# ELECTRON-BEAM HEATING OF METALS

G. E. Gorelik and S. G. Rozin

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Both the steady-state and the transient temperature distribution are found by the Monte Carlo method for a semiinfinite metal plate heated with an electron beam.

As a result of an electron beam acting on a metal, the kinetic energy of fast electrons is converted into thermal energy. The shape of the heat source thus generated is found from the distribution of energy losses from an electron in the metal $\rho(|\mathbf{r}-\mathbf{r}_0|, z)$ [1] and from the current density of the electron beam I:

$$q(r,\ z) = \frac{a}{4.2k}\int\limits_0^\infty\int\limits_0^{2\pi}\rho(|\mathbf{r}-\mathbf{r}_0|, z)\,J(r_0)\,r_0dr_0d\varphi. \tag{1}$$

The authors have calculated q(r, z) by the Monte Carlo method for electrons with a Gaussian current density:

$$J = \frac{I}{1.44a_1^2\pi}\exp\left(-\frac{r^2}{1.44a_1^2}\right). \tag{2}$$

The temperature field of a semiinfinite plate with a volume-distributed heat source q(r, z) can be found by solving the equation

$$\frac{\partial T}{\partial t} - a\Delta T = q(r,\ z) \tag{3}$$

under the assumption that there is no thermal flux at the surface:

$$\left.\frac{\partial T}{\partial z}\right|_{z=0} = 0. \tag{4}$$

Inasmuch as in many problems related to electron-beam heating of objects it is necessary to determine the temperature only at some critical points, one may consider it worthwhile to solve Eq. (3) by the Monte Carlo method. With the aid of simple transformations, we write the solution to Eq. (3) in a form convenient for calculations by that method:

TABLE 1. Temperature Distribution in a Semiinfinite Aluminum Plate, T°C (Accelerating voltage V = 128 kV, current I = 1 mA, $a_1 = 2.6\cdot10^{-3}$ cm, $d = 5.2\cdot10^{-4}$ cm, r = 0)

| z/d | $t\cdot10^6$, sec | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 10 | $T_{steady}$ |
| 0 | 5,1 | 14,0 | 21,8 | 33,2 | 58,8 | 182,2 |
| 1 | 6,7 | 15,0 | 22,6 | 35,6 | 59,3 | 184,3 |
| 2 | 8,4 | 17,4 | 25,1 | 38,1 | 60,7 | 185,9 |
| 3 | 10,4 | 20,0 | 27,9 | 40,7 | 62,9 | 187,1 |
| 4 | 12,4 | 22,3 | 30,1 | 42,7 | 64,3 | 187,2 |
| 5 | 13,3 | 23,2 | 30,8 | 43,0 | 63,8 | 185,2 |
| 6 | 12,2 | 21,5 | 28,8 | 40,3 | 60,2 | 180,0 |
| 7 | 8,9 | 17,2 | 23,9 | 34,8 | 53,6 | 171,0 |
| 8 | 5,6 | 12,8 | 18,9 | 28,9 | 46,6 | 161,6 |
| 9 | 3,7 | 9,7 | 15,1 | 24,2 | 40,5 | 153,1 |
| 10 | 2,8 | 7,7 | 12,3 | 20,5 | 35,4 | 145,2 |

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$$T(r,\ z,\ t) = V_q \int_0^1 dF(\xi) \int_0^1 dG(\rho) \int_0^1 d\Phi(\varphi) \frac{q(\xi,\ \rho)\ \mathrm{erfc}\left(\sqrt{\frac{R^2}{4at}}\right)}{4\pi R}, \tag{5}$$

$$R = \sqrt{(z-\xi)^2 + r^2 + \rho^2 - 2r\rho\cos\varphi}, \quad V_q = 2\pi r_q^2\, z_q, \tag{6}$$

$$F = \frac{\xi + z_q}{2z_q}, \quad G(\rho) = \frac{\rho^2}{r_q^2}, \quad \Phi = \frac{\varphi}{2\pi}. \tag{7}$$

Values characterizing the temperature variation with time are shown in Table 1 for a few points of a semiinfinite aluminum plate heated with an electron beam of radius $a_1 = 2.6 \cdot 10^{-3}$ cm, current I = 1 mA, and accelerating voltage V = 128 kV. The steady-state distribution is shown in the last column.

The calculations were performed on a MINSK-22 computer. The machine time was approximately 10 sec per temperature point. The temperature error, with the given heat source, was approximately 3%.

## NOTATION

| | |
|---|---|
| I | is the total current of electron beam; |
| $a_1$ | is the radius of electron beam, defined as the distance from center at which the current density is half the maximum value; |
| $r_0$, $\varphi$ | are the polar coordinates of the heat source; |
| z, r | are the normal and radial coordinates of a test point; |
| T | is the temperature; |
| t | is the time; |
| $a$ | is the thermal diffusivity; |
| k | is the thermal conductivity; |
| $r_q$, $z_q$ | are the radius and height of cylindrical region occupied by the heat source; |
| $\rho$, $\xi$, $\varphi$ | are the cylindrical coordinates of a point. |

## LITERATURE CITED

1. G. E. Gorelik and S. G. Rozin, Inzh. Fiz. Zh., 22, No. 6 (1972).