Life Time Diagnosis of Reed Relays Operated under Hot Conditions

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Abstract—**Contact marks and the amount of transferred metals on relay blades are analyzed in detail to evaluate the life time of reed relays. It is observed that contact metals of Rh and Ru transfer always from anode to cathode under hot (voltage and current applied) conditions, and transferred Ru is much less than that of Rh confirming a longer life of Ru contacts. We conclude that the amount of transferred metals is independent of loading elements of R, C and L, and inversely proportional to the life time. A method to determine the life time is proposed by optically measuring contact areas which are directly related to the transferred metals.**

I. Introduction

We have been using millions of reed relay a year for our products of IC testers, where we found that more than 90% of failed reed relays returned from our fields are due to the short at contact blades. It is hardly understandable for us whether the ground cause of the failure is due to defects in relays, or their life time which is strongly restricted by operation conditions and contact metals used[1,2]. Another difficulty to diagnose their causes of the failure is a poor reproducibility of the failed state. We hence encounter a serious problem not to find an effective countermeasure for problems of our customers.

Reed switches consist of a simple structure with two magnetically moving contacts (blades) fixed and sealed in a glass tube[1]. Blade surfaces are plated by Rh or Ru metal and kept in N_2 gas[1]. Failed states of switches are primarily classified as a high contact resistance and a locking (short) of two blades. We focus in studying locking failures of blades in the present paper, when switches are operated under hot (current flowing) conditions. The locking takes place with tran- sferring and accumulating contact metals[3]. We have carefully observed and analyzed contact surfaces to understand the locking phenomenon. We propose here a reasonable method of a life time evaluation of reed relays from a relationship between the volume of metal transfers and the on/off frequency of switches as a diagnosis method of failed reed relays.

II Experiment

A. *Samples*

Evaluation samples of relays are pulled out from four model circuits (see Table III) at suitable on/off frequencies. A total number of 120 pieces of reed relays is supplied for the experiment. We picked up two contact blades after breaking a glass tube in reed relay. Basic properties of Rh and Ru contacts are shown in Tables I and II. It is noted that two types of Rh blades with different surface roughness are employed in our experiments.

TABLE I
STRUCTURE OF REED BLADES

Parameter	Rh1	Rh2	Ru
Surface Roughness	1.0μm	3.0 μm	1.4 μm
Film Thickness	2.8μm	2.7μm	0.8μm
Oxidized Film Thickness	20nm	10nm	non
Underground material	Au/Ni/Cu	Au	Au

TABLE II
PROPERTIES OF CONTACT METALS

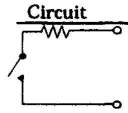
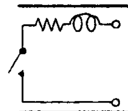
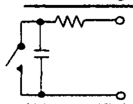
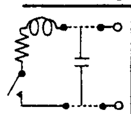
Properties	Rh	Ru
Melting Point	1960 degree	2450 degree
Thermal expansion	9.6×10^{-6} /K	6.8×10^{-6} /K
Thermal capacity	25.0 J/K mol	24.1 J/ K mol
Thermal conductivity	150W/m K	117W/m K

B. Sampling Methods

We constructed four kinds of simple electric circuits for each relay with different kinds of R, C and L to evaluate the amount of contact metal transfers. Used circuits are shown in Table III. The on/off frequency is varied from 2 x10 [7] to 1 x 10 [8], and its operation rate is constant to be 100Hz with a rectangular wave of 5V DC.

TABLE III

RELAY CIRCUITS and LOADS

Figure of Circuit	Contact Material	Load R	L	C	Cable
	Rh2 Rh1/Rh2/Ru Rh2	500Ω 5kΩ 50kΩ	—	—	—
	Ru	5kΩ	0.22 μH	—	—
	Ru	5k Ω	—	8pF	—
	Ru	5k Ω	—	—	0.22 μH 16.8 pF

Relays of 3 pieces are normally employed for each operation step, and obtained values are averaged. Hence, 15 samples are subjected to each operation condition.

C. Measuring Method

Metal transfers are analyzed and evaluated in the following way. Several transfer areas are often observed on a blade. We select the largest transfer area as an analysis point on a contact blade, because the largest area may be the most effective for the locking of contacts. Areas of metal transfers are measured by a laser profile microscope made by Keyence Co. Japan. Metal transfers are imaged on a monitor screen normally by magnification of 2000. Contact surfaces are scanned by a laser beam of λ = 685nm with stepping by 0.05 μm in height. The best height resolution is estimated to be 0.01 μm. Repeated accuracy of the measurement is 0.03 μm in the present measurement. The profile data of contact surfaces are recorded and filed in a PC. The amount of metal transfers can be monitored on the screen. The height of bumps or the depth of craters of metal transfers is measured as a distance from an average level of the scanning profile to the highest or the lowest level, respectively. Since various shapes of bumps or craters are observed on blades, the area of a bump or a crater is measured as multiplying the largest diameter of it by the shortest one.
The laser profile microscope has a merit to measure surface profiles without contacting, so one can measure the height and the depth of transfers repeatedly without scratches on the surface. The evaluation parameters are the height of bumps, the depth of craters, the area of transfer regions as well as the volume of metal transfers which is calculated by multiplying the height by the area of metal transfers. The height of bumps and the volume of metal transfers are measured as a function of the on/off frequency.

III Experimental Results

A. Rh1 Contacts with a Resistance

Figs. 1, 2 and 3 show relationships of the height, the area or the volume of bumps against the on/off frequency. A point to be emphasized is,
(1) On increasing the on/off frequency, the height, the area and the volume of bumps grow, i. e., those values are roughly proportional to the on/off frequency in the region from $2x10^7$ to $1x10^8$ of the on/off frequency.

Fig.4 demonstrates photographs of a pair of metal transfers (bump and crater) along with surface profiles of Rh1 at $2x10^7$ of the on/off frequency. The result can be summarized as follows. (2) Bumps exist always on the cathode surface, while craters exist on the anode surface. (3) Bumps and craters are formed very locally on contact surfaces. (4) A bump and crater pair forms contact marks like a cup and cone. (5) The height of a bump is 2.4 μm and the depth of a crater is 2.5μm, meaning that the bump size corresponds closely to that of the crater.

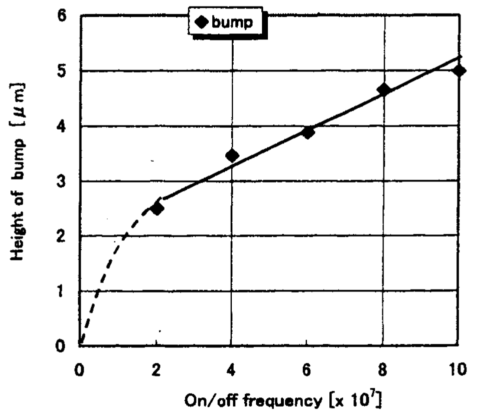


Fig. 1. Observed heights of bumps of transferred Rh 1 metal versus on/off frequencies.

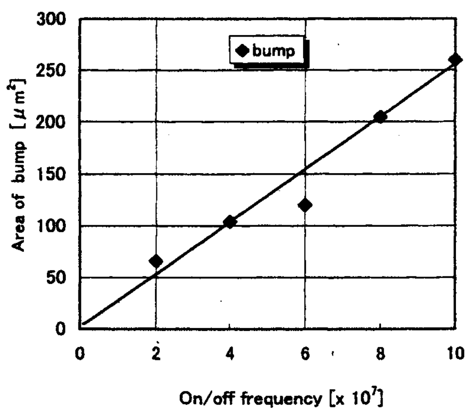


Fig. 2. Bump areas for transferred Rh 1 metal plotted against on/off frequencies.

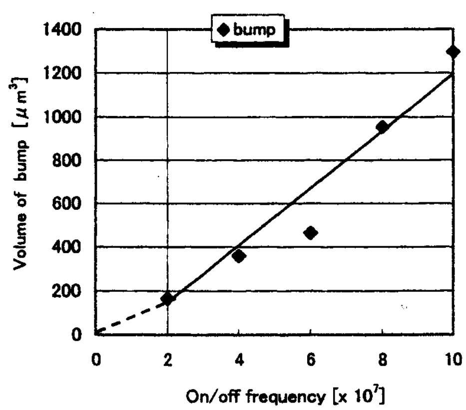
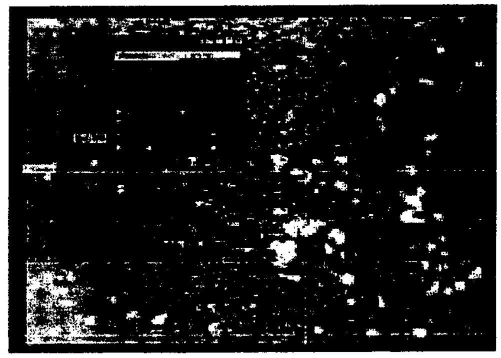
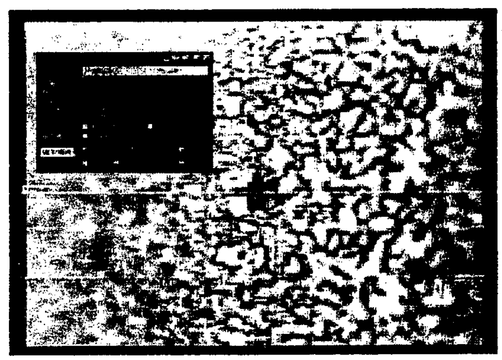


Fig. 3 Bump volumes of transferred Rh 1 metal plotted against on/off frequencies.



(a) crater picture



(b) bump picture

Fig. 4. A bump/crater pair of Rh 1 metal at $2x10^7$ of on/off frequency observed by a laser profile microscope, and surface profile traces of the bump and crater.

B. Rh2 Contacts with 3 kinds of R

Figure 5 depicts a relationship between the volume of metal transfer and the on/off frequency with R as a parameter. Summary of the result is in what follows. (1) The volume of bumps is linearly proportional to the on/off frequency. (2) The growth rate of bumps produced with 500Ω or 5kΩ is accelerated faster by 2 to 3 times compared with that with 50kΩ in average. In other word, more the current increases on the contacts, more is the volume of bumps. (3) It is confirmed that the formations of bumps and craters are independent of the current strength. (4) Though Rh1 and Rh 2 are the same contact metal, the volumes of metal transfers are different from each other at the same on/off frequencies due to different surface structures.

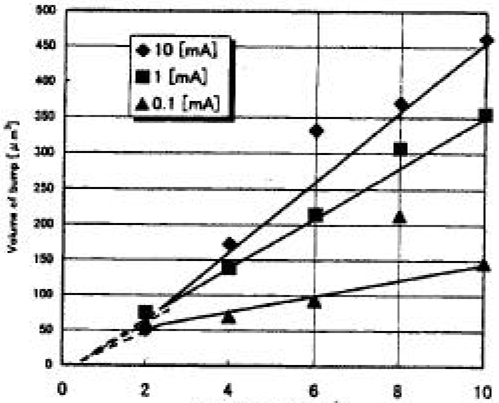


Fig. 5. Volumes of bumps for transferred Rh 2 metal versus on/off frequencies.

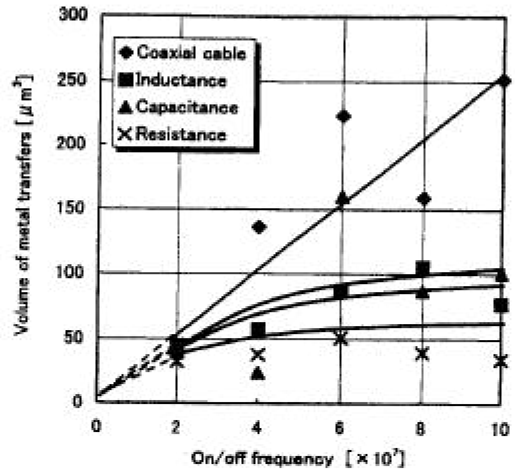


Fig. 6. Dependence of the volume of bumps of transferred Ru metal on R,C,L and coaxial cable as circuit loads as a function of on/off frequencies.

C. Ru Contacts with R, L, C and Cable

Fig.6 shows the volume of Ru bumps plotted against the on/off frequency with R, L, C or a coaxial cable. The result can be summarized as follows. (1) The volume of bumps produced with a coaxial cable is linearly proportional to the on/off frequency. (2) The volume of bumps produced with R, L, and C are proportional to the on/off frequency in nonlinear manners. (3) The growth rates of bumps with L, C and the coaxial cable are faster by 2 to 5 times than the rate with R. (4) Even though circuit loads are varied, it is always observed that bumps exist on the cathode and craters on the anode surface. (5) The volume of bumps of Ru is found to be 1/7 of that of Rh.

IV. Discussion

It is known that metal transfers on relay contacts are strongly influenced by the Thomson effect depending upon a current through the contact[1] in relay used under hot conditions, where a voltage is always applied between contacts during on/off operations. When a contact is closed, charges accumulated in load elements flow instantaneously through microscopic contact area, and a Joule's heat is generated there. If temperature of the contact is higher than the softening temperature of the contact, a molten bridge may be formed between the contacts [4-6]. When a current flows the bridge, the highest temperature region may move from center of the bridge to the anode side by the Thomson effect[4,5]. Therefore, increasing the on/off frequency, the contact metal is expected to transfer gradually from the anode side to the cathode side.

It is evidenced in the present experiment that metal transfers occur under any hot conditions. It is hence considered that the volume of metal transfers is affected by temperature of molten bridge, used metal, circuit loads and structure, and on/off frequencies. Current generates Joule's heat, which helps to raise temperature of molten bridge. The most important property of the contact metals is possibly melting temperature, and the thermal expansion, the specific heat and thermal conductivity of metals may influence the amount of metal transfers[4,5]. When L, C and a coaxial cable are connected in a circuit, contact areas may get damaged by a discharging energy[7-9]. Based on the Thomson mechanism, the volume of metal transfers may have a critical level sufficient for locking, which leads a reed relay eventually to its life time.

It can be concluded in the present study that the life time of reed relays can be determined by observing transferred metals on blades. The life time of Rh comes about at $8x10^6$ of on/off frequencies under a 10V/10mA condition with R in the circuit. We assume that the life time is defined approximately at a failure rate of 5% in a Weibull plotting chart. It becomes obvious that when the on/off frequency arrives at $8x10^6$ which corresponds to the life time of Rh, the volume of metal transfers is estimated to be $550\mu m^3$ in average. The critical volume of transferred Ru metal is similarly estimated to be $800\mu m^3$ at its life time under same elastic switch force as Rh. Using the above value of the on/off frequency, we can estimate roughly the transferred amount at the lifetime which depends weakly upon circuit loads with the relay.

V. Conclusion

(1) Contact metals of Rh and Ru transfer from the anode to cathode operated under hot conditions to form bumps on the cathode and craters on the anode.
(2) It is confirmed that the mechanism of metal transfers is based on the Thomson effect depending upon current through the contacts; the metal transfer is almost independent of loading elements of R, C and L in the relay circuit.
(3) Ru is better than Rh as a contact material, since the volume of bumps is 1/7 in average of that of Rh. The critical volume of transferred metals is $550\mu m^3$ and $800\mu m^3$ for Rh and Ru respectively at their life times.
(4) We are convinced that the volume of metal transferred is proportional inversely to the life time. It is hence related to the on/off frequency, so that the observation of the volume of bumps (transferred metal) is an excellent criterion of the lifetime of contact elements in relay.

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