Journal of Zhejiang University SCIENCE A
ISSN 1009-3095 (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Study on reliability technology of contactor relay

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Received Dec. 19, 2006; revision accepted Jan. 5, 2007

Abstract: In this paper, the reliability of contactor relay is studied. There are three main parts about reliability test and analysis. First, in order to analyze reliability level of contact relay, the failure ratio ranks are established as index base on the product level. Second, the reliability test method is put forward. The sample plan of reliability compliance test is gained from reliability sample theory. The failure criterion is ensured according to the failure modes of contactor relay. Third, after reliability test experiment, the analysis of failure physics is made and the failure reason is found.

Key words: Contactor relay, Reliability, Failure mode
doi:10.1631/jzus.2007.A0481 **Document code:** A **CLC number:** TB114.3; O224; O211.6

INTRODUCTION

The contactor relay is a kind of low voltage electrical apparatus, which is indispensable and widely used in automatic electrical system. Since the poor reliability of the contactor relay may cause the electrical system failure and result in lots of financial loss, it is important to have a detailed study of its reliability technology.

Recently, more and more researches have been carried out in the reliability area, such as the reliability evaluation of relay (Teverovsky and Sharma, 2003), the reliability analysis of relay (Li *et al*., 2005), the reliability assessment of switch (van Spengen *et al*., 2003) and the improvement technique of relay (Roettjer, 2005; Clark, 2004). However, few of them are about the reliability of contactor relay. It is the reason that we initiate the study on reliability of contact relay, which includes establishing the reliability index, constituting the reliability test plan and method, finding the weak part of product according to the failure analysis.

ESTABLISHMENT OF RELIABILITY INDEX OF CONTACTOR RELAY

There are many characteristic standards such as mean life, reliability probability and failure probability. In order to evaluate the reliability level, the failure ratio is selected to rank the level in (MIL-R-39016, 1962; GB/T15510, 1995; JB/T10522, 2005). Although different products have different features and failure modes, and those standards cannot be used directly to test the contactor relay; they are good references of contactor relay. The reliability index was considered according to the contactor relay work feature and failure mode as the same as the international and national standards. The contactor relay is a kind of control apparatus whose contact is an operation component and operates frequently. Accorded with the standards, the failure ration is the reliability index to rank the level of reliability. The failure ratio is the probability of product failures in operation in unit time after working time t. As the control apparatus, the reliability request of

contactor relay is to make sure it works well without failure. The failure ration can evaluate the reliability expediently as reliability index. The reliability level can be ranked according to the maximal failure ratio, as shown in Table 1.

Table 1 The title and symbol of failure ration and the maximal failure ration

Title of failure ratio rank	λ_{max} (1/10)
Sub level V	3×10^{-5}
Level V	1×10^{-5}
Level VI	1×10^{-6}
Level VII	1×10^{-7}

RELIABILITY TEST METHOD OF CONTACTOR RELAY

Since the contactor relays are in mass producing and used widely, they cannot be tested one by one and the sample plan must be considered. The failure ratio curve is shown in Fig.1. $L(\lambda)$, the acceptable probability, has relations with failure ratio as shown in Eq.(1) and Eq.(2) (Lu, 1996):

$$1-L(\lambda_0)=\alpha\,, \tag{1}$$

$$L(\lambda_1)=\beta\,. \tag{2}$$

where λ_0 is acceptable failure ratio; α is risk of producer; λ_1 is unacceptable failure ratio; β is risk of user.

By sample theory, the relationship among the operation time, failure ratio and acceptable failure time is shown in Eq.(3):

$$T=\frac{\chi^2_{1-\beta}(2A_c+2)}{2\lambda_1}\,. \tag{3}$$

And the maximal fault ratios of ratio ranks substitute the unacceptable fault ratios and the acceptable probability is 0.9. Base on reliability theory, the sample plan of reliability compliance test is gained from the relation of operation time and the acceptable fault time as shown in Table 2.

At the beginning of a failure ratio compliance test, the suitable failure ratio must be selected. From Table 2, according to rank of failure ratio and the acceptable failure size A_c, the termination time T_c can be obtained. Sample is randomly chosen from a qualified product that is ten times greater than the sample. The test is done according to the reliability compliance test method. The number of failure sample r and the failure time are accounted.

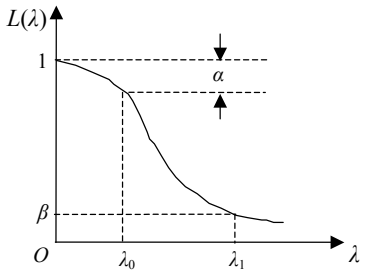

Fig.1 Sample curve of failure ratio

The test result is evaluated by the following principles. If the accumulating test time T reaches the termination time T_c, and r is not more than A_c ($r\leq A_c$), the product is qualified; in other words, the product reaches the chosen reliability rank. If the failure is greater than A_c ($r>A_c$) before T reaches termination time, the product is unqualified or cannot reach the reliability level.

The key part of the reliability is the determination of failure. The contactor relay failures are mainly reported by users and the lab test. The state of contactor affects the reliability of contactor relay directly. So the reliability tests of contactor relay are mainly the tests of the contactor (Minoura *et al*., 1999). The main failures of a contactor are the poor-contacting and melting. The contamination during the production, the oxide of contactor material and the dust may add extra contacting resistance of contactor to cause poor connecting of the circuit, that is, poor-contact. The large contact resistance may cause the melting of contactor because of the Joule heat at high current loading. Besides, the bounce of contactor results in the short arc and the high heat causes the melting of contactor material and welding. Therefore the contactor cannot break the circuit.

The determination of failure of contactor relay is based on the following rules. When a contactor is turned on, if the voltage across the contactor is greater than 5% of the voltage of power, the contactor is called poor-contact. When a contactor is turned off, if the voltage across contactor is lower than 90% of the voltage of power, the contactor cannot switch off the circuit.

Table 2 The failure ratio compliance test plan (acceptable probability=0.9)

Failure rank level	Termination time T_c ($\times 10^6$ times)									
	A_c=0	1	2	3	4	5	6	7	8	9
Sub level V	0.768	1.30	1.77	2.23	2.66	3.09	3.51	3.92	4.33	4.74
Level V	2.3	3.89	5.32	6.68	7.99	9.27	10.53	11.77	13.0	14.21
Level VI	23	38.9	53.2	66.8	79.9	92.7	105.3	117.7	130	142.1
Level VII	230	389	532	668	799	927	1053	1177	1300	1421

RELIABILITY TEST AND ANALYSIS OF CONTACTOR RELAY

In order to improve the efficiency and accuracy of reliability test, we prepare a device that applies a computer to test automatically, show the output of test on the screen, save and analyze the test data. The device can test different type products at the same time. The states of samples are judged from the voltage between the contactors, and failure date such as the failure time, failure number of contactor relay, failure feature are saved in the computer.

Various contactor relays were tested by this device. Neither users nor lab test reported any contact melting incidents because the capacity of contact is limited. The smaller the current of circuit is, the more failures happen. The test is set at a direct current load of 24 V and 100 mA. The samples of test were installed at the work place. The threshold of contact voltage is 1.2 V, while the threshold of voltage between open contacts is 21.6 V. The contactor relays operate at 3600 times per hour. The load factor is 50%. The total operating cycles are 6×10^5 times. If the contact voltage is higher than 1.2 V when the contacts switch on, the contacts are poor-contact and the failure is recorded. If the contact voltage is lower than 21.6 V when the contacts switch off, the contact is poor-open and the failure is recorded. The same contact fails in working more than 5 times, the failure information of the contact does not be recorded. All failures that happened before 4×10^5 times operation are poor-contact. All contact of two samples fail and poor-contact and poor-open happen by turns between 4×10^5 times and 6×10^5 times. The failure data are shown in Table 3.

Based on Table 3, the relation between the failure range and failure time is plotted in Fig.2 showing that the orderliness of the contact relay tally with the bathtub curve. The early failure occurs before 1×10^4 operation times. Occasionally, the failure occurs between 1×10^4 and 4×10^5 operation times. The tire failure happens after 4×10^5 times.

Table 3 The statistic of failure date of reliability test

Failure data range ($\times10^4$)	Failure times
0~1	24
1~10	3
10~20	2
20~30	5
30~40	6
40~60	29

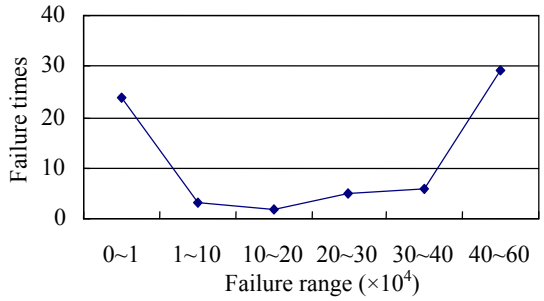

Fig.2 The relation between failure range and failure times

The failure test reveals that the early failure is caused by the bad raw material, poor crafts, neglect of producer, and so on. After that, the contactor relays hardly fail and its failure ratio is quite low and stable. Failure in this period is called Random Failure. During this period, the failure of contact is caused by the environment, such as dust or the machine vibrancy. At the end of 6×10^5 operations, the failure samples were checked. It was found that the shading coils of two samples are displaced and blocked between armatures. The wire of coil is scorched. The displacement of shading coil was caused by machine impingements and dislocated in the gap between the armatures. The gap was large enough to decrease the coil inductance when the armatures were closed. So the coil current increased and the wire was damaged.

Since the failure during this period is caused by fatigue of elements of contactor relay, it is called Fatigue Failure.

The post-test on failure mechanism reveals that the poor contact is the main cause of the early failure of contactor relay. To solve this problem, the contact material has to be correctly selected and the contact shape should be well designed for having a low and stable contact resistance. For improving the reliability of contactor relay, the screening test can be applied. Before using products, the 1×10^4 times operation can proceed and the early failure products can be picked out. By this way, the product can be used in the Random Failure period with high reliability level. Since the shading coil is the main reason to decrease the life of product at the period of Fatigue Failure, the reliability can be improved by the reinforced shading coil.

CONCLUSION

The reliability of contactor relay is studied in this paper. The reliability test was applied to the designed equipment according to the reliability method. The result of test showed that the failure ratio curve follows the bathtub pattern. The reasons of early failure, random failure and fatigue failure are found. The improvement method is put forward. The material and shape of a contact are the resolutions of the early failure. And 1×10^4 times operation screening test is useful to avoid the early failure. The shading coil is a reason of the fatigue failure. The reinforcement of the shading coil can improve the life of contactor.

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