Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Case Study on Relay Malfunction by Electrochemical Migration in Nuclear Power Plants

Kwang-Hyun Lee [a]* and, Yong-Goo Choi [a]
[a]*KHNP, Central Research Institute, 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, 34101, South Korea*
[*]*Corresponding author: leekh3512@khnp.co.kr*

1. Introduction

Relays are widely used in industrial fields including nuclear power plants(NPPs) for signal transmission, control and system isolation. During system operation, relay malfunctions occur due to various reasons and it is necessary to identify the cause of relay failures and replace the suspected relay with new one. Among the factors causing a relay malfunction, the electrochemical migration (ECM) caused by the flux used in the relay manufacturing process can cause insulation failure between the pins inside the relay. In this paper, we investigate the fault phenomenon and electrochemical migration mechanism of faulted relays and suggest ways to improve the reliability of relays in NPPs.

2. Relay malfunction case study

Fig. 1 presents a schematic drawing for testing the safety system in a NPP periodically. The integrity of the safety system is ensured through the periodic test. In order to confirm proper functioning of the safety system, the test switch in the test circuit is pushed to generate an alarm and the safety system (A) is operated through the interposing relay in each circuit.

During the actual functional test in a NPP, at the moment of pushing the test switch, not only safety system (A) but also safety system (B) operated abnormally. The cause of abnormal operation of safety system (B) is reduction of the insulation resistance between contacts in a common relay(malfunctioning relay in Fig. 1.) installed in the alarm circuit and the safety system circuit.

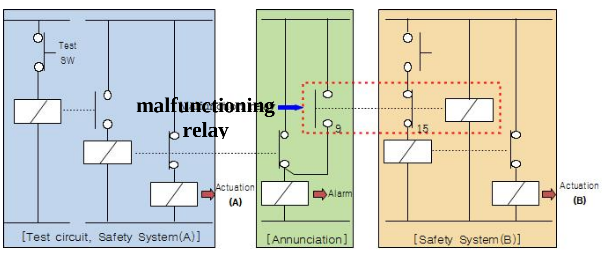


Fig. 1. Safety system test circuit

2.1 Characteristics of malfunction relay

The faulty relay is hermetically sealed and the outer cover of the relay is assembled with a metal enclosure to protect against dust, moisture, etc. The inside of the relay is filled with inert gas. In order to ensure sealing of the relay, the pins on the base plate is manually soldered during assembly of the relay.

To check the status of insulation between pin no. 9 and pin No. 15 in the malfunctioning relay, we measured the insulation resistance and obtained a value of 37kΩ, which was abnormally low. Whenever the insulation resistance was measured, the obtained value drifted. In Fig. 1, pin no. 9 is connected to the alarm circuit and pin no. 15 is connected to the operating circuit of safety system (B). Therefore, in case of reduction of the insulation resistance between pin no. 9 and pin no.15 of the malfunctioning relay, pushing the test switch for the function test of safety system (A) could generate an alarm and operate safety system (B) at the same time.

In order to check the inside of the malfunctioning relay, we separated pins on the base plate of the relay from part of the contacts and checked the relay by using the electro magnitude. There were scattered traces of corrosion caused by the flux while soldering pins of the relay base plate and a carbonization trace between pin no.9 and pin no.15 was also observed.

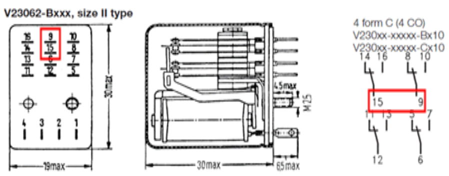


Fig. 2. Relay lay out and contacts configuration

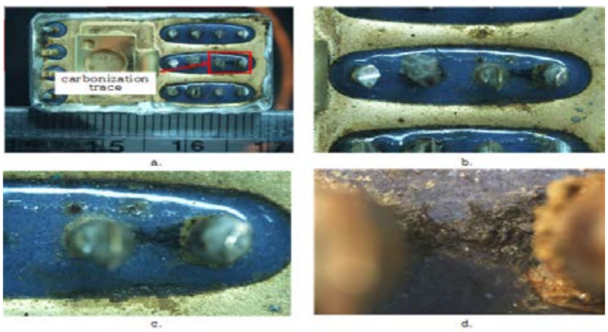


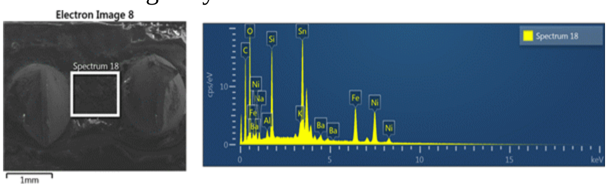
Fig. 3. Carbonization trace between pin no. 9, 15 of the malfunction relay

2.2 EDS mapping & spectrum

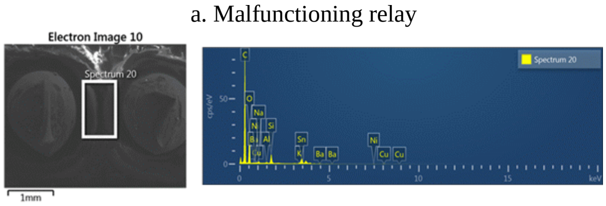
EDS(Energy Dispersive Spectroscopy) was used to identify the cause of insulation degradation between pins of the faulty relay and to analyze the chemical compositions of the carbonization trace of the malfunctioning relay causing system failure of the NPP.

In the EDS mapping test on the carbonization trace of the malfunctioning relay and a normal relay, greater amount of Fe, Sn and Ni were observed in the malfunctioning relay than in the normal relay. It is seen that it is possible to reduce the insulation resistance between pin no. 9 and 15 of the malfunctioning relay.

The results of the EDS chemical compositions analysis of the carbonization trace in the malfunctioning relay are presented in Table 1. and the EDS mapping test. On average, 28.95% Sn, 13.77% Ni and 10.42% Fe were detected, which are significantly higher than the corresponding values (3.91% Sn, 0.14% Ni(Fe not detected)) of the normal relay. This can be regarded as the cause of reduced insulation resistance between pin no. 9 and 15 of the malfunctioning relay.



a. Malfunctioning relay



b. Normal relay

Fig. 4. ESD composition analysis and spectrum

Table 1. Results of ESD composition analysis

wt.%

Specimen	C	O	Na	Al	Si	K	Fe	Ni	Cu	Sn	Ba
Malfunction Relay	-	32.84	1.91	0.80	7.80	1.22	10.42	13.77	-	28.95	2.28
Normal Relay	63.61	30.07	0.41	0.12	1.19	0.13	-	0.14	0.27	3.91	0.15

3. Electrochemical migration by flux corrosion

The types of flux are resin, organic and inorganic, and the flux used in electronic equipment is resin-based. The main materials of the resin are rosin, modified rosin, and synthetic resin, and rosin is made by refining the resin of softwood. Depending on the degree of flux activation, there are RA (Rosin Activated), RMA (Rosin Mildly Activated), and R (Rosin) types, and RMA type flux is the most used in the electronics industries.

ECM is a reaction phenomenon in which metal (Ag, Sn, Cu, Au, etc.) atoms move in the form of dendrites under high humidity and an electric field.[1] In the present of a voltage and moisture in the state where flux residue is remaining, ionization at the anode and precipitation at a cathode may occur. If this precipitation reaction continues, a dendrite will grow from the cathode to the anode and eventually cause short of the two conductors.

In the visual inspection of the actual malfunction relay, corrosion products due to the flux and the carbonization trace between pin no. 9, and 15 of the malfunctioning relay were observed, indicating that there is a possibility of influence by electrochemical migration.

Electrochemical migration can cause a short circuit in high temperature and high humidity conditions even in the case of using no-clean flux which is generally volatile in the soldering process by automation of electronic cards. Therefore, when soldering by hand, a rosin-based flux is generally used, and flux residues should be removed by using a cleaner after soldering.

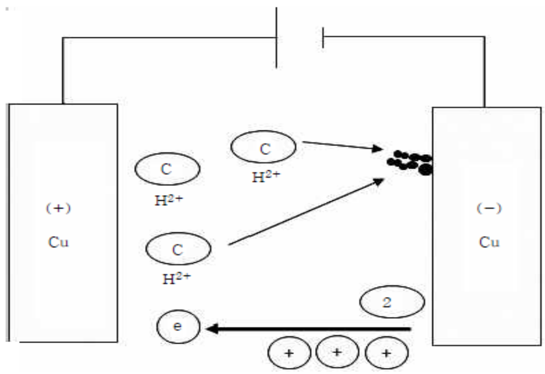


Fig. 5. Electrochemical migration

4. Mechanism of insulation resistance degradation between relay pins

Through the characteristics of the malfunctioning relay, visual inspection of the part of reduction of the insulation resistance between pin no. 9, and 15 and the chemical composition analysis through EDS mapping and spectrum, an excessive amount of flux was used on pin no. 9, and 15 of the malfunctioning relay was excessively used during assembly of the malfunctioning relay and the flux residue between the pin no. 9, and 15 of this relay was not removed after soldering. The malfunctioning relay installed in the safety system of NPP was energized and the inside temperature of the relay was high, which causes moisture in the flux residue to spread inside the relay. Therefore, the conditions of ECM were sustained for the relay operation time (5.3yrs). Eventually, the degradation of insulation resistance caused a short circuit between pin no. 9, and 15 of the relay and caused system failure.

5. Improvements

Through the mechanism of reduced insulation of resistance between pin no. 9, and 15 of the malfunctioning relay, the root cause of relay malfunction can be understood and methods of improvement can accordingly be identified. First, the root cause is that an excessive amount of flux was used while soldering pins on the relay base plate and the flux residue was not removed. Therefore it is necessary to enhance the quality of the relay and production process, such as using an appropriate amount of flux, using no-clean flux and removing residue flux.

In order to eliminate the faulty relay before it is used in the systems, it is necessary to prepare a procedure to check the resistance between pins of the relay.

The manufacturing process of hermetically sealed relays includes soldering pins and using fluxes. Therefore, for relay users, it is also possible to consider replacing hermetically sealed relays with cradle type relays that have transparent plastic covers and do not require a soldering process, if the environmental conditions of the relays are good.

6. Conclusions

The results of the case study on a faulty relay used in the NPP safety system and the failure mechanism analysis of the insulation degradation between pins can be used in various fields.

In particular, for hermetically sealed relays, the excessive use of flux during the soldering process can cause insulation degradation by electrochemical migration (ECM) and caution should be exercised in the selection of relay types considering their environment and importance.

REFERENCES

[1] 방정황, 이창우, “솔더링에서 플럭스 잔사가 전기화학적 마이그레이션에 미치는 영향”, Journal of KWJS, Vol.29, pp593-596, 2011

[2] Daniel Minzari 외4, “Electrochemical Migration on Electronic Chip Resistors in Chloride Environments” IEEE VOL 9, NO 3, 2009)

[3] Kirsten Stentoft Hansen 외 4인 "Effect of Soldering Flux Residues on Corrosion of Electronics" IEEE 2009