THE INFLUENCE OF MAGNETIC AND ELECTRIC FIELDS ON DISPLACEMENT CURRENT OF A REED

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In the paper the influence of a displacement current on the switch dynamics has been analysed and discussed. Calculations have been performed for the reed switch under operation when an electric field of a high intensity appears within the contact area due to a load voltage applied across the blade tips.

В докладе рассматривается и анализируется воздействие тока смещения на динамику геркона. Были произведены расчеты в рабочем состоянии геркона, когда электрическое поле высокой интенсивности возникло внутри контактной области благодаря подаваемому на концах контакт-деталей напряжению нагрузки.

1. Introduction

Displacement current can be a real hazard for various reed switch applications since; it results in rapid failure due to the contact sticking. This phenomenon is strongly related to the contact gap variation with time under operation therefore, to the way of energizing. It is enhanced by the electric field intensity within the contact area as well. Therefore, for vacuum reed switch operating under high rated voltage of the contact load the displacement current can be even a key factor limiting their applicability.

In the paper the influence of the electric field intensity within the contact area under the reed switch operation on the displacement current value and its variation with time is analysed and discussed. The simulations and measurements have been carried out for vacuum reeds of the A-type when the DC load voltage up to about 25 kV applied. On the basis of both theoretical and investigated results the conclusions about the influence of a magnetic energizing (due to a coil) and the DC voltage value applied across the contacts on the displacement current phenomenon are formulated.

2. Analytical approach

The analysis has been performed for an A-type symmetrical reed switch the most often used in practice (Fig. 1). The contact area (an overlap of the blades tips) constitutes a capacitor with movable conducting plates under operation. For given driving ampere-turns value Θ of a coil an attractive force F_m between the blades under closure is strongly related to variation of the contact gap permeance G_μ, what using formulas developed by Roters and Cullen [1-2] can be expressed as:

$$F_m = -\frac{1}{2}\Theta^2 \frac{\partial G_\mu}{\partial x} \approx -\frac{\mu_0 \Theta^2}{m}\left[\frac{bd}{x^2} + \frac{1}{\pi x}\left(\frac{4b\tau}{x+\tau} + \frac{4d\tau}{x+2\tau}\right)\right] \qquad (1)$$

where:
- m - reduced mass of the blade,
- μ_0 - magnetic permeability of free space,
- τ, b, d - dimensions of the blade (see Fig. 1a),
- x - contact gap length.

At the end of the closure the blades are highly accelerated due to a snap action, what results in related variation of the contact gap capacity with the blades displacement x. Therefore, if only a load voltage U is applied across the contact a displacement current I_d arises as a result of variation of an electrical charge Q accumulated at the blades tips. It occurs at any transient state of the reed operation however; under the contact closure is the dominant. Moreover, the blades displacement can be reinforced by an electrostatic attraction due to an electric field energy W_e stored inside the capacity C equivalent to the reed contact area. The electrostatic force F_e is particularly serious for vacuum reed of a high DC voltage U and can be expressed as:

$$F_e = -\frac{\partial W_e}{\partial x} = -\frac{1}{2}\frac{\partial C(x)}{\partial x}U^2 \qquad (2)$$

where the contact capacity is given in the form [3-4]:

$$C(x) = \varepsilon_0 \left[\frac{bd}{x} + \frac{4b}{\pi} \ln \left| 1 + \frac{\tau}{x} \right| + \frac{2d}{\pi} \ln \left| 1 + \frac{2\tau}{x} \right| \right] \tag{3}$$

ε_0 - is electric permeability of free space.

The displacement current I_d can be calculated from simplified formula (when use only x- component of the electric flux density) [4]:

$$I_d(t) \approx \frac{\partial C(x)}{\partial x} \cdot \frac{dx}{dt} U(t) \tag{4}$$

To calculate the gap length variation with time $\left(\frac{dx}{dt}\right)$ an equation for blade motion has to be considered. When assume the reed symmetry, it is in a form (for the reed closure):

$$\frac{d^2 x}{dt^2} + 2\rho \frac{dx}{dt} + \omega_0^2 \left(\frac{g_0}{2} - x \right) = \frac{F_m + F_e}{m} \tag{5}$$

where: 2ρ - is a damping coefficient,
ω_0 - angular frequency of the blade self-vibration,
g_0 - contact gap length under steady state of the open reed.

If neglect the blade damping and substitute $E_q(1)$ and $E_q(2)$ into $E_q(5)$ the displacement current is finally obtained as:

$$I_d(t) \cong -U(t)\varepsilon_0 \left[\frac{bd}{x^2} + \frac{4\tau}{\pi x} \left(\frac{b}{x+\tau} + \frac{d}{x+2\tau} \right) \right] \cdot \sqrt{-\omega_0^2 x (g_0 - x) + \frac{\varepsilon_0 U^2(t) + 2\mu_0 \Theta^2}{m} \cdot \left[bd \left(\frac{1}{x} - \frac{1}{g_0} \right) + \frac{4b}{\pi} \ln \left| \frac{1+\frac{2\tau}{x}}{1+\frac{2\tau}{g_0}} \right| + \frac{2d}{\pi} \ln \left| \frac{1+\frac{2\tau}{x}}{1+\frac{2\tau}{g_0}} \right| \right]} \tag{6}$$

The calculations carried out for miniature A-type reed model (b = 120µm, d = 265µm, τ = 70µm, g_0 = 80µm, m = 0.001kg) of operated ampere-turns Θ_0 equal to 200A have indicated non linear variation of the magnetic force F_m value with the time under operation what, for the reed closure is shown in Fig 2. As a result the blade displacement x (therefore the gap length value) varies also nonlinearly and the displacement current I_d can be relatively high. When the load voltage to 15 kV_{DC} is applied its value can ready up to about 8A prior to the moment of the contact closure what, can be compared from Fig 3.
Note, that voltage across the contact $U(t)$ also varies in transient at a moment of the DC supply application U_0 (see Fig 1b). Therefore, due to the electrostatic force F_e generation the blades can short to vibrate even, for the reed being in a released steady state of operation. It is not considered as a good for the reed switch reliability since its resistance to impact and mechanical shocks tends to be decreased. Calculated values of the electrostatic contact force F_e and the displacement current I_d as a function of time (therefore as a function of the gap length x) are illustrated for example in Fig 4.
The formula for the displacement current during the reed releasing is much easier derivable [3]. However, the I_d values calculated for the same reed sample are found to be much below these under the closure.

3. Experimental results

To confirm the theoretical results the A - type vacuum samples (ZP-3 and ZP-4) were tested under the increased load voltage conditions [4]. It was found, that when the voltage exceeded some value the blades started to vibrate with their self-frequency. As a result a respective variation of the displacement current with time was observed in the load circuit (the reeds were not energized). The blades vibrations were reinforced with the increase of the voltage what finally resulted in repeated prestriking and/or closure of the contact in transient (see Fig 5.). The computations were found to be satisfactory agreement with experiment (accuracy about 20%) however, only in a case of not excessive gap length variations. Otherwise, prestriking or short circuits of the very short contact gap in transient were visible.

4. Conclusions

The displacement current which is associated with time-varying electric fields is generated under the reed operation and is particularly dangerous during the contact closure. Its value depends on geometrical dimensions of the contact gap, mechanical parameters of the blades (which influence their velocity) and the load voltage value applied. Increasing the voltage value changes the reed performance, so that the blades can start to vibrate even for the reed switch being in a steady released state. It decreases the resistance of the reed to impacts and mechanical vibrations and can lead even to repeated contact closure even if the voltage applied is below the breaking value.

List of figures

References

[1] Cullen G. W. A Practical Theory for Reed Switches, Proc. 19th NARM Conference, Stillwater, 1971.

[2] Roters H. C. Electromagnetic Devices. John Wiley and sons, New York, 1941.

[3] Zawiślański J., Miedziński B. Displacement Current of Reed During Operation. Proc. IC-CEMCA Conf. Nagoya, 1986, pp. 607-612.

[4] Miedziński B., Zawiślański J., Shoffa V.N. The Influence of a Displacement Current on Dynamics of a H.V. Reed. Proc. ICEC-2000, Stockholm, 2000, pp. 57-60.

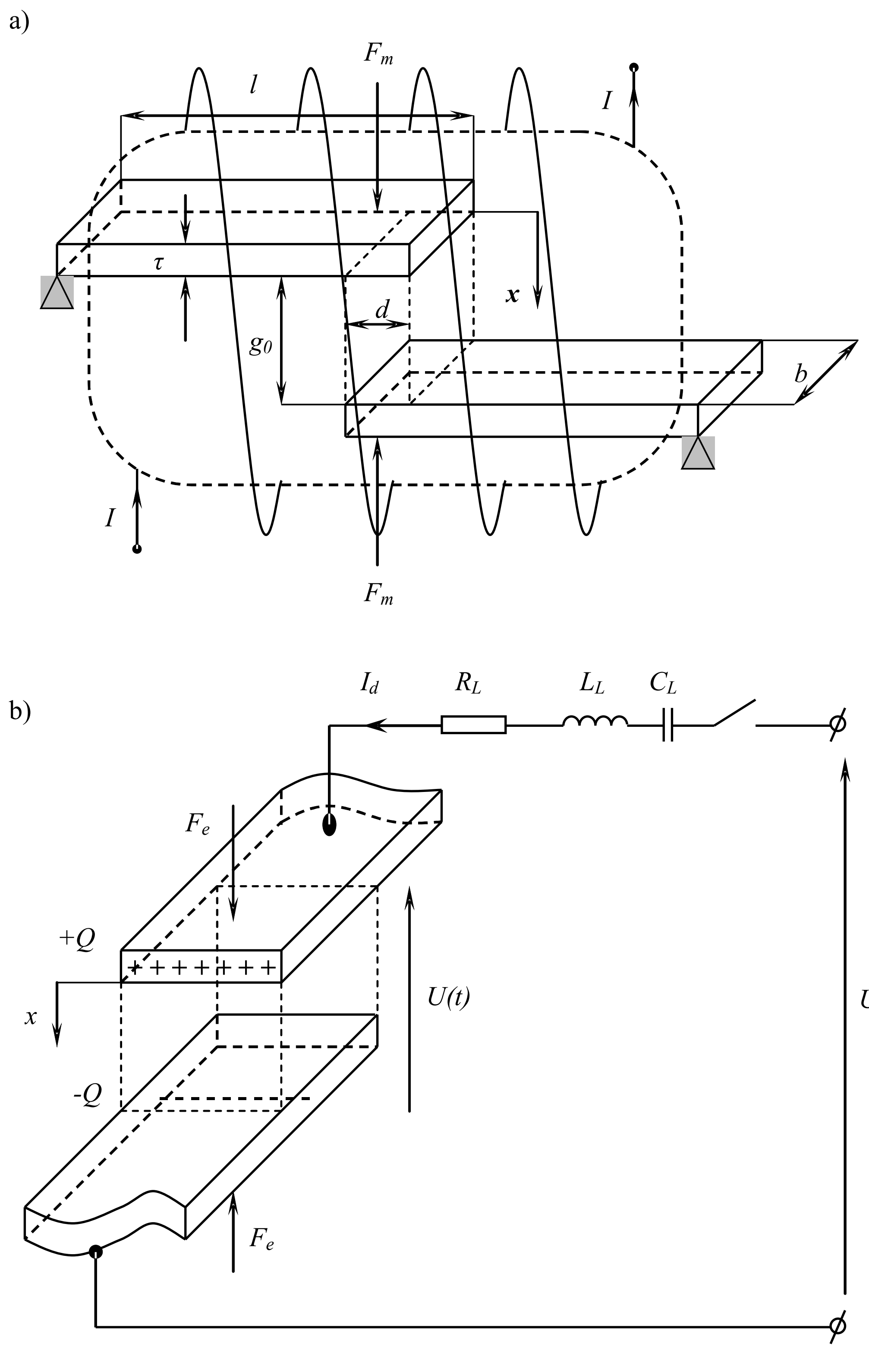
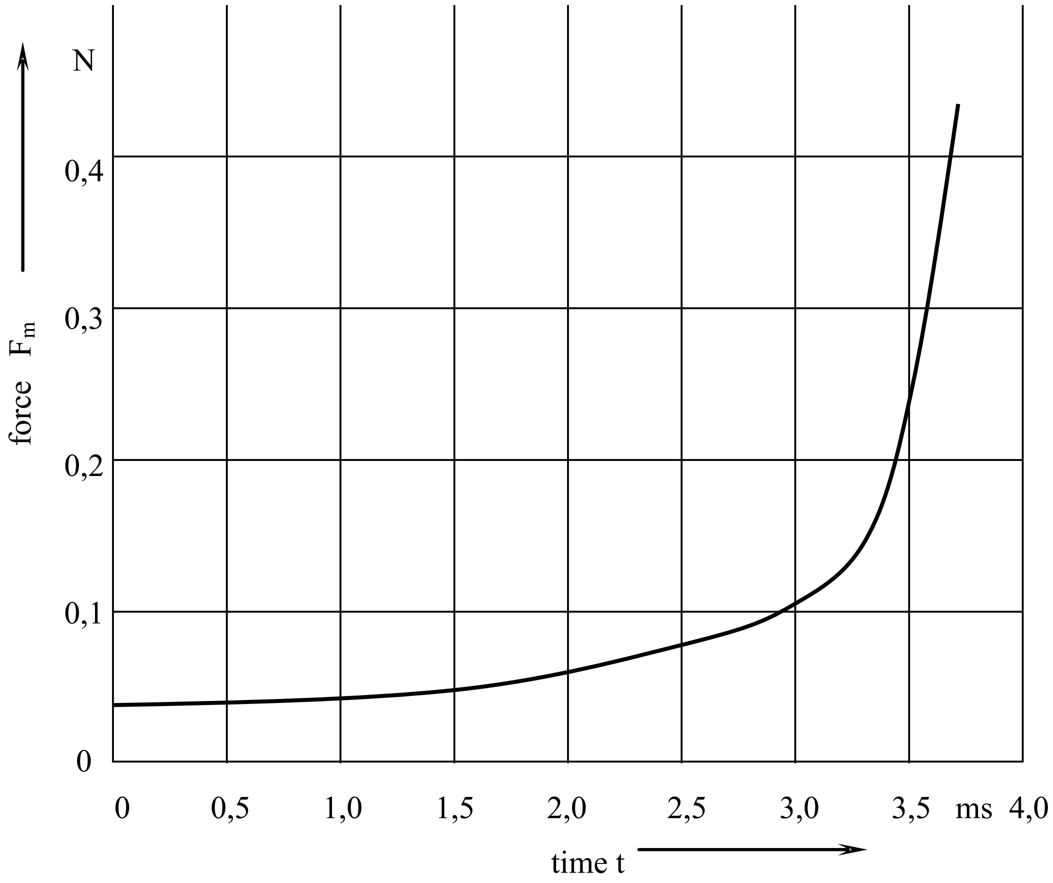


Fig 1.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0,3
0,2
0,1
0
force F_m
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0,5
1,0
1,5
2,0
2,5
3,0
3,5
ms
4,0
time t

Fig 2

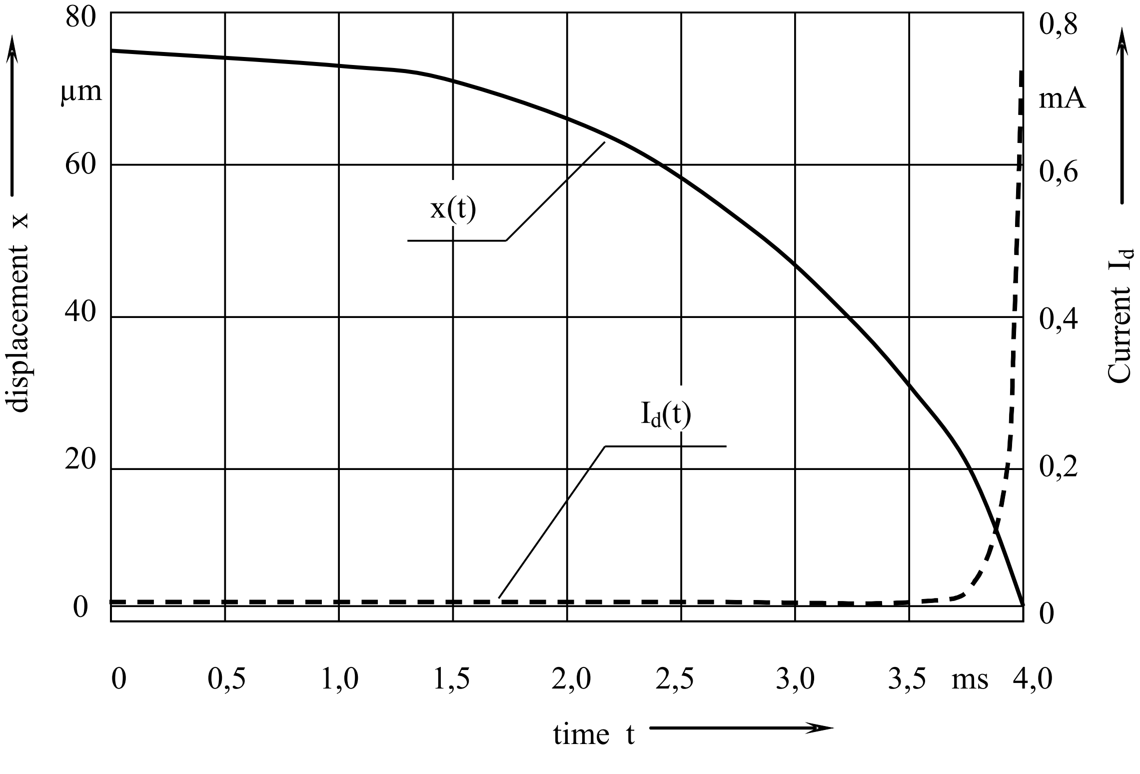
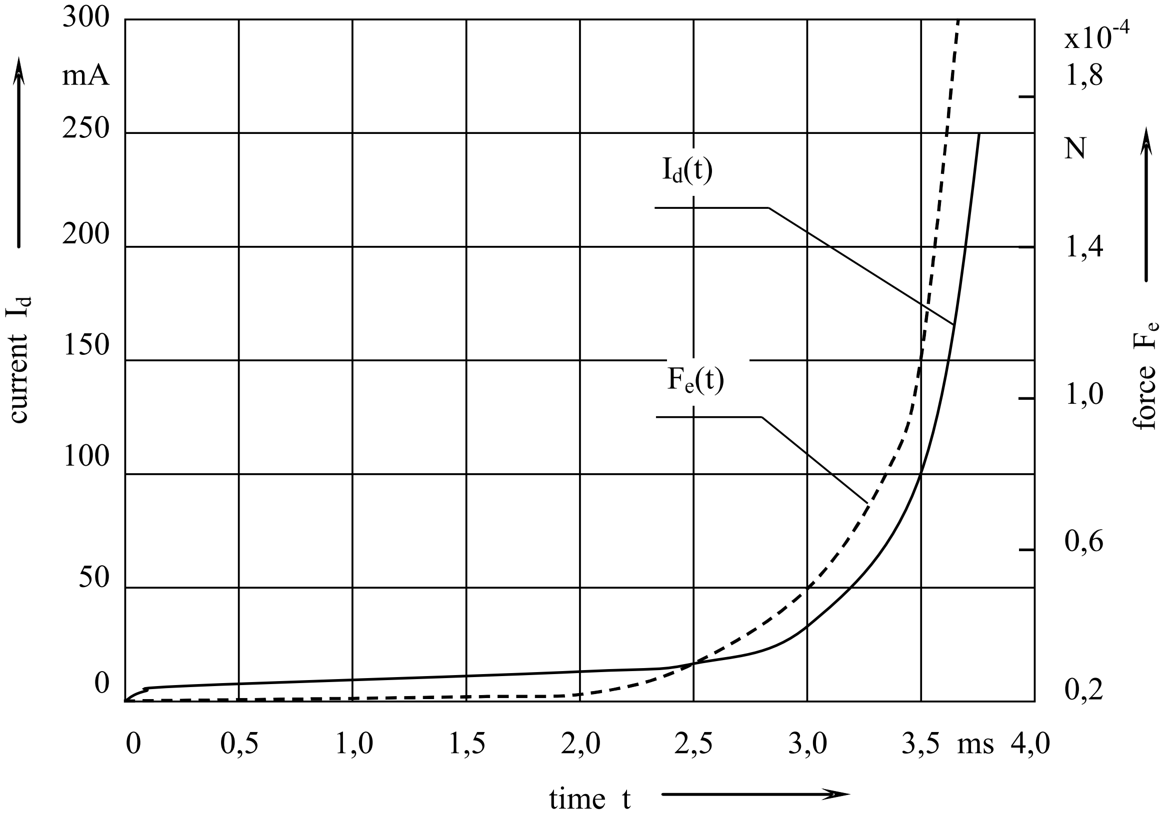

80
µm
60
40
20
0
displacement x
0,8
mA
0,6
0,4
0,2
0
Current I_d
x(t)
$I_d(t)$
0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
ms
4,0
time t

Fig 3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mA
250
200
150
100
50
0
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$I_d(t)$
$F_e(t)$
x10^-4
1,8
N
1,4
1,0
0,6
0,2
force F_e
0
0,5
1,0
1,5
2,0
2,5
3,0
3,5 ms
4,0
time t

Fig 4.

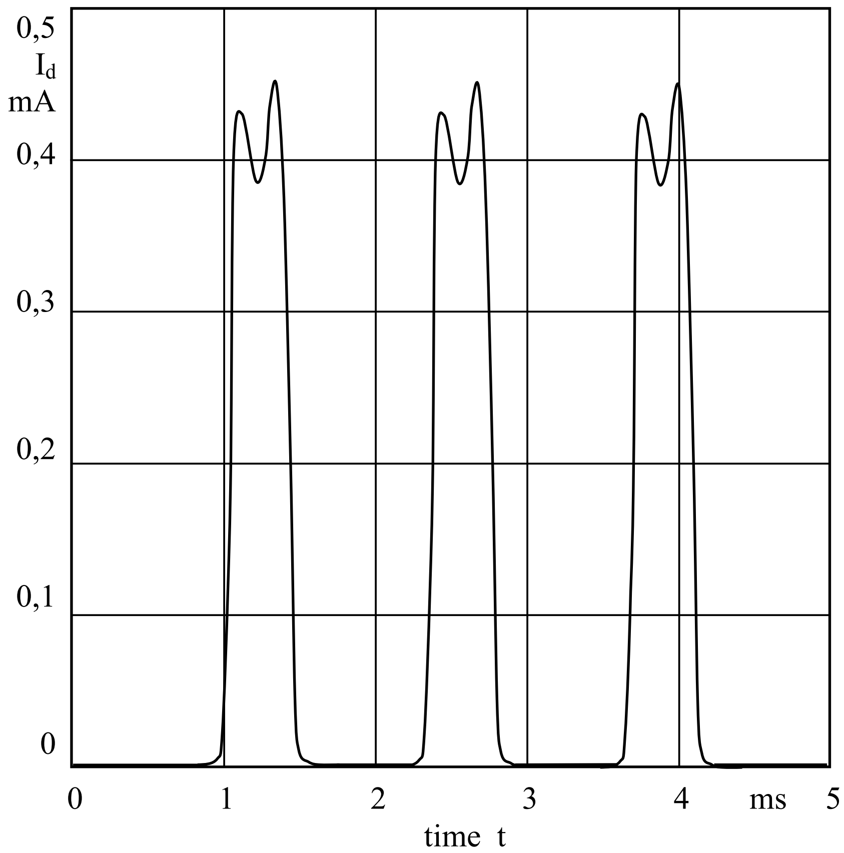
0,5
I_d
mA
0,4
0,3
0,2
0,1
0
0
1
2
3
4
ms
5
time t

Fig 5.