the solution (A1) to the Laplace equation ($\sqrt{V}$).
B	Constant coefficient in the solution (A1) to the Laplace equation ($\sqrt{V}$).
C	Constant coefficient in the solution (A1) to the Laplace equation ($\sqrt{V}$).
D	Constant coefficient in the solution (A1) to the Laplace equation ($\sqrt{V}$).
d	Distance between a sheet and a nearby grounded plane above the sheet (m).
g	Distance between a sheet and a nearby grounded plane below the sheet (m).
J_x	Surface current density (A/m) in Fig. 5.
L	Characteristic length (m), size of a sheet or span length between conveyance rollers.
n	Integer in the range $(0, \infty)$.
P	Constant coefficient in the solution (A1) to the Laplace equation (V).
R	Constant coefficient in the solution (A1) to the Laplace equation (V/m).
S	Constant coefficient in the solution (A1) to the Laplace equation (V/m).
T	Constant coefficient in the solution (A1) to the Laplace equation $(\mathrm{V/m^2})$.
t	Time (s).
R_e	Electric Reynolds number defined in (1) (dimensionless).
U	Speed (m/s).
x	Distance coordinate in the plane of the web (m).
Δx	Length of a web element (m) in Fig. 5.
z	Distance coordinate normal to the web surface (m).
α	Constant $(\mathrm{m^{-1}})$ in the solution (A1) to the Laplace equation.
ε_0	Permittivity of free space; 8.854×10^{-12} (F/m).
ε_1	Permittivity of web or sheet material (F/m), taken to be approximately $3\varepsilon_0$.
Φ	Electric potential (V).
ρ_0	Sheet resistivity $(\Omega/\square)$.
$\rho_{s,0}$	Initial uniform charge density $(\mathrm{C/m^2})$ defined in (A18).
σ_s	Sheet conductivity (S) or (Ω^{-1}).
τ^e	Charge relaxation time (s).
τ^m	Mechanical transport time (s).
τ_n	Time constant (s) defined in (11) and (A22).
Ψ	Stream function (V).

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I. INTRODUCTION

ELECTROSTATIC charges are responsible for a variety of problems in industrial processes and consumer products that use webs or sheets. Problems include particle contamination from attracting dust, sheets that stick to each other causing jams or double feeds, and electrical discharges that cause system resets in the digital control system and damage to electrical components. These problems can be mitigated by increasing the surface conductivity of the insulating sheets by coating the surface with a conductive layer or sometimes by increasing the relative humidity.

To be effective, the surface conductivity must be sufficiently high for electrostatic charge to dissipate quickly compared with the mechanical transport time of the process. During the product commercialization process, determining the required surface conductivity is complicated because charge dissipation depends on both surface conductivity and geometry.