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CONTACT RELIABILITY OF MAGNETIC CONTROL RELAYS

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I. INTRODUCTION

In the last few years, automation has rapidly increased in all fields of industry. Formerly machinery and other equipment commonly used 50∼70 auxiliary relays in sequence control systems, but at present it is not uncommon to find examples where several hundred or even more than a thousand relays are used. In accordance with these trends, there is a greater demand for auxiliary relays of higher reliability. In addition to long electrical and mechanical service life, another criterion now used to judge the performance of relays is high contact reliability, i.e. the absence of contact failure, so as to insure continuous operation without any misses in the control sequence.

The results of investigations into accident conditions in control equipment carried out by the Institute of Electrical Engineers of Japan showed that about 20% of all accidents in magnetic contactors and relays present major problems and that the reduction of contact failure will lead to a corresponding increase in the reliability of the system as a whole. To do this, it is essential to know the nature of contact failure in magnetic control relays so as to be able to take appropriate measures during the design stage.

II. CONTACT RELIABILITY

Contact reliability can be thought of as the probability that the contacts will always open and close a circuit at the current, voltage and ambient conditions stipulated for a specified number of operations. There are also many cases when the contact failure rate is employed as a measure of contact reliability.

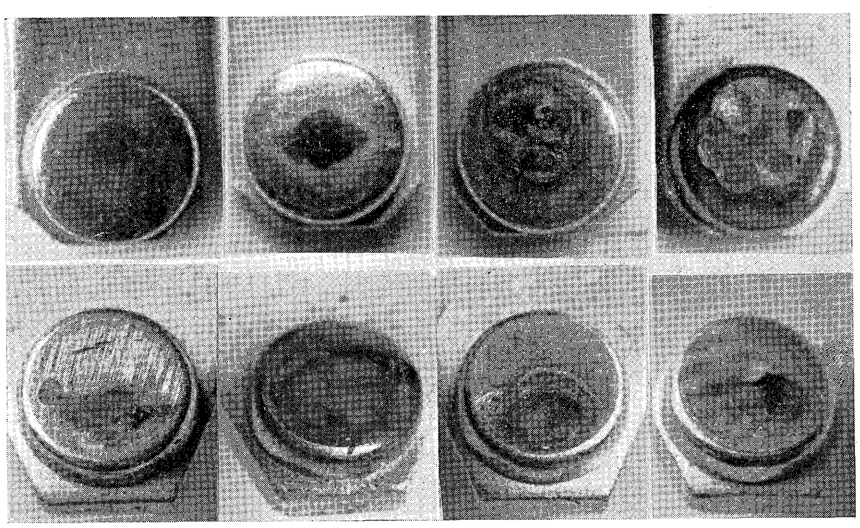
1. Causes of Contact Failure

When silver-type contacts are used in magnetic control relays, contact failure occurs because of the formation of a high resistance film or the accumulation of dirt in the space between the contacts.

The high resistance film which prevents conduction can be considered in standard atmospheres as consisting of (1) carbides formed by the carbonization of organic gases in the air by arcing heat, (2) dirt (3) particles of the relays unit caused by wear during switching, and (4) oxides formed by arcing heat from iron, aluminum, silicon, calcium etc. in the dirt.

Moving contacts

Stationary contacts



① Dc 3 v 50 ma ② Dc 48 v 9 ma ③ Ac 24 v 460 ma ④ Ac 100 v 110 ma

Fig. 1 Contacts of SRC 50-3F after 1 million load operations

Fig. 1 shows the contact surface conditions of a typical Fuji Electric magnetic control relay, the SRC 50–3F, after 1,000,000 operations under various circuit conditions. In circuits where the current and voltage is large, the dirt and abrasion particles on the contact surface have been burned at random due to arcing, and the surface has been discolored a blackish-yellow by oxides and carbides. In cases of low voltage and current, there are no arcs or sparks, and the carbides and oxides on the surface do not change the color. However, dirt and wear particles do accumulate on the contact surface.

2. Contact Failure and Contact Resistance

When contact resistance increases abnormally due to the above mentioned reasons, contact failure results. Since contact failure occurs in a random fashion and reproducibility is very low, the exact relation between contact resistance and contact failure is not too clear.

Fig. 2 shows the variation in contact resistance with the number of operations for an inductive-load magnetic control relay with contact applications as parameters. The contact resistance change is the highest in closing and breaking type contacts and low in carrying contacts and self holding contacts. The resistance value for non-carrying contacts used only for mechanical switching naturally changes little with contact use.

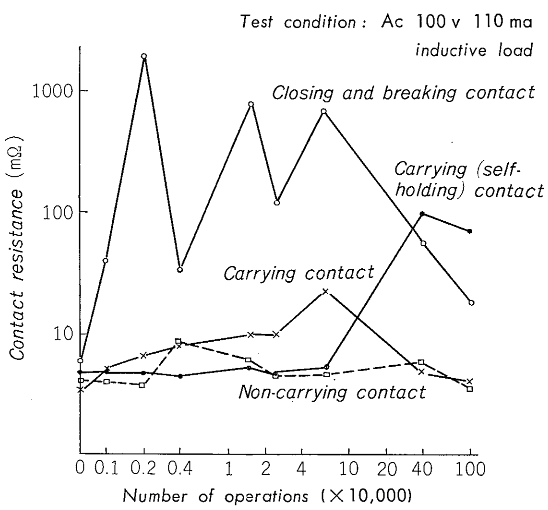


Fig. 2 An example of variation in contact resistance

3. Contact Reliability Test

1) Test method

Various circuits can used for the contact reliability tests, but the so-called Allen-Bradley method[(4)] circuit as shown in *Fig. 3* was used to collect data. However, reliability can not be obtained with this method especially with relay operation at low power because it switches the coil current of the unit to

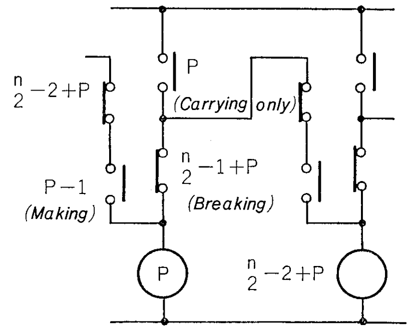
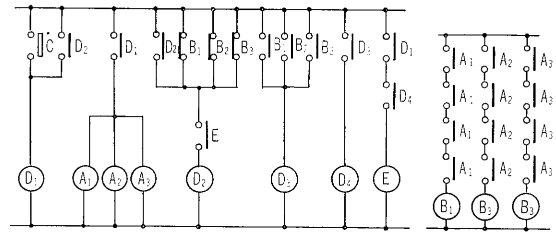


Fig. 3 Fundamental test circuit diagram



$A_1 \sim A_3$: *Test samples*
$B_1 \sim B_3$: *Load*
$D_1 \sim D_4$, E : *Auxiliary relay*
C : *Pulse contact*

Fig. 4 Test circuit for changeable loads

be tested. Therefore, the special circuit shown in *Fig. 4* was used for the actual reliability tests.

2) Test results

Tests were conducted using the SRC 50–2F (3a3b contacts), SRC 50–3F (4a4b contacts), and SRC 50–3 (2a2b contacts) types of magnetic control relays which are included in the Fuji Electric SRC series as shown in *Fig. 5*. Various contact shapes and pressures were also tested to see if these had any influence on the reliability.

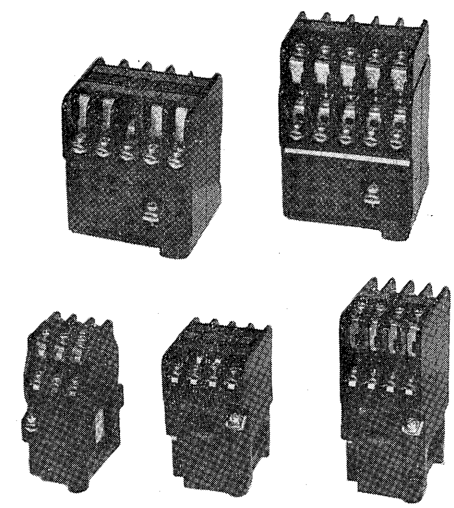


Fig. 5 SRC 50 series auxiliary relays

The cumulative distribution of contact failure vs. number of operations when the voltage and contact

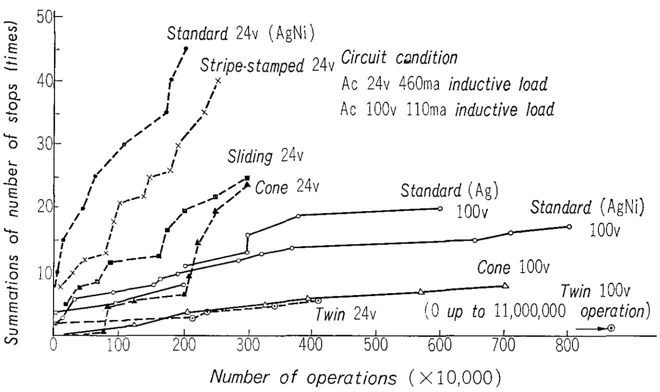


Fig. 6 **Reliability test of SRC 50-3F type**

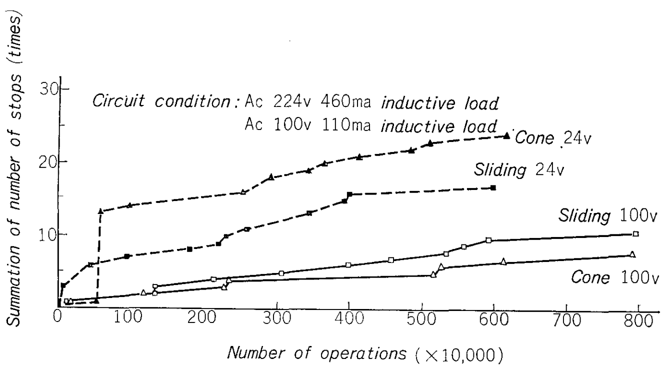


Fig. 7 **Reliability test of SRC 50-3 type**

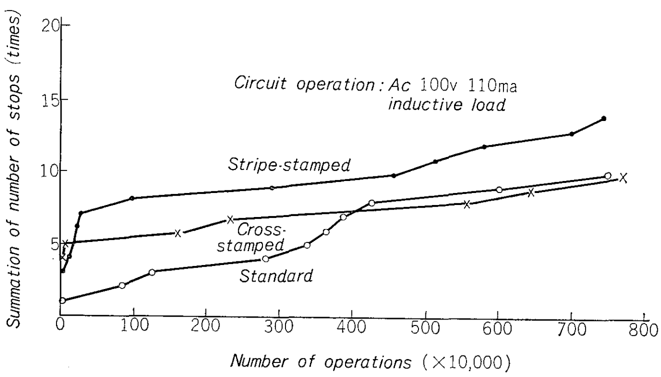


Fig. 8 **Reliability test of SRC 50-2F type**

shape varied is shown in *Fig. 6~8,* for the above three types of relays. Since these tests were meant only to show trends, the same number of operations were not always used and the tests were stopped at appropriate points between 100,000 and 10,000,000 operations.

(1) Mean time between failure (MTBF) and failure rate

As can be seen from the summation curves of contact failure frequency, the mean time between failure $\bar{L}$ can be expressed by the following equation if failure is considered as occurring according to an exponential distribution.

$$\bar{L}=\frac{N\tau_n}{n}$$

where N: Total number of contacts

τ_n: Number of contact switchings when "n" contact failures occur

The failure rate λ is

$$\lambda=\frac{1}{\bar{L}}$$

These values have no relation to the number of switchings[6]. The $\bar{L}$ and λ values can be expressed by multiplying the confidence level which is expressed as 95% of the reliability according to a random variable by a coefficient determined by n. The results expressed in this manner are shown in *Tables 1* and *2*.

Table 1 **Contact Reliability of SRC 50 Series Relays**

Type	Contact Arrangement	Shape of Contact (Material)	Type of Contact	Test Conditions				No. of Operations (×10,000)	No. of Stops (times)	Failure Rate (Contact failure per contact) (×10⁻⁸)	
				No. of relay	Voltage (v)	Current (ma)	Frequency of switching operations (times/hr)			Estimated average value	Confidence level 95%
SRC 50-3F	4 a 4 b	Standard (AgNi)	Butt	20	200	55	12,000	1100	4	0.23	0.5∼0.06
SRC 50-3F	4 a 4 b	Standard (AgNi)	Butt	20	100	110	12,000	800	17	1.3	2.0∼0.76
SRC 50-3F	4 a 4 b	Standard (Ag)	Butt	20	100	110	12,000	600	20	2.1	3.1∼1.28
2) SRC 50-2F	3 a 3 b (2 a 2 b)	Standard (Ag)	Butt	20	100	110	18,000	750	10	1.65	2.82∼0.79
2) SRC 50-2F	3 a 3 b (2 a 2 b)	Cross-stamped (Ag)	Butt	20	100	110	18,000	750	10	1.65	2.82∼0.79
2) SRC 50-2F	3 a 3 b (2 a 2 b)	Stripe-stamped (Ag)	Butt	20	100	110	18,000	750	18	3.00	4.58∼1.77
SRC 50-3F	4 a 4 b	Standard (AgNi)	Sliding	20	100	110	12,000	600	12	1.30	2.13∼0.67
SRC 50-3F	4 a 4 b	Cone (Ag)	Butt	20	100	110	12,000	700	8	0.7	1.26∼0.3
SRC 50-3	2 a 2 b	Standard (AgNi)	Sliding	20	100	110	12,000	800	11	1.7	2.83∼0.85
SRC 50-3	2 a 2 b	Cone (Ag)	Butt	20	100	110	12,000	800	8	1.25	2.25∼0.54
SRC 50-3F	4 a 4 b	Cone No. 1 (AgNi)	Sliding	20	100	110	12,000	800	7	0.55	1.03∼0.22
SRC 50-3F	4 a 4 b	Cone No. 2 (AgNi)	Sliding	20	100	110	12,000	650	7	0.7	1.31∼0.28
SRC 50-3F	4 a 4 b	Cone No. 3 (AgNi)	Sliding	20	100	110	12,000	750	5	0.4	0.82∼0.13
SRC 50-3F	4 a 4 b	Twin	Butt	20	100	110	12,000	1100	0	0	<0.19
SRC 50-3F	4 a 4 b	Standard (AgNi)	Butt	20	24	460	12,000	200	44	13.8	18.1∼10.0
SRC 50-3F	4 a 4 b	Stripe-stamped (AgNi)	Butt	20	24	460	12,000	260	40	9.6	12.8∼6.9
SRC 50-3F	4 a 4 b	Standard (AgNi)	Sliding	20	24	460	12,000	300	25	5.2	7.4∼3.46
SRC 50-3F	4 a 4 b	Cone (Ag)	Butt	20	24	460	12,000	300	24	5.0	7.1∼3.2
SRC 50-3F	4 a 4 b	Cone (Ag)	Sliding	20	24	460	12,000	400	24	3.7	5.3∼2.37
SRC 50-3F	4 a 4 b	Twin	Butt	20	24	460	12,000	420	6	0.9	1.74∼0.33

Note: 1) Test circuit is shown in Fig. 5.
2) Contacts 2a and 2b were used for the test
3) Contact shape

Standard | Cross stamped | Stripe stamped | Standard with wiping action | Cone | Cone with wiping action | Twin

Spherical surface against plane surface | Spherical surface against cone projection | Spherical surface against triangle pole projection | Cone surface against plane surface | Spherical surface against plane surface

(2) Early failure

There are various causes which influence the rate of failure in magnetic control relays used for the first time[(6)]. The failure rate λ given above is a constant value not related to the number of switchings. In actual practice, however, the early failure rate is very large and the constant failure rate is reached only after the relay has been used for some time. The early failure rate can be decreased by such measures as raising the switching voltage, increasing the contact pressure and varying the shape and type of contact. Improvement is especially noticable when conic contacts are used.

(3) Contact failure and contact material

When tests were carried out using a magnetic control relay with a contact pressure of 50 g or above and a contact load of the relay inductive va or over, no difference was noted between contacts made of silver or silver/nickel even in adverse atmospheres[(7)].

(4) Contact failure and contact shape

The contact failure rate naturally differs according to the shape of contact. With the standard type contact (sphere to plane surface) as a basis, *Table 3* shows such differences according to the results given in *Tables 1* and 2.

Fig. 9 shows the relation between contact failure and circuit conditions with contact shape and type as parameters.

(5) Contact failure and contact pressure

The greater the contact pressure, the less the contact failure. As can be seen from *Fig. 10*, there is a considerable difference between pressures of 35 g and 50 g, but between 50 g and 100 g, the difference is small. The contact pressure for the SRC 50 series

Table 2 **Contact Reliability for SRC 50 Series Relays**

Type	Contact Arrange-ment	Shape of Contact (Material)	Type of Contact	Test Conditions: No. of relay	Test Conditions: Voltage (v)	Test Conditions: Current (ma)	Test Conditions: Frequency of switching operations (times/hr)	No. of Operations (×10,000)	No. of Stops (time)	Failure Rate (Contact failure per contact) (×10^{-8}): Estimated average value	Failure Rate (Contact failure per contact) (×10^{-8}): Confidence level 95%
SRC 50-2F (Special)	3 a 3 b (3a)	Standard (Ag) 35 g	Butt	4	48	9	12,000	100	8	66.5	110~38.6
SRC 50-3F	4 a 4 b (4a)	Standard (AgNi) 50 g	Butt	3	48	9	12,000	100	5	41.6	85~13.5
SRC 3631-0	4 a	Standard (AgNi) 100 g	Butt	3	48	9	12,000	100	5	41.6	85~13.5
SRC 50-3F	4 a 4 b (4a)	Standard (AgNi) 50 g	Sliding	3	48	9	12,000	100	1	8.3	30.7~0.25
SRC 50-3F	4 a 4 a (4a)	Cone (Ag) 50 g	Butt	3	48	9	12,000	100	6	50.5	96.3~18.4
SRC 50-3F	4 a 4 b (4a)	Twin 50 g	Butt	3	48	9	12,000	100	0	—	<23.3
SRC 50-2F (Special)	3 a 3 b (3a)	Standard (Ag) 35 g	Butt	4	24	460	12,000	100	2	16.7	46.4~2.02
SRC 3631-0	4 a	Standard (AgNi) 100 g	Butt	3	24	460	12,000	100	2	16.7	46.4~2.02
SRC 50-3F	4 a 4 b (4a)	Standard (AgNi) 50 g	Sliding	3	24	460	12,000	100	1	8.3	30.7~0.25
SRC 50-2F (Special)	3 a 3 b (3a)	Cone (Ag) 35 g	Butt	4	24	460	12,000	100	0	—	<23.3
SRC 3631-0	4 a	Cone (AgNi) 100 g	Butt	3	24	460	12,000	100	1	8.3	30.7~0.25
SRC 50-3F	4 a 4 b (4a)	Twin 50 g	Butt	3	24	460	12,000	100	0	—	<23.3
SRC 50-2F (Special)	3 a 3 b (3a)	Standard (Ag) 35 g	Butt	4	3	5	12,000	1.6	200	105,000	126,000~85,500
SRC 50-3F	4 a 4 b (4a)	Standard (AgNi) 50 g	Butt	3	3	5	12,000	10	46	3,830	5000~2800
SRC 3631-0	4 a	Standard (AgNi) 100 g	Butt	3	3	5	12,000	30	22	610	885~380
SRC 50-3F	4 a 4 b (4a)	Standard (AgNi) 50 g	Sliding	3	3	5	12,000	100	8	66.5	118~28.5
SRC 50-2F (Special)	3 a 3 b (3a)	Cone (AgNi) 35 g	Butt	4	3	5	12,000	2.5	110	36,700	42,500~29,800
SRC 50-3F	4 a 4 b (4a)	Cone (Ag) 50 g	Butt	3	3	5	12,000	10	62	5150	6500~3950
SRC 3634-0	4 a	Cone (AgNi) 100 g	Butt	3	3	5	12,000	30	27	750	1050~495
SRC 50-3F	4 a 4 b (4a)	Twin 50 g	Butt	3	3	5	12,000	100	4	33.5	73~9.1
SRC 3631-0	4 a	Twin 100 g	Butt	3	3	5	12,000	100	3	25	59.5~5.15

Note: 1) Test circuit is shown in Fig. 4 2) Voltage 3 v and 48 v are dc; 24 v is ac

Table 3 **Comparison Between Differential Types of Contacts**

Load		Cross-Stamped	Stripe-Stamped	Cone	Sliding	Twin
Ac 24 v or Over Inductive Load	Improvement of early defects	×	×	◎	○	◉
	Improvement of MTBF	×	×	○	○	◉
Low Voltage Low Current Load	Improvement of early defects	×	×	×	◎	◉
	Improvement of MTBF	×	×	×	◎	◉

Note: × indicates no difference from standard
○ indicates somewhat effective
◎ indicates sufficiently effective
◉ indicates highly effective

of relays has been selected as 50 g or above, which test data has shown to be appropriate.

(6) Contact failure and voltage and current

Fig. 9 shows that the smaller the circuit voltage and current, the greater the contact failure. At low voltages and currents like those in transistor circuits, only twin or sliding type contacts can be used in practice.

(7) Contact failure and series or parallel connection of contacts

When all the contacts are connected in parallel, the probability of contact failure increases two squared so that this type of connection is almost never used.

In this type of configuration, twin contacts are the best. Their reliability tests show that at 100 v, not a single failure occurred during 11,000,000 operations. Although this result can not be compared with those

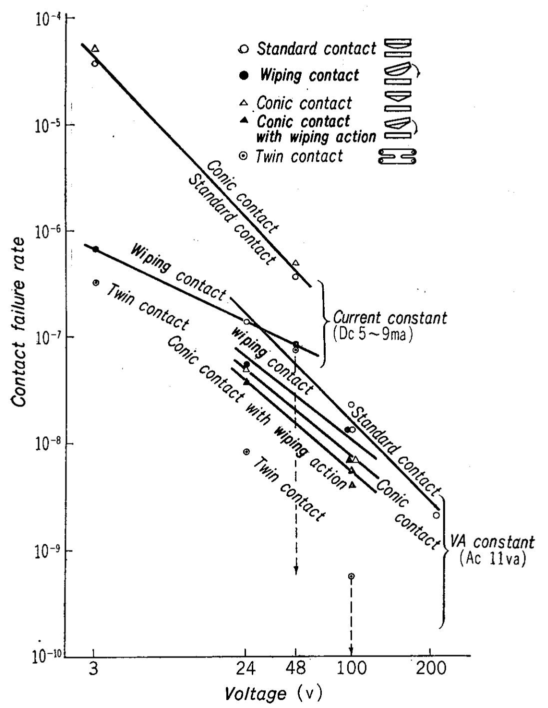


Fig. 9 Relation of contact failure to voltage used

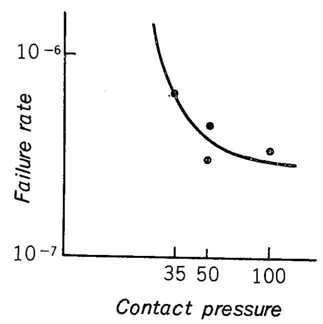


Fig. 10 Relation of contact failure to contact pressure

for any other type of contacts, their reliability increases 120 times at 3 v.

4. Improvement of Contact Reliability

From *Table 3*, it is evident that the reliability of twin contacts is the best from all standpoints. Fuji Electric produces the WRC series of high reliability auxiliary relays using twin type contacts.

However, the capacity of twin type contacts is lower than that of standard type contacts and the cost tends to be higher. For these reasons, they are used only when very high reliability is required.

For general-use magnetic control relays, the best contact reliability can be achieved by using contacts similar to the standard sphere to plane surface contacts. From the results shown in *Table 3*, it is evident that it is possible to lessen both early failure and failure due to low circuit voltage and current by employing the conic contact with sliding action. In this way it is possible to achieve higher contact reliability without lowering the capacity or raising the cost. Details concerning this type of contact will be introduced in a later paper.

III. SELECTION OF MAGNETIC RELAYS

The above sections have sought to clarify the nature of contact failure in magnetic relays but the application of these results in selecting the most appropriate magnetic control relay has not been explained. A method of selection using a simple graph will be introduced here.

In equipment or machinery employing two types of magnetic control relays with MTBF values of $\overline{L}_1$ and $\overline{L}_2$, the MTBF of the relay contacts when only 1 contact failure is confirmed in an average of 10^8 switching operations must be as follows:

$$\frac{1}{10^8} \leqq \frac{n_1}{\overline{L}_1} + \frac{n_2}{\overline{L}_2}$$

where n_1: Number of contacts in the MTBF$=\overline{L}_1$ relay

n_2: Number of contacts in the MTBF$=\overline{L}_2$ relay

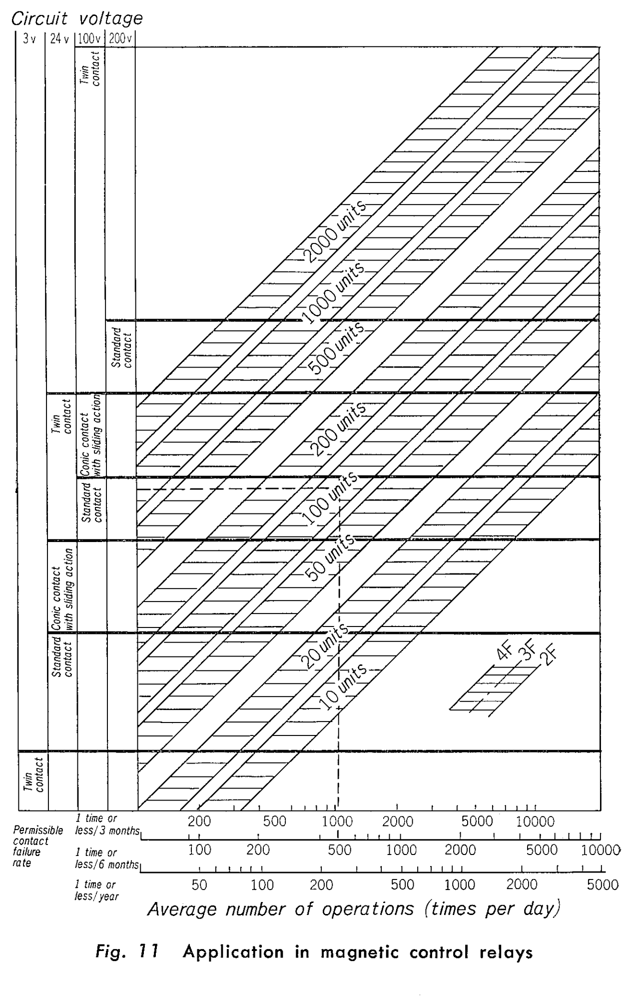


Fig. 11 Application in magnetic control relays

Using this formula, a magnetic relay selection graph was compiled as shown in *Fig. 11.* When making this graph, the number of contacts for the desired relays was assumed to be about 70% of the number of relay contacts estimated from actual experience concerning former control panels. The curves are in the form of bands because the number of contacts differ according to the type of relay. For the 5a5b (10 contacts) relays such as the SRC 50–4F the upper part of the curve is applicable.

For 4a4b relays (8 contacts) such as the SRC 50–3F, the middle curves are used, while for 3a3b relays such as the SRC 50–2F the lower part of the curves are applicable. For relays with only 4 contacts such as the SRC 50–3, the graph is applied by counting 2 units as 1.

The way to use the graph is given below.

(1) First determine the number of magnetic relays to be used.

(2) Including the total number of relays, determine the average number of operations per day per relay. When determining the approximate number of operations, refer to *Table 4.*

Table 4 **Number of Load Operations of Magnetic Control Relays (times per day)**

Type of Operating Time	Degree of Frequency of Switching Operation	Number of Switching Operations (times/day)
Three Shifts; Machinery and Equipment Operating 20 hr/day	High	5000～10,000
	Medium	1000～5000
	Low	Less then 1000
Two Shifts; Machinary and Equipment Operating 14 hr/day	High	3000～6000
	Medium	600～3000
	Low	Less then 600
One Shifts; Machinary and Equipment Operating 8 hr/day	High	1500～3000
	Medium	300～1500
	Low	Less than 300

(3) Determine the permissible contact failure rate for the equipment.

When these three steps are completed, the shape of the contact can be chosen from the diagram. Below is a practical example of how to use the graph.

Example :

Machinery : transfer machine

Number of relays : 40 SRC 50–3F units and 80 SRC 50–3F units

Average number of operations : 500 times/day

Permissible contact failure rate : 1 time/6 months

In this case, 2 SRC 50–3 units are counted as one unit so that the total number of relays used becomes 100. From the 500 times/day point on the 1 time or less/6 months line on the abscissa, project a perpendicular line up to the 100 unit band. From the point where this perpendicular line intersects the 100 unit band, make a horizontal line to the left until its intersection point, the appropriate contact shapes and circuit voltages can be determined. In this case, the applicable data are standard contacts with 100 or 200 v, twin contacts (WRC type) with 24 or 100 v and conic contacts with sliding action at 100 v. Therefore, if the circuit voltage is 100 v or above, standard or conic contacts with sliding action can be used and if the voltage is 24 v, twin contacts of the WRC type can be used.

IV. CONCLUSION

In the communication field, contact reliability has long been a problem and there has been considerable research on the subject. However, this problem has only recently been taken up in the high voltage field. Since the contact failure rate is in the order of 10^{-8} and there is no reproducibility, it takes 2～3 months to gather any data and research therefore takes a long time. However, data has been collected under normal circumstances and the nature of contact failure in magnetic control relays is almost completely understood. It is planned to use the the results of this research to develop a new type of magnetic relay.

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