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SOME COMPONENTS OF SWITCHING ARC ENERGY BALANCE UP TO 30 ms BURNING TIME[1]

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The energy balance of low voltage switching arcs for currents from 230 to 14700 A and burning time up to 30 ms in the deion-type quenching chamber is reported. The energy components absorbed in contacts and quenching chamber have been measured calorimetrically. The other components of energy balance, like the vaporization of contacts and the heating-up of the surrounding air are presented.

О НЕКОТОРЫХ СОСТАВЛЯЮЩИХ ЭНЕРГЕТИЧЕСКОГО БАЛАНСА КОНТАКТН ГУГИ ВПЛОТЬ ДО ВРЕМЕНИ РАЗРЯДА 30 мс

В работе сообщается об энергетическом балансе контактных дуг при низком напряжении для токов от 230 до 14 700 А и времени горения вплоть до 30 мс в камере с искрогашением деионизационного гипа. Энергия составляющих, абсорбированных в контактах и камере искрогашения, измерены калориметрически. Приводятся также другие составляющие энергетического баланса, такие как испарение контактов и нагрев окружающего воздуха.

I. INTRODUCTION

The most frequently used type of quenching chamber of the low-voltage switchgear is the deion-type quenching chamber, provided with a set of metal plates of various shapes. This type remains in the centre of interest in connection with contact switching-devices as circuit breakers and contactors.

Considerable attention has been devoted to the construction problem of the deion-type quenching chambers, especially to the optimum shape and number of metal plates. Moreover, the material of the plates and contacts, etc., is studied as well [1, 2, 3, 4].

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The results of the up to now presented works do not enable to create a comprehensive mathematical model. The reason is that it is not possible to define, at least approximately, the geometry of the occurring switching arc. Thus the models of the arc applicable to the designs of high-voltage circuit breakers, as e.g. the model of Mayr [5] and that of Cassie [6], the equation of Elenbaas-Heller [7] etc. cannot be used for calculations.

The first step to exclude the empirical approach to the construction of the quenching chamber may lie in a better knowledge of the energy balance of arc occurring in switching processes. This paper gives account of the above problem concerning the low-voltage switchgear. The heat absorbed in both the contacts and the deion-type quenching chamber is measured. The heat of vaporization of contacts and that absorbed in the surrounding air is determined as well.

II. EXPERIMENTAL CONDITIONS

Measurements were performed using the model of a current-limiting circuit breaker with the following nominal parameters: current 160 A, voltage 500 V, breaking capacity 20 kA at 550 V, $\cos\varphi = 0.25$. For our measuring purposes the circuit breaker was adapted for easy dismantling and removing of the fixed contact and the quenching chamber. A simplified model — section is shown in Fig. 1.

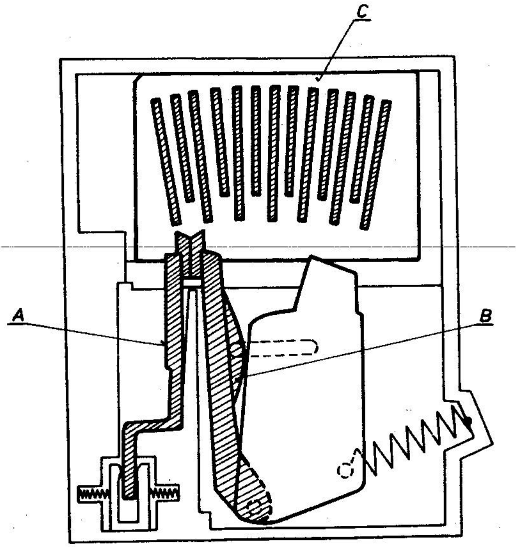

Fig. 1. A simplified model-section of the JR2 limiting circuit breaker. A — the fixed, removable contact, B — the movable contact, C — the quenching chamber.

A being the fixed contact, B the moving contact and C the quenching chamber.

The circuit breaking experiments have been performed at 500 V, $\cos\varphi = 0.3$ and currents ranging from 230 to 14700 A.

The arc heat absorption in the fixed contacts and the quenching chamber has been measured calorimetrically [8].

The heat required for the vaporization of a part of contacts has been determined by means of the weight difference of the removable fixed contact after each experiment. The heat absorbed in air was determined under the assumption of an isochoric process in a tight box by measuring the pressure increase.

III. RESULTS OF MEASUREMENTS

Energy of arc

The energy of the arc W_0 has been evaluated graphically from the voltage and current oscillograms of the switching process. The analysis shows the values of W_0 to be the function of the measured arc current I according to the equation

$$W_0 = 1782.73 \times I^{0.963} \qquad [\text{J, kA}] \qquad (1)$$

Relative heat absorption in contacts

Let the heat absorbed in the fixed contact of the circuit breaker be W_K. Let us assume that the energy is transferred from the arc into the contacts symmetrically. Then the movable contact is supplied with the energy W_k, too. Hence, the relative heat absorbed in both contacts is

$$w_k = (2W_k/W_0)100 \qquad [\%].$$

By means of the least squares method the dependence for the measured current range 230—14700 A is

$$w_k = 15.663 \times I^{-0.204} \qquad [\%, \text{kA}]. \qquad (2)$$

Relative heat absorbed in quenching chamber

Let W_z denote the heat absorbed in the quenching chamber. The relative quantity is defined by the relation $w_z = (W_z/W_0)100$ [%]. The experimental results exhibit the dependence

$$w_z = 44.9 \times I^{-0.04} \qquad [\%, \text{kA}] \qquad (3)$$

Relative heat required for the vaporization of contasts

The dependence obtained for the mean loss in weight ΔG [mg] is non-linear. It may be approximated by the relation $\Delta G = 0.000458 \times I^{1.399}$ [mg, A]. The heat W_v required for vaporization is $W_v = k \times \Delta G$ [J], where $k = 1.73$ [J mg^{-1}]. Using the measured dependences the relative heat $w_v = (W_v/W_0)100$ [%] may be approximated by the relation

$$w_v = 1.8211 \times I^{0.367} \qquad [\%, \text{kA}]. \tag{4}$$

For currents $I < 1$ kA a rapid increase is observed and the course is non-linear; for currents $I > 1$ kA the relation (4) may be linearized into the form

$$w_v = 1.5 + 0.35 \times I \qquad [\%, \text{kA}]. \tag{5}$$

Relative heat absorbed in air

The heat component absorbed in air is denoted by W_p [J]. After substitution of the corresponding constants for the isochoric process it may be defined as

$$W_p = 0.6548 \times 10^{-3} T \Delta p \qquad [\text{J, K, Pa}], \tag{6}$$

where T is the temperature of air in the box before the experiment and Δp is the pressure increase. The relative heat $w_p = (W_p/W_0)100$ [%] has been approximated by the relation

$$w_p = 9.068 \times I^{0.608} \qquad [\%, \text{kA}]. \tag{7}$$

The energy balance is completed by the relative component w_j [%], which represents the Joule-losses in the current-carrying parts of the circuit-breaker others than those in the contacts. The magnitude of w_j was established by measuring the resistance of the whole circuit-breaker r and the resistance of the fixed contact r_k. The Joule losses in the fixed contact are already included in the component W_k. Hence

$$w_j = \frac{(r - 2r_k) I^2 t_0}{W_0} 100 \qquad [\%, \Omega, \text{A, s, J}] \tag{8}$$

where t_0 denotes the arc-burning time at the appropriate I. For currents $I \leq 10$ kA the component w_j is ranging from 5 to 7 %.

IV. DISCUSSION OF RESULTS

The total energy balance consisting of the above discussed components of relative shares of energy is given in Fig. 2. The area between the neighbouring curves corresponds to the respective component.

The components W_k and W_z were determined calorimetrically with an accuracy of about 5 %. The accuracy of the relative shares of energy w_k, w_z, w_v, w_p and w_j can be estimated up to 10 % approximately. On the upper limit of the considered current range $I \sim 10$ kA the sum of components equals roughly to 100 %. For lower currents it does not reach 100 %, e.g. for $I \sim 1$ kA the sum is about 70 %. The relative heat not mentioned so far is w_x [%]. It can be interpreted as the heat absorbed in those parts of the circuit breaker, which have not been involved into measurements and as possible inaccuracies appearing in the determination of the absorbed heat. The relative error for small currents increases.

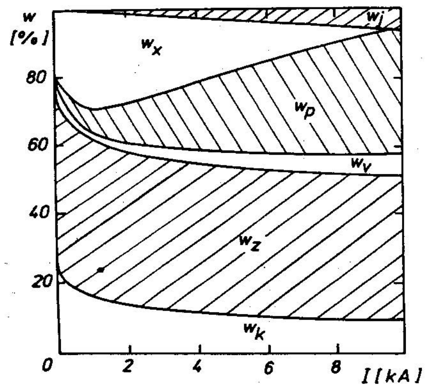

Fig. 2. A schematic drawing of the energy balance. w_k is the relative heat absorbed in contacts, w_z is the relative heat absorbed in quenching chamber, w_v is the relative heat required to vaporization of contacts, w_p is the relative heat absorbed in air, w_j is the relative heat absorbed in current carrying parts of the circuit breaker (besides the contacts) due to passage of current, w_x is the relative heat not involved in our measurement.

The analysis of the established dependences according to relations (1)—(7) shows some regularities in accordance with the results of other authors. There has been once more verified the decrease of the relative heat in contacts w_k with an increasing arc current (2), [9—13].

The behaviour of the component of relative energy absorbed in the quenching chamber w_z (3), which remains practically constant and is independent of the magnitude of the arc current I, differs from that of the component w_k (2). This coincides with the results in [14]. The difference may be due to the fact that the arc burns on the contacts throughout the whole time of its existence, while in the quenching chamber it burns for part of this time only. Further, the velocity of the medium part of an arc passing through the set of deionizing plates increases with the current. Hence, the time of the arc passage through the chamber decreases with the current. As a result a very slow decrease of the energy component w_z with the increasing current is obtained (3). The approximative relations for the vaporization of the material of contacts (4) and for the absorption in air (7) correspond with those in similar studies by other authors [15] and [16].

V. CONCLUSION

Results of measurements give, for the first time, the energy balance of the whole deion-type quenching chamber in the form of the components making its direct application in construction possible. The energy balance has been compiled for currents of up to 14700 A. The data presented may be a stimulus for further creative research concerned with an exact model of low-voltage switchgear quenching chambers.

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