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MODELLING OF ELECTROLYTE FLOW IN INTERELECTRODE GAP IN ELECTROCHEMICAL MACHINING

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Summary: *Paper presents mathematical model of two-dimensional electrolyte flow in interelectrode gap and calculation results for form electrodes with development geometrical features. I the study of fluid motion we are concerned with following laws: principle of conservation of momentum, conservation of mass and conservation of energy. Obtained solutions let us describe velocities of electrochemical digestion of machining surface. Distributions of thickness, pressure, velocity, temperature, and gaseous phase volume concentration of interelectrode gap after using simplified assumptions are presented.*

Keywords: *electrochemical machining, multiphase flow, energy, mass, momentum.*

1. INTRODUCTION

Shaping by electrochemical machining (ECM) requires connecting the working electrode to the negative pole of direct current source and workpiece to the positive pole. Electrolyte is supplied to an interelectrode gap. During ECM electrolyte, flowing across the gap, carries away digestion products from electrodes surfaces. Mainly there are molecules of hydrogen and digestion material [3]. It is possible to say that in interelectrode gap multiphase flow occurs. Hydrodynamics parameters of this flow decide on exchanging process of mass, momentum, and energy thereby, thus on electrolyte properties.

2. MATHEMATICAL MODEL

The system of equations which describes the two-dimensional electrolyte flow in interelectrode gap (Fig. 1) follows from the principle of conservation of momentum and mass conservation law [1].

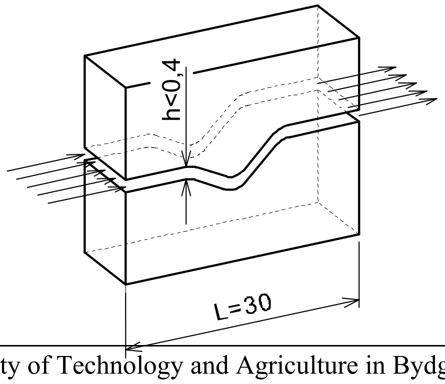

Fig. 1. The interelectrode gap

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Equations of motion resulting from the mass conservation law for electrolyte (liquid) and hydrogen (gas) respectively are following:

$$\frac{\partial}{\partial t}(\rho_e)+\frac{\partial}{\partial x}(\rho_e v_x)+\frac{\partial}{\partial y}(\rho_e v_y)=0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho_h)+\frac{\partial}{\partial x}(\rho_h v_x)+\frac{\partial}{\partial y}(\rho_h v_y)=j\eta_H k_H h^{-1} \tag{2}$$

Equations resulting from the principle of conservation of momentum for electrolyte assume the form:

$$\rho_e\left(\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}\right)=F_x-\frac{\partial p}{\partial x}+\mu_e\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_x}{\partial y^2}\right) \tag{3}$$

$$\rho_e\left(\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}\right)=F_y-\frac{\partial p}{\partial x}+\mu_e\left(\frac{\partial^2 v_y}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}\right) \tag{4}$$

Equations resulting from energy principle for electrolyte assume form:

$$\frac{\partial}{\partial t}(\rho_e T_e)+\frac{\partial}{\partial x}(\rho_e v_x T_e)+\frac{\partial}{\partial y}(\rho_e v_y T_e)=\frac{\partial}{\partial y}\left(a\frac{\partial T}{\partial y}\right)+\frac{Q}{c_p} \tag{5}$$

Equations (1 ÷ 5) should carry out the following border conditions:

- for velocity

  $v_x=0$, $v_y=0$ for $y=0$, and $y=h$

- for pressure

  $p=p_w$ for $x=x_w$

  $p=p_z$ for $x=x_z$

- for temperature

  $T=T_0$ for $y=0$, and $y=h$

where:

x_w – co-ordinate of the interelectrode gap beginning,

x_z - co-ordinate of the interelectrode gap end,

T_0 – temperature of electrodes.

Electrolyte flow was analysed in local curvilinear orthogonal coordinate system.

For the solution of equations system resulting from the principle of conservation of momentum and the mass conservation law the following simplified assumptions were introduced:

- electrolyte flow is stationary, two-dimensional, laminar, and isothermal,
- inertial forces of electrolyte flow are passed over, there is limitation to the so called Reynolds' approximation,
- influence of unit mass force is omitted,
- it were assumed that:

  $$h(x, t) << L$$

  i.e. thickness of the gap is small in comparison to the length of the interelectrode gap.

Accepting the above mentioned assumptions after estimating characteristic for a flow in narrow gap of equations set (1 ÷ 5) is following:

- continuity equation of electrolyte flow:

$$\frac{\partial}{\partial x}(\rho_e v_x)+\frac{\partial}{\partial y}(\rho_e v_y)=0 \tag{6}$$

- continuity equation of hydrogen flow:

$$\frac{\partial}{\partial x}(\rho_h v_x)+\frac{\partial}{\partial y}(\rho_h v_y)=j\eta_H k_H h^{-1} \tag{7}$$

- principles of conservation of momentum
  - for x direction

$$\frac{\partial^2 v_x}{\partial y^2}=\frac{1}{\mu}\frac{\partial p}{\partial x} \tag{8}$$

  - for y direction

$$\frac{\partial p}{\partial x}=0 \tag{9}$$

- conservation of energy

$$v_x\frac{\partial T}{\partial x}+v_y\frac{\partial T}{\partial y}=a\frac{\partial^2 T}{\partial y^2}+\frac{Q}{\rho_c c_p} \tag{10}$$

From the equation (9) we have

$$p=p(x)$$

After integrating the equation (9) and taking into consideration border conditions we have:

$$v_x=\frac{1}{2\mu}\frac{dp}{dx}\left(y^2-yh\right) \tag{11}$$

Let us introduce to our considerations the concept of volume flow rate:

$$Q_V=\int_0^h v_x dx \tag{12}$$

thus, after rearranging we obtain

$$\frac{dp}{dx}=-\frac{12\mu Q_V}{h^3} \tag{13}$$

so that

$$v_x=\frac{6Q_V}{h^3}\left(y^2-yh\right) \tag{14}$$

Substituting to continuity equation of electrolyte flow (6) the velocity distribution (14) then integrating we define the component v_y in the form:

$$v_y=\frac{-6Q_V}{h^3}\left(h^2h'y^3-h'h^3y^2\right) \tag{15}$$

Integrating equation (13) and respecting border conditions for pressure we obtain:

$$p=p_z-12\mu Q_V\left(A(x)-A_0\right) \tag{16}$$

here $A(x)=\int\frac{dx}{h^3}$, $A_0=A(x_0)$.

Equation which describes the volume concentration of gaseous phase is obtained on the basic of balance gas mass flowing across interelectrode gap:

$$\frac{\partial(\rho_H v_x)}{\partial x}+\frac{\partial(\rho_H v_y)}{\partial y}=\eta_H k_H j h^{-1} \tag{17}$$

Assuming that the concentration is changing along interelectrode gap, i.e. $\beta=\beta(x)$, after integrating equation (17) crosswise gap we have:

$$\frac{\partial}{\partial x}\rho_H\int_0^h v_x dy+\rho_H v_y\Big|_0^h=\eta_H k_H j \tag{18}$$

hence

$$\frac{\partial \rho_H}{\partial x}=\frac{\eta_H k_H j}{Q_V} \tag{19}$$

where

$$\rho_H=\beta\rho_{H0},\ \rho_{H0}=\frac{\mu_H p}{R_H T} \tag{20}$$

μ_H – hydrogen molar mass,
R_H – gas constant,
$h(x)$ – local height of interelectrode gap,
ρ_{H0} – hydrogen density.

Introducing equation (19) and the function describing current density [2] to equation (18):

$$j=\frac{\kappa_0\Phi_{TG}^{-1}(U-E)}{h} \tag{21}$$

now we obtain:

$$\frac{\partial\beta}{\partial x}=\frac{\eta_H k_H R_H}{\mu_H}\frac{\kappa_0\Phi_{TG}^{-1}(U-E)}{Q_V h}\frac{T}{p} \tag{22}$$

Integrating the equation (22) and taken into consideration that $\beta=0$ when $x=x_0$ we obtain formula which describing distribution of volume concentration of gaseous phase:

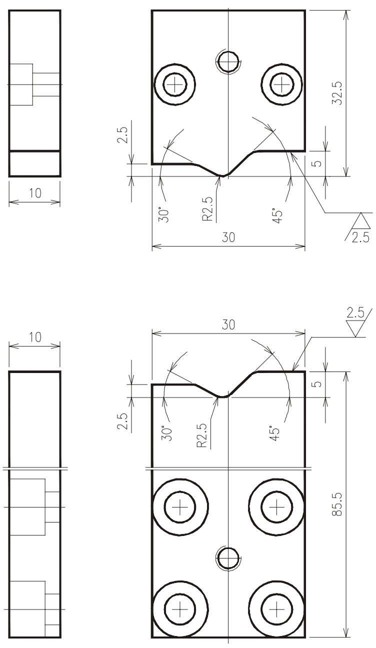


Fig. 2. Geometrical features of electrodes

$$\beta = \frac{\eta_H k_H R_H}{\mu_H} \frac{\kappa_0 \Phi_{TG}^{-1} \left(U - E\right)}{Q_V h} \frac{T}{p} x \tag{23}$$

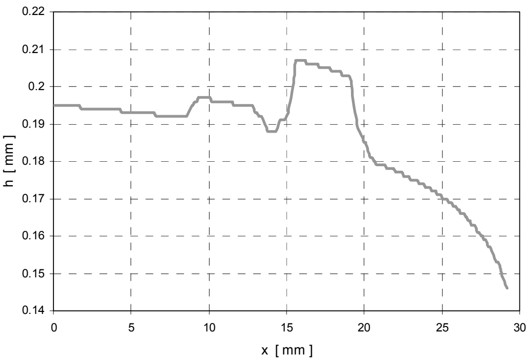
The equation allowing us to determine temperature distribution in gap (10) was solved numerically with the method of finite differences using velocity distributions v_x and v_y describing by formulae (14) and (15).

Obtained solutions let us describe velocities of electrochemical digestion of machining surface. This velocity is described by equation [2]:

$$\frac{\partial Y_A}{\partial t} = k_v \kappa_0 \Phi_{TG}^{-1} \frac{U - E}{d_{\min}} \sqrt{1 + \left(\frac{\partial Y}{\partial x}\right)^2} \tag{24}$$

$$\Phi_{TG} = \frac{1}{S} \left[\int_0^h \frac{dy}{\left(1 + \alpha(T - T_0)\right)\left(1 - \beta\right)^{3/2}} \right] \tag{25}$$

a)



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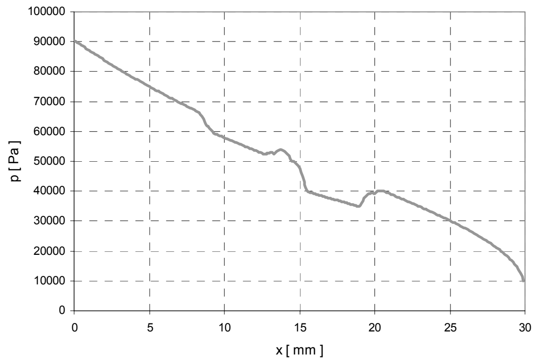

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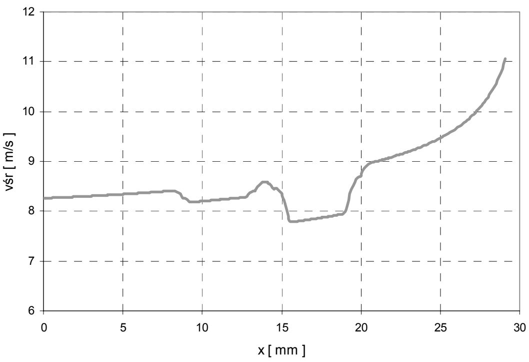

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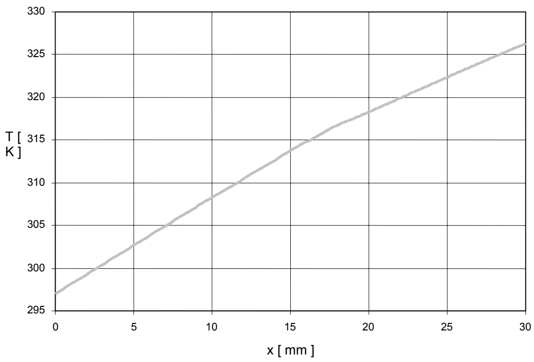

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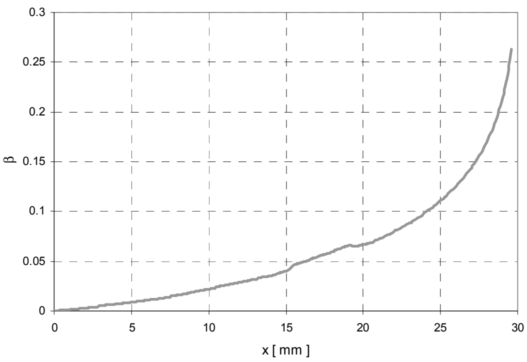

Fig. 3. Distributions:
a) thickness of interelectrode gap,
b) pressure,
c) velocity,
d) temperature,
e) volume concentration of gaseous phase.

where:

k_v –coefficient of electrochemical machining,

α_T – temperature coefficient of electrical conductivity,

κ_0 – specific conductivity of medium.

3. CALCULATION RESULTS

Calculations for form electrodes with geometrical features shown in figure 2 were performed. Calculations were performed to obtaining stable state. More important parameters of machining were shown in Table 1.

Table 1. Important parameters of machining

Initial gap	0.2 mm
Velocity of feed motion ER	0.0125 mm/s
Interelectrode voltage	15 V

On diagrams (Fig. 3) distribution thickness h of interelectrode gap, pressure p, average velocity of electrolyte flow v_{sr}, average temperature T, and volume concentration of gas β along interelectrode gap are presented.

4. RESULTS DISCUSSION

On the basis of results showed on diagrams (Fig. 3 a ÷f) it is possible to formulate following conclusions:

– thickness of interelectrode gap (Fig. 3a) is changing. It has influence to velocity of electrochemical digestion and the angle of inclination of working electrode profile to machining direction,
– non-uniform distribution of the interelectrode gap thickness has significant influence on pressure distribution and electrolyte flow velocity (Fig. 3b, 3c)
– changing of volume concentration of gaseous phase and electrolyte temperature (Fig. 3d, 3e) has important influence on the flow physical conditions.

5. REFERENCES

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