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Determination of the cathode erosion and temperature for the phases of high voltage discharges using FEM simulations

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Abstract

A discharge produces an energy input in the cathode material, which causes the erosion of the material surface. The principal mechanism of erosion is the formation of craters mainly due to melting. From calorimetric results published in the literature, the amounts of energy delivered to the cathode for the different phases of the discharge (breakdown, arc and glow discharge) were calculated. A FEM model was developed to simulate the temperature distribution and the phase transitions, which allows the definition of molten and evaporated zones. These zones were compared with the volumes of craters done in Pt-samples at air with pressures ranging between 1 and 9 bar and static electrode gaps of 2 mm. The breakdown energy is enough to melt an amount of material, which is responsible for the formation of very flat craters. The formation of deeper overlapped craters observed in experiments can not be produced during the breakdown; they are produced by the arc phase of the discharge. The assumption of the crater area as the area for the energy exchange between plasma and material gives the best results in the simulation. The glow discharge produces only a light heating of the cathode, without any significant erosion.

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1. Introduction

The purpose of the ignition discharge is to bring energy into the fuel–air mixture to initiate the combustion. However, part of the total electrical energy is absorbed by the electrodes, causing the heating and erosion of the electrode material.

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Nomenclature

α	energy absorption coefficient (m^{-1})
η_E	fraction of energy absorbed by the electrodes
η_G	fraction of energy going to the gas
η_R	fraction of energy lost by radiation
ρ	density ($g\,m^{-3}$)
c_p	specific heat ($J\,g^{-1}\,K^{-1}$)
C_S	spark plug capacity (F)
E_b	energy discharged during the breakdown (J)
f_{SL}	fraction of solid material during melting
f_{LV}	fraction of liquid material during evaporation
H	enthalpy ($J\,g^{-1}$)
i	current (A)
i_{A0}	initial arc current (A)
i_{G0}	initial current of the glow discharge (A)
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
k_T	Toepler constant ($V\,s\,m^{-1}$)
kt_s	quotient between depth of the molten region and depth of the crater
kv_s	quotient between volume of the molten region and volume of the crater
l_0, b	height and width of volume of control (m)
l_F	spark gap (m)
L_b	latent heat of evaporation ($J\,g^{-1}$)
L_m	latent heat of fusion ($J\,g^{-1}$)
P_T	total electrical power (W)
P_E	power consumed in the resistance R_E (W)
P_F	power of the spark (W)
q	charge (C)
$\dot{q}_{ext}$	power input by the discharge per unit volume of material ($W\,m^{-3}$)
$\dot{q}_{SL}$	power per unit of volume consumed in the phase transition solid–liquid ($W\,m^{-3}$)
$\dot{q}_{LV}$	power per unit of volume consumed in the phase transition liquid–vapor ($W\,m^{-3}$)
Q_F	flowing charges (C)
(r, z)	coordinates (m)
r_A	arc radius at the cathode (m)
r_{A0}	initial arc radius at the cathode (m)
r_G	radius of the glow discharge at the cathode (m)
r_{G0}	initial radius of the glow discharge at the cathode (m)
r_s	quotient between simulated and experimental crater radius
r_{sp}	cathode spot radius (m)
R_E	internal resistance of the spark plug (Ω)
R_F	resistance of the spark (Ω)
t	time (s)
T	temperature (K)
T_0	initial temperature (K)
T_{0b}	temperature range for the phase transition liquid–vapor (K)
T_{0m}	temperature range for the phase transition solid–liquid (K)