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Measured Dissipated-Energy in Switching-off by Electric Contacts*

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The measurement of the dissipated energy in switching-off has been attempted to make clear the function of spark on electric contacts, which may unfortunately cause the combustible gas, such as propane gas etc, to catch fire and result in fire accidents.

By utilizing the "Memoriscope" has been the meaurement carried out and the feature of this method is to provide the information on not only the amount of dissipated energy involved in one action but also on the trace of its instantaneous power which can affect catching fire delicately.

Presented in this paper are the discussion of this measuring method and the measured results which are obtained experimentally in order to investigate the dependence of the energy dissipation on variety of contacts, contacts' deterioration and circuit arrangements.

§ 1. Introdution

There have been, far and near, the explosion or fire accidents of the combustible gas such as propane gas etc., which have been often guessed to be due to the electric spark in switching-off by small electric contacts in electric appliance for household. However, it is considerably difficult to put the scientific ground in order, which loads to the conclusion that their causes of catching fire are the electric spark, since its phenomenon is very complicated and depends upon various conditions. The authors have attempted experimentally catching-fire tests and consequentlly, has recognized the high probability of catching-fire in certain conditions. In such cases, the ignition source is the electric spark from the electric contacts, so it is necessary to know well their characters. The dissipated energy in switching-off by electric contacts, which can be the cause of catching fire, is to be taken into account from two points of view; one: amount, another; manner of the dissipation, in other words, the watt vs. time characteristics.

The systematic study on the amount of this energy has been already presented in detail by prof. Hō, but it is not refered to the watt vs. time characteristics. On the other hand, Mr. Kimoto has reported the measured example of the watt-time curve on the electric discharge machining, though this is relatively monotonous phenomenon. The phenomenon when contacts are opened, however, is complicated due to the variation of the gap length.

The authors have measured the transient voltage and current in switching-off of contacts by the use of "Memoriscope", and investigated the transient characteristics of the spark. Presented in this paper are the discussion of this measuring in order to investigate the dependence of the energy dissipation on variety of contacts, contacts' deterioration and circuit arrangements.

§ 2. Measuring Method

(1) Measuring Method

The dissipated energy W in switching-off may be expressed as the integral of the instantaneous power p with respect to time t, where p is designated as the product of the instan-

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taneous voltage e_a across contacts by the instantaneous current i_a Then, the relation may be written as follows.

$$W=\int pdt=\int e_a\cdot i_a\cdot dt$$

The measuring circuit is shown in Fig. 1.

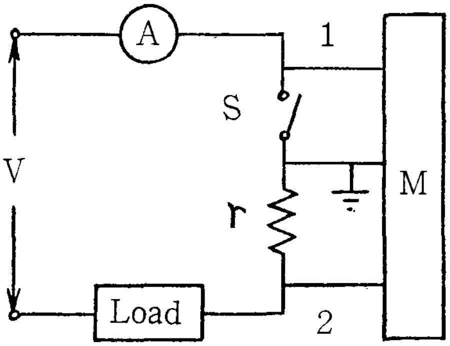

Fig. 1. Measuring circuit
V : Supply voltage
S : Testing contact
r : Shunt resistance
M : Memoriscope
A : Ammeter

The values of e_a, i_a and p were obtained with the measured by "Memoriscope". As compared with the so far used "Repeated method", this method has two merits; first, to be possible to measure both the amount and the manner of the energy dissipation by one single sweep; second, to be able to distinguish the behavior of one action from the other, because the spark by each action is not always identical.

(2) Problems of the Measurement

Rapidity of Switching-off

The action of the testing contacts is caused by the snap mechanism, and therefore the rapidity of switching-off may be considered to be always constant.

Synchronization

Synchronizing the signal of the sweep of "Memoriscope" to switching-off action of contacts is required to insure the "Memory" of the voltage and current characteristics in the discharge. Since the duration of the discharge is about $10^{-2}\sim10$ [msec], and the sweep duration of "Memoriscope" is about $0.5\sim5$ [msec/cm], it is necessary for synchronizing by the hand-worked action to select good timing. In practice it is possible.

Accuracy

The error induced in this measuring method has something to do with "Memoriscope", photograph and its reading-out. Fig. 1 shows the experimental circuit that has a d-c supply and a resistive load. Fig. 2 shows the characteristics of the voltage and the current in the case of Fig. 1. The circuit equation in the discharging period can be written as

$$E=e_a+R\cdot i_a$$

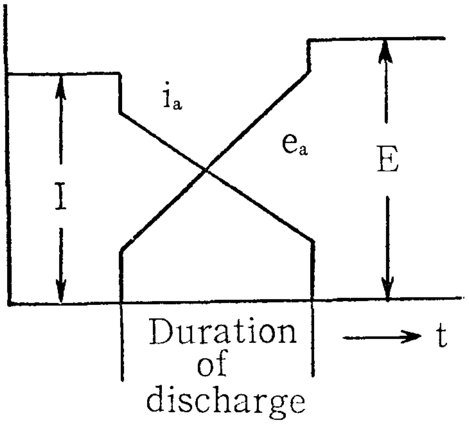

Fig. 2. The voltage e_a and the current i_a in switching-off when d-c supply and resistive load

By inserting the values of e_a and i_a obtained respectively from about three hundred sheets of photographs to the last equation, it was known that the difference between the $e_a+R\cdot i_a$ and d-c supply voltage E was within about 5%. Accordingly, if let the errors of e_a and i_a be respectively within 5%, it is considered that the error of power p is put within 10%.

§ 3. Influence of the Kind and the Deterioration of Contacts

The influence of the kind and the deterioration of contacts upon the energy dissipation was investigated by testing some examples with d-c resistive load.

(1) Measuring Conditions

The measurements have been carried out with the contacts as shown in Table 1.

(2) Measuring Results

The measured and shown in Table 2. Fig. 3 shows the relation of the dissipation energy and the duration of discharge. And in Fig. 4 the transient voltage, current and power are shown with respect to various testing contacts, that is, SA, SB$_1$, SC$_1$ and SC$_2$.

(3) Discussion

From the viewpoint of the kind of contacts

Table 1 Testing Contacts

Symbols	Types of Contacts	new or old
SA	Cord switch (National)	new
SA_2	Cord switch	new
SB_1	Pressure switch (Yamadadenki, PS-13)	new
SC	Magnet switch for electric refrigerator (Hitachi)	15 years of duty
SC_1	Thermostat switch for electric refrigerator (National)	new
SC_2	Thermostat switch for electric refrigerator (National)	4 years of duty
SC_3	Thermostat switch for electric refrigerator (Hitachi)	The spring of snap mechanism is forced to be weakened purposely
SD	Thermostat for Denkikotatsu (National, 100V-100W)	5 years of duty
SE	Thermostat for Denkigama (Toshiba, 100V-600)	5 years of duty

It is found from Fig. 3 that the amount of dissipated energy is roughly in proportional to the duration of discharge, and this relation corresponds to the following equation given by Prof. Hō, when the first term is neglected.

$$W=\frac{1}{2}LI^2+\frac{I^2E^2}{32\delta v}$$

where W: Dissipated energy
L : Inductance of circuit
I : Current through contacts
E : Source voltage
δ : Design constant of contacts
ν : Velocity of switching-off

From Table 2, the following facts are pointed out.

(a) The duration of arc-discharge in switching-off by the same contacts, is not always constant even under the same condition.

(b) Even if the sort of contacts is the same, the scopes of variations of the duration differ from each other.

(c) Roughly speaking, the shapes of the transient voltage, current or power are similar with respect to various contacts respectively.

This is also valid on the other contacts or under the other conditions.

From the viewpoint of deterioration of contacts

The deterioration of contacts is roughly classified electrical one and mechanical. The former one includes the meltings of contact surfaces by the repetition of arc-discharge and/or the transformation of contacts in shape etc., and the latter one includes the fatigue of the spring of snap mechanism and/or the wear and tear of friction parts etc. Furthermore, the contact surface may be eroded by chemical action too.

From the measured of SC_1, SC_2 and SC_3 in Table 2, it is pointed out that the effects of mechanical deterioration, particularly of the fatigue of the spring in snap mechanism, is larger than that of electrical one.

§ 4. Influence of Circuit Conditions

The duration of arc-discharge and the energy dissipated in switching-off will be considerably influenced by the circuit conditions such as supply and load etc.

(1) Measuring Conditions

The measurements have been carried out in the two cases of d-c and a-c supply, when the load are resistive or inductive.

(2) Measuring Results

The measured dissipated-energy and duration under the above mentioned conditions is shown in Table 3. The transient voltage, current and power are shown in Fig. 5. Fig. 6 shows the phase relations of the transient voltage and current in switching-off, when the a-c supply is used.

(3) Discussion

d-c Supply:

As previously described, in the d-c circuit with the resistive load, if the source voltage and the current are constant, the amount of dissipated energy is roughly in proportional to the duration of discharge, and the shapes of the transient are similar. But, when the load is inductive, the amount increases and the

Table 2 Measured results of various testing contacts

Voltage	90 V		60 V		30 V	
Testing contacts	Dissipated energy (W. S)	Duration of discharge (mS)	Dissipated energy (W. S)	Duration of discharge (mS)	Dissipated energy (W. S)	Duration of discharge (mS)
SA	0.13	8.0	0.057	4.4	0.0051	0.8
	0.11	6.5	0.074	6.0	0.0040	0.6
	0.23	13.0	0.087	6.8	0.0041	0.6
	0.14	8.5	0.061	4.8	0.0056	0.8
	0.14	8.5	0.073	5.6	0.0064	1.0
SA_2	0.13	9.5	0.055	4.8	0.00054	0.075
	0.072	6.0	0.064	5.6	0.0015	0.2
			0.042	3.6	0.0028	0.375
			0.039	3.2	0.0011	0.15
			0.053	4.4	0.0017	0.225
SB_1	0.036	2.5	0.015	1.2	0.0017	0.24
	0.041	3.0	0.018	1.6	0.0014	0.2
	0.047	3.0	0.023	2.0	0.0002	0.04
	0.037	2.5	0.015	1.2	0.0012	0.16
	0.045	3.0	0.014	1.0	0.0013	0.18
SC	0.12	7.0	0.072	5.6	0.00061	0.1
	0.11	6.5	0.065	5.2	0.00052	0.075
	0.13	7.5	0.011	8.4	0.00063	0.1
	0.11	6.5	0.080	6.0	0.00087	0.125
	0.13	7.5	0.085	6.4	0.00053	0.075
SC_1	0.019	1.1	0.0095	0.8	0.0029	0.4
	0.016	1.0	0.0097	0.8	0.0028	0.4
	0.013	0.9	0.010	0.8	0.0018	0.25
	0.018	1.1	0.010	0.8	0.0021	0.3
	0.017	1.0	0.010	0.8	0.0028	0.4
SC_2	0.016	0.9	0.0089	0.7	0.0017	0.25
	0.015	0.9	0.0088	0.7	0.0020	0.3
	0.016	0.9	0.0069	0.7	0.0017	0.25
	0.013	0.9	0.0074	0.6	0.0018	0.25
	0.018	1.2	0.0077	0.6	0.0019	0.25
SC_3	0.028	1.7	0.015	1.3	0.0041	0.55
	0.027	1.7	0.014	1.2	0.0035	0.45
	0.029	1.7	0.012	1.0	0.0034	0.45
	0.027	1.7	0.016	1.2	0.0029	0.4
	0.026	1.5	0.0099	0.8	0.0062	0.85
SD			0.053	4.4	0.00061	0.1
			0.044	3.4	0.0021	0.3
			0.056	4.2	0.00047	0.075
			0.049	3.4	0.0037	0.525
			0.028	2.2	0.0018	0.275
SE	0.047	2.5	0.052	4.0	0.0019	0.275
	0.057	3.0	0.020	1.6	0.0029	0.4
	0.049	2.5	0.021	1.8	0.00065	0.1
	0.042	2.5	0.014	1.2	0.00033	0.05
	0.043	2.5	0.017	1.4	0.00063	0.1

when current: 1.0 (A), resistive load

transient phenomena become more complicated.

a-c Supply:

In the a-c circuit, the duration of arc-discharge and the amount of dissipated energy depend extremely upon the timing of switching-off. In the circuit with inductive load, the variation of voltage is larger, the variation of current is slower and the shapes of the transient are more and more complicated.

§ 5. Conclusion

The measurement of the dissipated energy in switching-off has been carried out by the

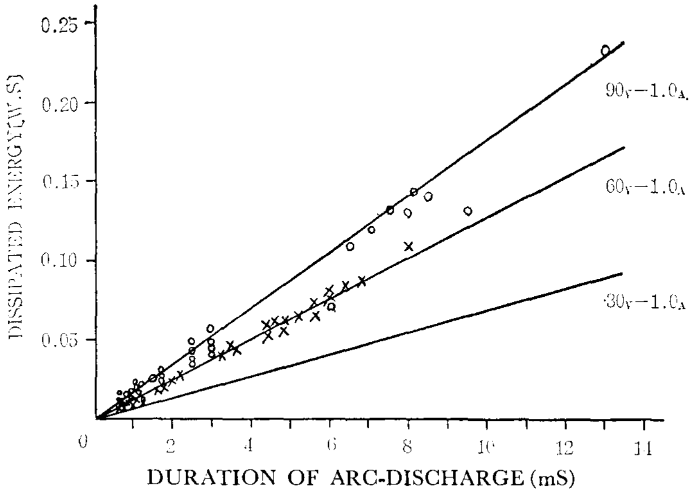

Fig. 3. The relation between dissipation and duration in switching-off

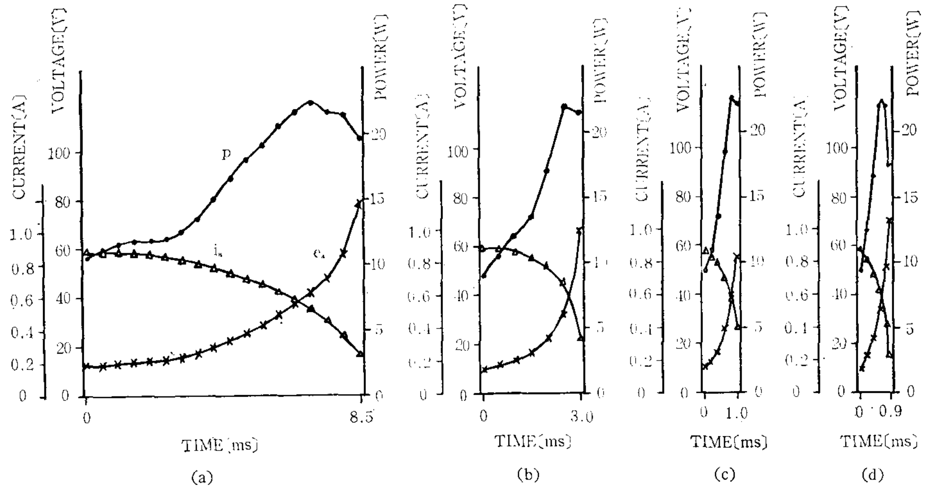

Fig. 4. The transient voltage, current and power when d-c supply and resistive load
(*a*) *SA* (*b*) *SB* (*c*) *SC* (*d*) *SC*

Table 3 Measured results when d-c or a-c supply

Voltage	d-c 90 V						a-c 100 V			
Load	R		R + L (100 mH)		R + L (200 mH)		R		R + L (100 mH)	
Testing contacts	Dissipated energy (W.S)	Duration of discharge (mS)	Dissipated energy (W.S)	Duration of discharge (mS)	Dissipated energy (W.S)	Duration of discharge (mS)	Dissipated energy (W.S)	Duration of discharge (mS)	Dissipated energy (W.S)	Duration of discharge (mS)
SC$_1$	0.019	1.1	0.069	2.4	0.14	4.8	0.030	1.4	0.092	3.2
	0.016	1.0	0.064	2.4	0.15	4.8	0.039	1.7	0.072	2.2
	0.013	0.9	0.073	2.8	0.14	4.8	0	0	0.100	3.1
	0.018	1.1	0.078	2.8	0.14	4.6	0	0	0.065	2.2
	0.017	1.0	0.064	2.6	0.13	4.6				

when current: 1.0 (A)

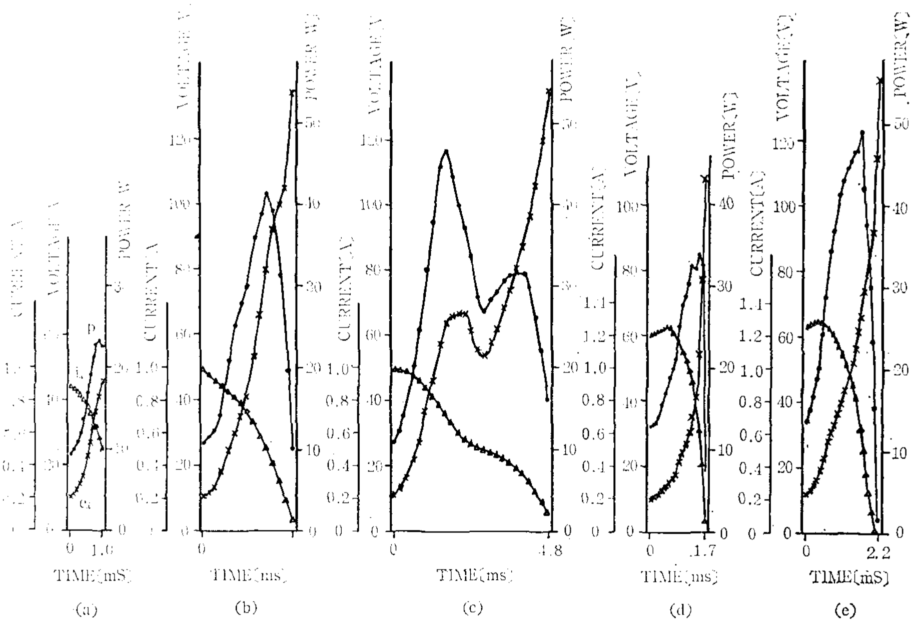

Fig. 5. Transient voltage, current and power when d-c or a-c supply, resistive or inductive load

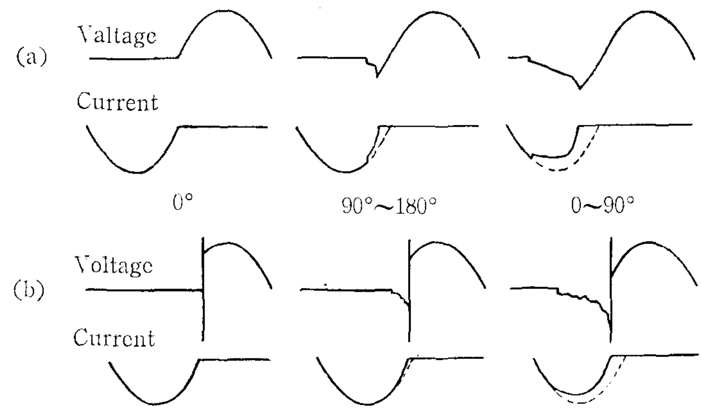

Fig. 6. The current phase in switching-off
(*a*) *Resistive load* (*b*) *Inductive load*

use of the "Memoriscope", and the results have explained the dependence of the energy dissipation on variety of contacts, contact' deterioration and circuit arrangements.

References

1) S. Hō: *Electric Contact and Switch* (1964) Kinbarashuppan.
2) Y. Kimoto: J. I. E. E. of Japan 80 (1960) 334.