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THE DYNAMICS AND THE TRANSIENT STATES IN THE CLOSING CONTACTS

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ABSTRACT
Contradictory technical requirements for the contact construction parameters as contact materials and geometry, external mechanical forces of spring exerted at the contact surface, velocity of contact closing and opening operation, number of contact fingers and so on, require an individual compromise for each device depending on its design and duty. In the paper questions of estimation of the dynamics of movement of the contacts, having in view the existence of contact bounds process are answered. The mechanism of their formations was explained by experimental investigations. The object of investigation was a making switch, especially the movement of its contacts after their impact. Moreover, the dynamic model of contact by which the observed movement of contacts could be explained quantitatively, was determinated. In this paper, the answers for some evaluation criteria will be discussed and Dynamic Force Analysis methods to compare different designs of contacts will be introduced.

KEY WORDS
Power switching, bounds process, impact of contact

1. Introduction

The aim of theoretical analysis and experimental investigations was the estimation of the dynamics of contacts of electrical switches, having in view checking the existence of contact rebounds and explanation of the mechanism of their formations. During the switching operation, the arcing contacts are subject to extreme mechanical and thermal stresses [3,4]. Switching under load, especially for very high currents, is the most complicated case for simulation, when the physics of phenomena shall be considered in realistic way. Due to the high closing velocities [2] for minimize arcing, the contact fingers have tendency to rebounds from the butt with a higher deflection than in the closed position. Analytic description of above problems is in many cases very difficult. Investigations were accomplished on the model of making switch (Fig. 1). The aim of investigation in making switch in particular was the movement of moving contact after the initial contact. After the first contact the finger bounces several times against the butt, until the contact is closed.

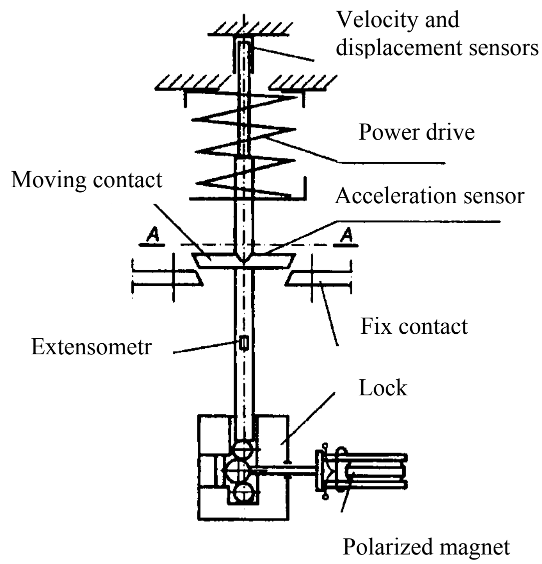


Fig. 1. Schema of making switch with marked measuring points

Switching on current in an electric circuit generally occurs not due to securing the contact of contacts, but as a result of electric break down of the isolation of the given environment [1]. The switching-on arc glowing time depends hence on the value of the intensity of electric field in the contact area, and on the velocity of contacts closing. So, the design of contact has to consider several partially contradiction requirements. In this paper not the complex processes in the contact zone itself are of primary interest, but the mechanical deformation of the contact tulip due to dynamic load. Expensive production and experimental testing of different alternatives can be supplemented by application of Dynamic Force Analysis method.

2. Investigations and analysis

The basis of analysis was the measurement of the velocity of moving contact after initial contact. (Fig.2).
On the basis of analysis the velocity of contact one can ensure:
a) existence of two phases of movement in period A-C (Fig. 2b), i.e. phases AB, in which contacts are closed and phase BC, when contacts are open;
b) in phase BC, moving contact moves with approximately uniform acceleration what proves, that in this period acts only force of constant value, equal to statical force of spring of driving mechanism in making switch.

a)

b)

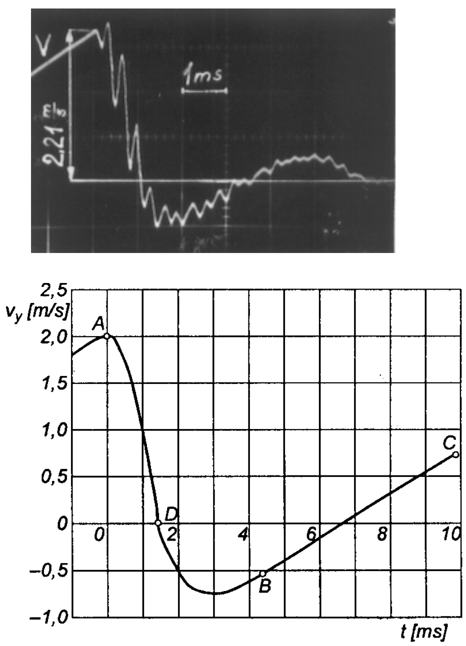


Fig. 2. Velocity of moving contact vs time;
a) oscillogram, b) averaging of wave form of velocity

For the explanation of the dynamics of movement of contact after the initial contact (very significant for dispersing of energy), the analysis of possible reasons of losses was made. These are:

- friction force in contact,
- resisting force dependent on the velocity of a contact.

As a result of analysis it was stated, that friction appears in the form of resisting force dependent on velocity. The most simple form was an assumption of the simple proportionality between resisting force and velocity *v* of contact (1),

$$F_{op} = \lambda v \tag{1}$$

Besides, taking into account the relatively small degree of the oscillation of velocity of contact, in relation to the overall velocity, the model with one degree of freedom (Fig. 3) was assumed for the dynamic analysis of contact.

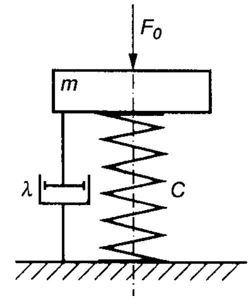


Fig. 3. Model of contact with one degree of freedom

On the basis of this model, the value of damping coefficient λ and the value of equivalent stiffness c of contact were determined.
The equation of motion of such a contact system is as follows

$$m\frac{dv}{dt} + \lambda v + c y_s = F_o \tag{2}$$

where:

$m = m_1 + m_2$ – reduced mass of contacts,
y_s – contact displacement,
F_0 – contact force,
v – contact velocity

In equation (2) are well-known: reduced mass of contacts m, the value of velocity in the initial contact v_0 , and contact force F_0 . It is necessary to determine values of damping coefficient λ and the value of equivalent stiffness *c* of contact. For this purposes the suitable balance equations for period of movement of contacts (phase AB, Fig. 2b) were proposed:

- balance of energy, by integrating the equation of motion for a contact system (2), in relation to the contact displacement y_s ;

$$\frac{m}{2}(v_p^2 - v_k^2) = \lambda \int_0^{y_{sm}} v dy_s + \lambda \int_{y_{sm}}^0 v dy_s = \lambda J \tag{3}$$

where:
the value of energy J, could be calculated by numerical integration of velocity diagram $v(y_s)$ in Fig. 4. As a result it is possible to find the value of damping coefficient λ.

- balance of motion, by integrating the equation of movement of contact as a function of time *t* ;

$$m\int_0^{t_{AB}} dv + \lambda \int_0^{t_{AB}} v dt + c\int_0^{t_{AB}} y_s dt = \int_0^{t_{AB}} F_o dt \tag{4}$$

From equation (4) after transformations it could be obtained:

$$m(v_k - v_p) = -cJ + F_o t_{AB} \tag{5}$$

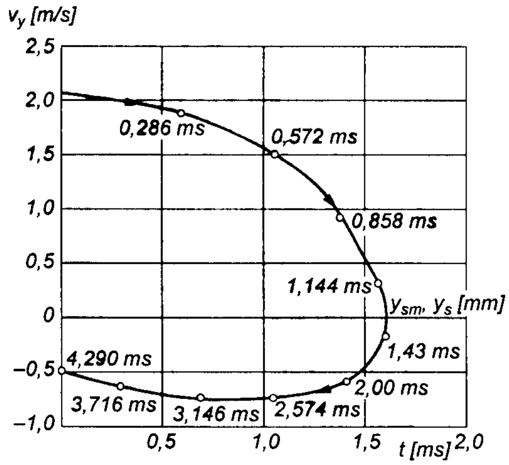


Fig. 4. Dependence of velocity *v* versus contact displacement y_s

It is possible to calculate the value of integral *J*, by numerical integration of contact displacement $y_s(t)$, (Fig. 5). It allows to determine the value of equivalent stiffness c of contact.

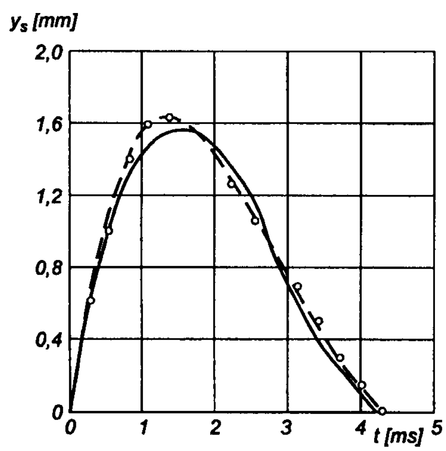


Fig. 5. Displacement of contact y_s as a function time t; calculated —, experimental ---

Having calculated the values of equivalent stiffness *c* of contact and damping coefficient *λ*, it is possible to determine the displacement of contacts, taking into account the coincidence of the solution the equation of motion:

$$y_s(t) = \frac{F_o}{c} + e^{-\alpha t}\left[\left(\frac{v_p}{\omega} - \frac{F_o}{c}\frac{\omega_o}{\omega}\cos\Theta\right)\sin\omega t - \frac{F_o}{c}\frac{\omega_o}{\omega}\sin\Theta\cos\omega t\right] \quad (6)$$

where:

$$\alpha = \frac{\lambda}{2m}; \qquad \omega_o = \sqrt{\frac{c}{m}}; \qquad \omega = \sqrt{\omega_o^2 - \alpha^2};$$

$$\Theta = \arcsin\frac{\omega}{\omega_o}$$

Results of the calculated displacement of contact after the initial contacts (broken line) are presented in Fig. 5.

3. Velocity of contact closing

The break down of the contact gap occurs at the moment of equalising of contact gap dielectric strength u_p (t_s, t) with the momentary value of the voltage u(t) applied to the gap (Fig. 6).

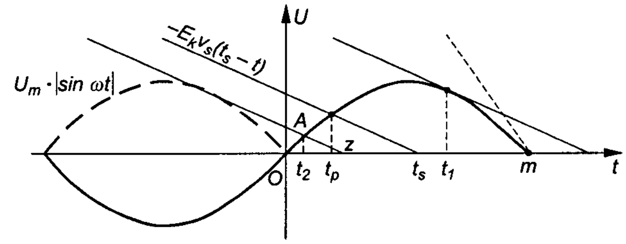


Fig.6. Determination of the breakdown moment

Assuming that the breakdown voltage is proportional to the distance between the contacts, and that it is not polarity-dependent, it is possible to determine the time t_p when the breakdown occurs during current switching on from the relation:

$$U_m|\sin\omega t| = E_k v_s(t_s - t_p) \quad (7)$$

where:

E_k – critical value of electric field strength,
t_p – moment of break down of contact gap,
t_s – moment of contact closing.

The arc duration $t_a = t_s - t_p$ depends on the velocity v_s of contact closing, and on the electric field strength value E_k [2,4]. In flat contact face arrangements the velocity v_s of the contact gap decrease is equal to the velocity v_y of the axial motion of the moving contacts. On the other hand, in tulip or conical contact arrangements the velocity v_s is smaller than the velocity v_y, and in the case of a system with conical contact tips (Fig. 7) it amounts to:

$$v_s = v_y \sin\alpha' = v_y \cos(90^0 - \alpha) \quad (8)$$

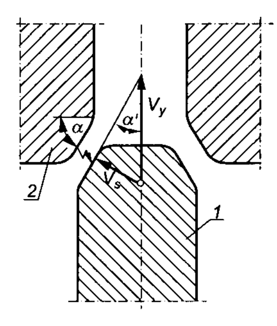


Fig. 7. Example of the conical contact tip: 1 – moving contact, 2 – stationary contact

The arc duration t_a is illustrated in fig. 8 by the slope of the straight line $y = -E_k v_s (t_s - t)$ in relation to the assumed time axis t.

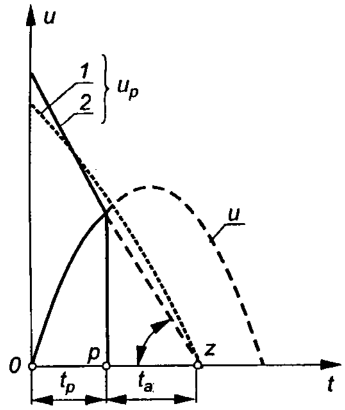


Fig. 8. Determination of time of electric arc, during switching on of current

The arc duration depends on the value of electric strength against contact gap breakdown and on the value of velocity v_s of contact closing. In the given conditions, this time will be the shorter, the closer to zero value the voltage phase is.

For the sake of switching the current on in an electric circuit at the exact moment of voltage, i.e. to avoid the breakdown of contact gap, two practical conditions must be fulfilled [2]:

1. the dynamic strength of the contact gap during contact closing should be higher than the instantaneous value of the supply voltage;
2. the scatter of making time of electric switch $t_c = t_p + t_{az}$ should be possibly lowest; for making switches the scatter of making time values should be considered satisfactory if:

$$\Delta t_c \le 5^0 el \qquad (9)$$

Switching on is, hence, at any voltage phase angle (Fig. 6) including the phase angle corresponding to the moment of voltage passing the zero value, provided that the condition for k, is satisfied:

$$k = \frac{E_k v_s}{\omega U_m} \ge 1 \qquad 10)$$

Minimum value of the velocity of contacts at the moment of their mechanical contact, at which the contact gap will not be broken down during electric circuit switching on, can be determined from the relationship:

$$v_s \rangle \frac{\omega U_m}{nE_k}$$

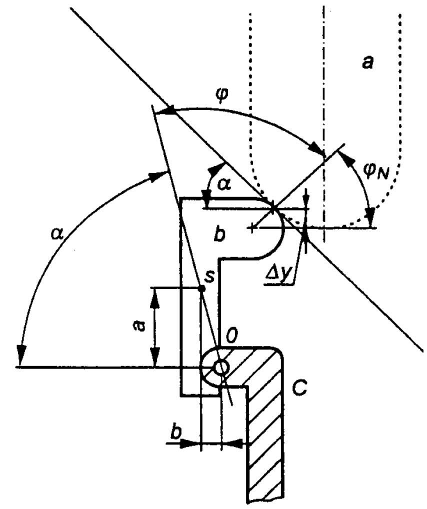
(11)

The selection of a determined phase of switching current on requires the application of an electronic system to control the process of the switches, e. g. making switch or synchronised switch.

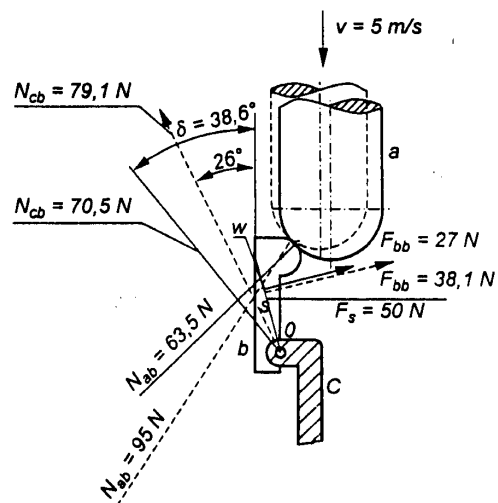
4. Dynamic force analysis of tulip contacts

It is necessary to remember, that a higher velocity of tulip contacts, leads to a higher mechanical impulse on the contact fingers tips and an oscillation in the fingers [2].

a)



b)



c)

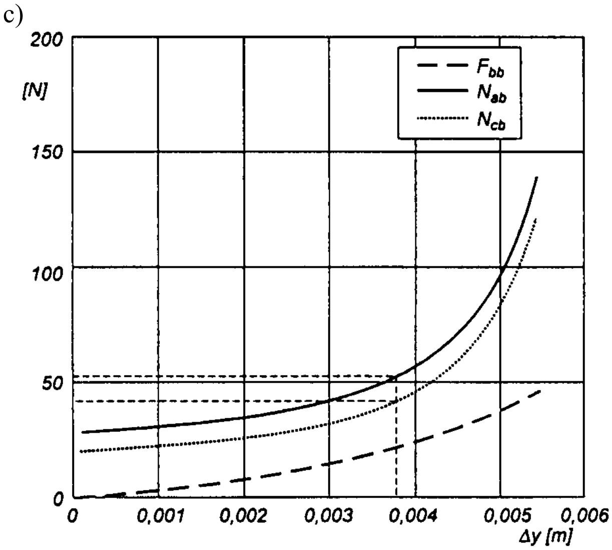


Fig. 9. Dynamic force analysis of contacts

Due to this mechanical impulse, the deflection of the finger tip is higher than for a quasi-static switching and it may lead to the rebounds of contacts.
According to the results of simulation technique and practical experiments, after the initial contact, the finger bounces several times against the plug until the contact is closed. The oscillating behaviour after the first contact is highly dominated by the natural frequencies connected with geometry, materials of contacts and the inertia of the fingers of contact. At the level of designing process of contacts, the classical Dynamic Force Analysis (DFA) method (Fig. 9) is very useful too.

First of all this method allows to investigate value and angle of reactive forces in a switching contact N_{ab} and dismembering non switching contacts N_{cb} . These two important parameters of the reactive force enable to estimate the value of the external spring forces exerted at the contact surface, against mechanical rebounds and welding. So, above kind of analysis is carry out from the point of view of the influence of different shapes of guiding head of contacts, moment of inertia of the fingers and velocity of moving contact, on the dynamics of contacts.

5. Conclusion

Consistency of the measured results of velocity and displacement with values calculated on the basis of the assumed model and coefficients calculated according to global energetic and motion criteria, proves the correctness of the model. It was confirmed by the results of investigations, that the proposed mathematical model with one degree of freedom is quite sufficient for analysis of the dynamics of motion of contacts after the initial contact, applied in making switches. It is not necessary to take into account the wave-processes in the analysis of dynamics of motion for contacts, during their vibrations.
The higher velocity of contacts leads to a higher mechanical impulse on the contact fingers tips and an oscillation in the fingers and it may lead to the rebounds of contacts.
Dynamic Force Analysis allows to investigate value and angle of reactive forces in a switching N_{ab} and dismembering non switching contacts N_{cb} , to eliminate at finally rebounds of contacts.
The optimal reduction of the burn-off rate is possible if the contact surface, the moving direction, the speed of the movement and the contact material will be harmonised.

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