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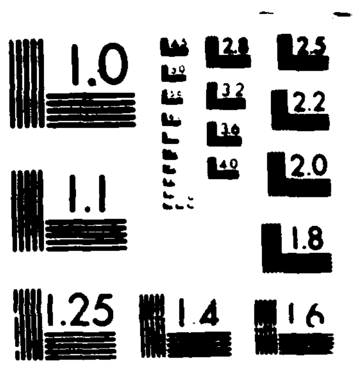

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FOREIGN TECHNOLOGY DIVISION

AN ANALYSIS OF THE DYNAMICS OF A LIQUID-METAL CONTACT DEVICE

by

B.L. Aliyevskiy, A.I. Bertinov, A.G. Sherstyuk

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А а	*А а*	A, a	Р р	*Р р*	R, r
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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
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Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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An Analysis of the Dynamics of a Liquid-Metal Contact Device

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Statement of the problem. Liquid-metal contacts based on mercury, sodium-potassium alloys, gallium and other low-melting-point metals are employed for the electrical connection of rotating and stationary parts of direct-current and alternating-current devices. A theoretical and experimental investigation was conducted with respect to direct-current unipolar machines ~~/1/~~ and electrotechnological machine tools ~~/2/~~. Contact devices of the ring type are employed for the transmission of heavy currents (Russian translation)

In the general case various loads act on the liquid metal of a rotating ring contact (Fig. 1): friction forces and external pressure, inertial forces (centrifugal, gravitational, et al.), and also electromagnetic (electrodynamic) forces. The behavior of liquid metal under the effect of the indicated loads has been examined in a number of works /1-4/, however, the dynamics of a liquid-metal contact device has not been investigated up to the present time in a general way.

The dynamics of a slip ring has important significance, since under specific conditions, in particular in the case of impermissible electrodynamic effects, the spilling of the liquid metal from the contact zone (inter-electrode gap) can occur, which leads to the breaking of the electrical circuit A similar phenomenon is also possible in the case of impermissible inertial effects as a result of the movement with acceleration (deceleration) $a(a_x, a_y, a_z)$ of the rotating contact device, for example, in electrotechnological machines tools with a moving working member.

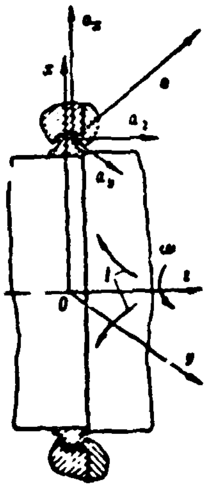

Fig. 1. General diagram of a loaded liquid-metal contact.

In this article the dynamics of a liquid contact is investigated on the basis of a general Navier-Stokes equation, which is simplified with the introduction of certain assumptions, facilitating the solution of the problem. The steady state of a liquid metal is analyzed under the effect of electrodynamic and inertial loads. It is considered in this case, that in the steady state the ring of liquid metal in the inter-electrode space moves, without being deformed, i. e., that the resultant acceleration of the metal particles under the total effect of all the loads is equal to zero $\left(\frac{dv}{dt}=0\right)$.

The dynamics of the continuous motion of a viscous liquid in the general case is described by a Navier-Stokes equation /5/ and the condition of continuity:

$$\rho\left[\frac{\partial v}{\partial t}+(v\nabla)v\right]=-\nabla p+\eta\Delta v+\left(\zeta+\frac{\eta}{3}\right)\nabla(\nabla v)+f \qquad (1)$$

$$\frac{\partial\rho}{\partial t} + \nabla\rho v = 0. \qquad (2)$$

Designated in (1) and (2) are:

- ρ - the density of the liquid metal;
- v - the velocity vector of an elementary volume of the metal;
- p - pressure;
- η - the dynamic viscosity (coefficient of internal friction);
- ζ - the "second" viscosity (the coefficient of friction with a change in the volume of a compressible liquid);
- f - the volumetric density of extraneous forces (forces of nonhydrodynamic origin).

We will conduct an analysis of the motion of the liquid under the following assumptions: a) a moving liquid metal in a contact is incompressible $\left(\frac{\partial\rho}{\partial p} = 0\right)$, since its speed is considerably less than the speed of the propagation of sound in the liquid metal; b) due to the considerable thermal inertia the density of the liquid metal does not depend on time $\left(\frac{\partial\rho}{\partial t} = 0\right)$; c) the thermal conductivity of the metal is very high, therefore grad T=0.

Under these assumptions the equation of continuity (2) takes the form /6/

$$\operatorname{div} \mathbf{v} = 0,$$

consequently, in equation (1)

$$\nabla(\nabla \mathbf{v}) = \operatorname{grad} \operatorname{div} \mathbf{v} = 0,$$

and it is recorded in simplified form

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}\nabla)\mathbf{v} = -\frac{1}{\rho}\nabla p + \nu\Delta\mathbf{v} + \mathbf{F}, \qquad (3)$$

where $\nu = \frac{\eta}{\rho}$ - the kinematic viscosity;

$F=\frac{f}{\rho}$ - the density vector of mass forces, having an acceleration dimension and which takes the inertial and the electromagnetic loads into account in the general case.

Estimation of the electromagnetic loads. Let us represent equation (3) in the form of a system of two equations

$$\frac{\partial \mathbf{v}}{\partial t}+(\mathbf{v}\nabla)\mathbf{v}=-\frac{1}{\rho}\nabla p_{\text{м}}+\nu\Delta\mathbf{v}+\mathbf{F}_{\text{м}}. \quad (4)$$

$$0=-\frac{1}{\rho}\nabla p_{\text{э}}+\mathbf{F}_{\text{э}}. \quad (5)$$

where

$$\mathbf{F}_{\text{м}}=\frac{\mathbf{f}_{\text{м}}}{\rho};\ \mathbf{F}_{\text{э}}=\frac{\mathbf{f}_{\text{э}}}{\rho};\ \nabla p_{\text{э}}+\nabla p_{\text{м}}=\nabla p;$$

$\mathbf{f}_{\text{м}}\{f_{\text{м}x}, f_{\text{м}y}, f_{\text{м}z}\}$ - is the volumetric density vector of the inertial forces;

$\mathbf{f}_{\text{э}}\{f_{\text{э}x}, f_{\text{э}y}, f_{\text{э}z}\}=\frac{d\mathbf{T}_{\text{э}}}{dV}=[\mathbf{jB}]$ - the volumetric density vector of the electromagnetic forces;

j - the current density in the liquid metal;

B - the magnetic induction in the contact zone, caused by the current field, occurring through the contact, and by other fields;

$dT_{\text{э}}$ - the elementary electromagnetic force, acting on element dV of the volume of the metal;

$p_{\text{м}}$ and $p_{\text{э}}$ - pressures of mechanohydraulic and electromagnetic nature.

System of equations (4), (5) was written under the condition, that the velocity field is determined by the inertial loads, then it is necessary to examine equation (5) as an equation of perturbing effects.

For simplifying the analysis we will assume, that internal friction is absent in the contact liquid, i. e., ν=0. Actually losses to friction occur even at relatively low speeds in the liquid metal. Under the assumption that ν=0 we will take the permitted error into account by introducing in the ring contact instead of the actual velocity field and acceleration field the average angular velocity for the core of the metal flow $\beta = \frac{\omega}{\xi}$, where ω - the angular velocity of the rotating electrode and $\xi > 1$ /7/.

For the steady (equilibrium) state of the liquid metal, for example, when the ring of liquid metal of the de-energized contact is formed by the inertial loads, the following equation is valid

$$\frac{dv}{dt} = \frac{\partial v}{\partial t} + (v\nabla)v = 0. \tag{6}$$

In this case equation (4) is transformed into an Euler equation for the steady-state motion of an ideal incompressible liquid:

$$\operatorname{grad} p_{и} = f_{и} = \rho F_{и}. \tag{7}$$

The steady-state regime is also not disrupted in this case, if

$$|\operatorname{grad} p_{и}| \geq |\operatorname{grad} p_{э}|. \tag{8}$$

since $|\operatorname{grad} p_{и}|$ serves as a measure of the operation of the resultant of the inertial forces $f_{и} = \rho F_{и}$, and $|\operatorname{grad} p_{э}|$ - of the electromagnetic forces.

In the steady-state regime inequality (8) should be satisfied for the entire volume of the liquid metal of the contact, thus taking (5) and (7) into account the maximum inequality should also be valid

$$|[(\rho F_{иx})^2 + (\rho F_{иy})^2 + (\rho F_{иz})^2]^{0.5}_{макс}| > f_{э.макс}. \tag{9}$$

With disruption of condition (9), i. e., when $f_{э} > f_{и}$ the metal flows out of the contact.

The obtained inequality (9) is applicable for the calculation of the magnitude of the permissible current (current-carrying capacity) in the contact device with a horizontal axis of rotation (Fig. 2) in the absence of its displacement. For maximum evaluation we will consider, that accelerations in the axial direction are absent, i. e., $F_{иz} = 0$.

and the remaining relationships have the form:

$$F_{\text{м}x} = \beta^2 x - g;$$

$$F_{\text{м}y} = \beta^2 y;$$

$$f_{\text{э}} = j_{\text{к}} B_1 = \frac{\mu_0 j_{\text{к}} I}{\pi D_1} = \frac{\mu_0 I^2}{3\pi^2 D_1 D_{\text{к}}}.$$

Here $\beta = 0.5\omega$, since with dimensions characteristics for the contacts it is possible to consider $\xi \approx 2$ /1, 8/;

j_k - the current density in the contact;

B_1 - the magnetic induction of current field I, flowing in the circuit with the rotating contact;

D_1 - the diameter of the free surface of the liquid metal;

D_k - the diameter of the rotating contact.

Since liquid-metal moving contacts are employed, as a rule, in devices with relatively large current values, then in comparison with B_1 it is possible to disregard the other fields. For high-speed contacts the centripetal acceleration $\beta^2 x \gg g$. Then, in accordance with (9), with given dimensions and speeds of the contact

$$\sqrt{2}\rho\left(\frac{\omega}{2}\right)^2 \frac{D_1}{2} \geqslant \frac{\mu_0 I^2}{3\pi^2 D_1 D_{\text{к}} l_{\text{к}}}$$

or

$$I \leqslant \pi D_1 v_{\text{к}} \sqrt{\frac{3\rho l_{\text{к}}}{\sqrt{2}\mu_0 D_{\text{к}}}} = \frac{\rho v_1^2 \pi}{\sqrt{2}\mu_0 j_{\text{к}}}, \qquad (10)$$

where $v_{\text{к}} = 0.5\omega D_{\text{к}} = \frac{\pi n D_{\text{к}}}{60}$ - the linear speed of the electrode at diameter D_k (n - the rate of rotation);

$v_1 = \frac{v_{\text{к}} D_1}{D_{\text{к}}}$ - the linear speed of the electrode at diameter D_1.

On the basis of (9) it is possible to derive the expression for estimating the permissible value of j. A deficiency of the corresponding expressions, obtained with less general premises /1-4/, is the absence of consideration of all the possible inertial loads and the obtaining of them as a result of the solution of a one-dimensional problem. The latter leads, in particular, to a difference in $\sqrt{2}$ times the quantitative results for the estimation of the permissible current I, calculated in accordance with /1-4/ and in accordance with expression (10).

<u>Estimation of the permissible inertial loads</u>. Let us examine the steady state, at which condition (9) is fulfilled. In the general case a rotating contact device can move in space with acceleration a, which also takes the force of gravity into account. The condition, at which the maximum values a_x, a_y, a_z do not lead to impermissible deviation od the points of the free surface of the liquid metal from the calculated position in the steady state, is determined by the expression (see the appendix)

$$\frac{(D_k - D_1)\delta_0}{\beta^2}(a_x + a_y) + \frac{2L}{\beta^2} a_z < 0.5 D_1 (D_k - D_1)\delta_0 \qquad (11)$$

where, in accordance with the designations of the geometric dimensions, presented in Fig. 2. $L=L_1+0.5\delta_0 (D_k-D_1) \operatorname{tg} \alpha_k$, and δ_0 - is the maximum permissible relative deviation.

For satifying inequality (11) it is possible not to take the effect of the accelerations on the liquid metal of the contact into account.

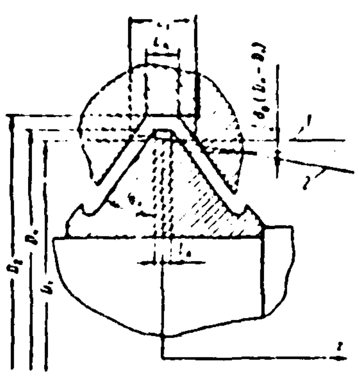

Fig. 2. The main geometric dimensions of a liquid-metal contact.
1 - the calculated level line; 2 - the level line with a perturbing effect.

As illustration of the obtained calculational formula the dependence I=f(v), calculated on the basis of (10), for certain values of j_k, is presented in Fig. 3. Curves were plotted for mercury (solid lines)

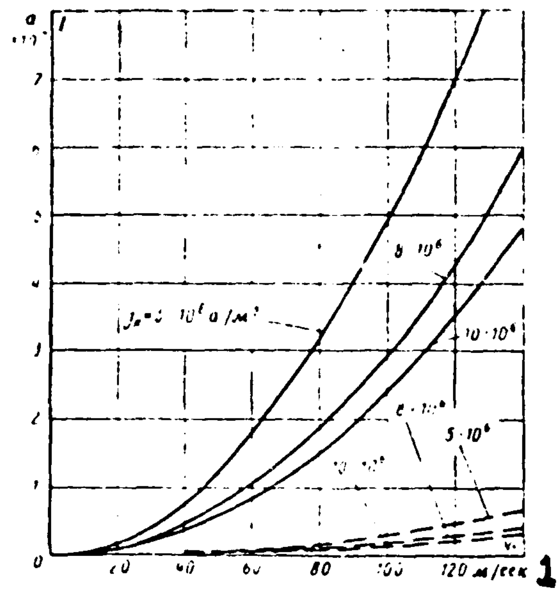

Fig. 3. The dependence of permissible current in a liquid-metal contact on its linear velocity.

KEY: 1 - m/ s.

and sodium-potassium alloy (broken lines) at a temperature of $T=323^{\circ}$ K. Fig. 4 shows the straight lines $a_x+a_y=f(a_z)$, calculated according to (11), for three values of β, which define the zones of normal operation of the liquid-metal contact.

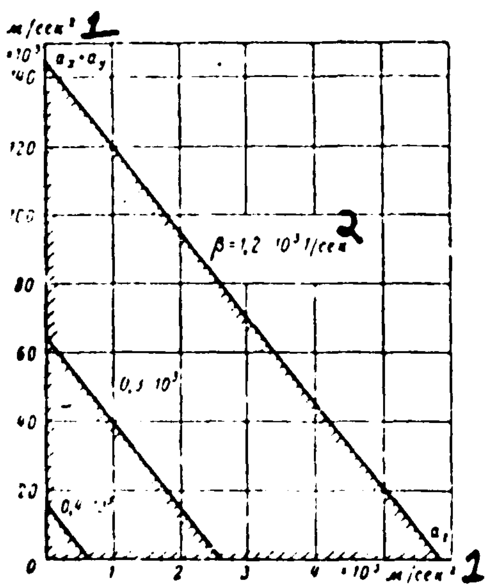

Fig. 4. Regions of permissible axial and radial accelerations of a liquid-metal contact device with D_1=200 mm;

L=4mm; D_k-D_1=2.32 mm, δ_0=0.14.

KEY: 1 - m/s^2, 2 - 1/s.

Appendix. According to the determination of the complete differential of the scalar field of the inertial forces

$$dp_{и} = \frac{\partial p_{и}}{\partial x}dx + \frac{\partial p_{и}}{\partial y}dy + \frac{\partial p_{и}}{\partial z}dz. \quad (P-1)$$

For the free surface $p_{и}$ is equal to the pressure of the ambient atmosphere $p_{и} = p_0$ =const and $dp_{и} = 0$, thus on the basis of (7) and (12)

$$F_{иx}dx + F_{иy}dy + F_{иz}dz = 0. \quad (P-2)$$

In this case taking the centripetal acceleration from (P-2) into account we find

$$(\beta^2 x + a_x)dx + (\beta^2 y + a_y)dy + a_z dz = 0. \quad (P-3)$$

Integrating (P-3), we obtain

$$\frac{1}{2}\beta^2 x^2 + \frac{1}{2}\beta^2 y^2 + a_x x + a_y y + a_z z - C = 0. \quad (P-4)$$

where C - the arbitrary constant of integration.

The corresponding (P-4) equation for increases in the coordinates of the point of the free surface of the liquid metal with disregarding of the magnitudes of the second order of smallness has the form

$$x\Delta x + y\Delta y + \frac{a_x}{\beta^2}\Delta x + \frac{a_y}{\beta^2}\Delta y + \frac{a_z}{\beta^2}\Delta z = 0. \quad (P-5)$$

Let us introduce relative magnitudes of the deviations

$$\delta_x = \frac{\Delta x}{\Delta x_0} \text{ and } \delta_y = \frac{\Delta y}{\Delta y_0}.$$

where $\Delta x_0, \Delta y_0$ - the base dimensions, determined by the structure of the contact device; Δz, equal to Δz_0 let us define as the given increase in the axial coordinate, within the limits of which deviations $\Delta x, \Delta y$ are possible.

Taking as x, y calculational coordinates x_0, y_0 of the examined point of the surface, and as their relative magnitudes the maximum permissible deviations $\delta x_0, \delta y_0$, on the basis of (P-5) we can write

$$\frac{a_x}{\beta^2}\Delta x_0 \delta x_0 + \frac{a_y}{\beta^2}\Delta y_0 \delta y_0 + + \frac{a_z}{\beta^2}\Delta z_0 < x_0 \Delta x_0 \delta x_0 + y_0 \Delta y_0 \delta y_0. \quad \text{(P-6)}$$

Inequality (P-6) is true for the calculational point with coordinates x_0, y_0, which are connected functionally in such a way, that the magnitude, standing on the right side of the inequality, varies between their minimum and maximum values. Thus for the entire set of calculational points the following inequality is valid

$$\frac{a_x}{\beta^2}\Delta x_0 \delta x_0 + \frac{a_y}{\beta^2}\Delta y_0 \delta y_0 + \frac{a_z}{\beta^2}\Delta z_0 < < (x_0 \Delta x_0 \delta x_0 + y_0 \Delta y_0 \delta y_0)_{min}. \quad \text{(P-7)}$$

where accelerations a_x, a_y, a_z are functions of the coordinates. From (P-7) it is possible to find the maximum permissible values of these accelerations, at which the inequality is still not disrupted.

Within the limits of rather small increases for any geometric shape of a contact it is possible to consider the surface of the liquid metal cone-shaped; then in accordance with the designations of the dimensions of the contact, shown in Fig. 2, we will assume

$$x_0^2 + y_0^2 = 0{,}25 D_1^2;$$

$$x_0 = 0{,}5 D_1; \quad \Delta x_0 = \Delta y_0 = 0{,}5(D_k - D_1);$$

$$\Delta z_0 = L = L_k + [D_2 - D_1 + 0{,}5\delta_0 (D_k - D_1)] \operatorname{tg} \alpha_k.$$

Moreover, we will set $\delta x_0 = \delta y_0 = \delta_0$

Substituting these values in (P-7), we obtain inequality (11).

<u>Conclusions</u>. The conducted analysis makes it possible to determine the parameters of the electromagnetic loads, at which the ring of

liquid metal, formed by the inertial loads, does not move in the inter-electrode space, and the accelerations, which do not cause the impermissible deviation of the free surface of the liquid metal from the calculated.

Bibliography

1. Бертинов А. И., Алиевский Б. Л., Троицкий С. Р., Униполярные электрические машины с жидкометаллическим токосъемом, изд-во «Энергия», 1966.

2. Годжелло А. Г., Вопросы устойчивости и стабильности жидкометаллического токосъемного устройства, Автореферат диссертации, Московский энергетический институт, 1965.

3. Watt D. A., The Development and operation of a 10 kw homopolar generator with mercury brushes. Proceedings of IEE, v. 105, 1958, pt. A, № 21.

4. Суханов Л. А., Сафиуллина Р. Х., Бобков Ю. А., Расчет жидкометаллического токосъема униполярных машин, «Электротехника», 1965, № 6.

5. Ландау Л. Д., Лифшиц Е. М., Электродинамика сплошных сред, Физматгиз, 1959.

6. Кирко И. М., Жидкий металл в электромагнитном поле, изд-во «Энергия», 1964.

7. Дорфман Л. А., Гидродинамическое сопротивление и теплоотдача вращающихся тел, Физматгиз, 1960.

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