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Typical defects analysis of metal parts of substation secondary components

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Abstract. The selection of metal materials used in secondary components only considers the conduction of signals, ignoring the possible corrosion and fracture caused by the interaction of environmental factors such as temperature, humidity and harmful ions during the long-term service. Operational and maintenance experience shows that failures of metal parts in secondary components are emerging in endlessly due to improper selection of materials, unqualified materials and unfavourable environmental factors. In this paper, through the analysis of several secondary component failures, the typical defects of metal parts in secondary component are revealed, and some basic principles that should be followed in the selection of metal materials for secondary components are put forward, which can guide the design, acceptance and maintenance of secondary components.

1. Introduction

Secondary components are important control components in primary equipment of substation, such as relays, switching switches, auxiliary switches, travel switches, terminal row of secondary cable cores, etc. Their "healthy" service is an important guarantee that directly determines the reliable operation of primary equipment and rapid isolation of power grid faults[1].The selection of metal materials for secondary components only considers the conduction of signals, but does not consider the possible corrosion and fracture problems caused by the interaction of environmental factors such as temperature, humidity and harmful ions during the long-term service, and does not explicitly set service life. At present, the metal materials used in secondary components are various, ranging from galvanized steel, hot-dipped galvanized steel, brass and stainless steel. Several major failures of control circuit have occurred, including rejection of 500 kV circuit breaker switch and total station voltage loss of 220 kV transformer substation, due to the corrosion and fracture of metal parts in secondary component.

In this paper, through the analysis of several secondary component failures, the prominent problems existing in the metal parts of secondary components are revealed, and some basic principles that should be followed in the selection of materials for secondary components are pointed out, which can guide the design, acceptance and maintenance of secondary components.

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2. Unreasonable material selection

2.1. Selection of low-grade materials

In the process of substation maintenance and operation, the failure of CA10 series switch of LW10B circuit breaker manufactured by a manufacturer has been found many times. The typical defects include damage, contact site rust and spring breakage, as shown in Figure 1, which can result in the opening and closing control failure of circuit breaker. For example, after disassembling the far and near control switch of a 500 kV circuit breaker in a substation, it is found that four of the eight rows of contacts are corroded and springs are broken, some of which are powdered. During overhaul of the 614 circuit breaker for a 220 kV transmission line in a 500 kV substation, the far and near control switch broke during operation.

Failure analysis of CA10 series switch of LW10B circuit breaker has been carried out. It was found that the metal materials for contacts, gaskets and compression springs are made of ordinary galvanized steel or 200 series stainless steel. These materials have poor corrosion resistance and are easy to rust and fracture in wet environment during long-term service[2]. The test results show that the contact spring of CA10 series switch with serious rust is made of galvanized carbon steel and its metallographic structure is fibrous tempered sorbite, as shown in figure 2. However, under the same service conditions, contact springs made of 304 stainless steel are with good surface condition, and their metallographic structure is fibrous deformed austenite and carbide[3], as shown in figure 3.

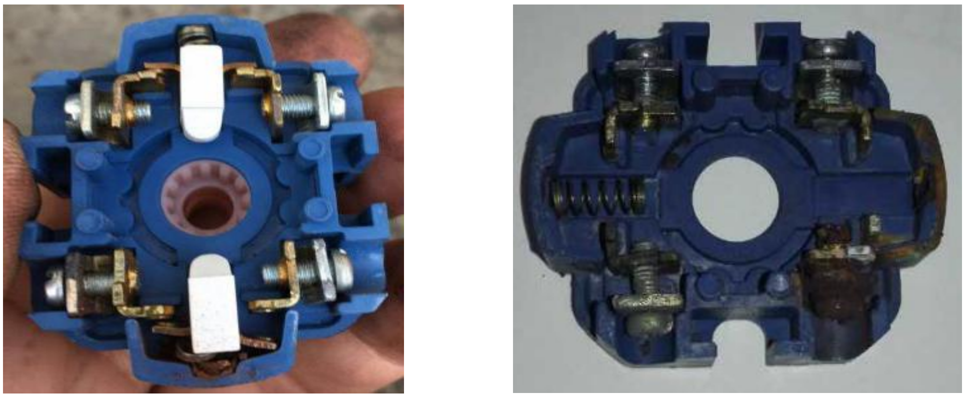

Figure 1. Defects of CA10 series far and near control switches

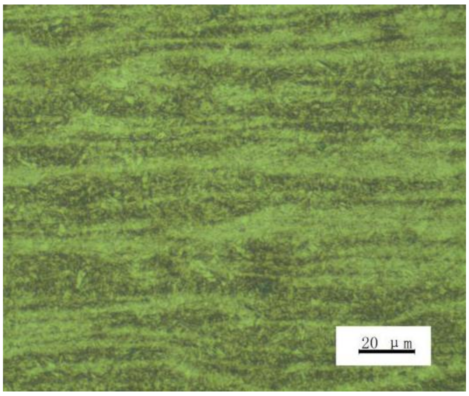

Figure 2. Metallographic structure of contact springs with serious rust

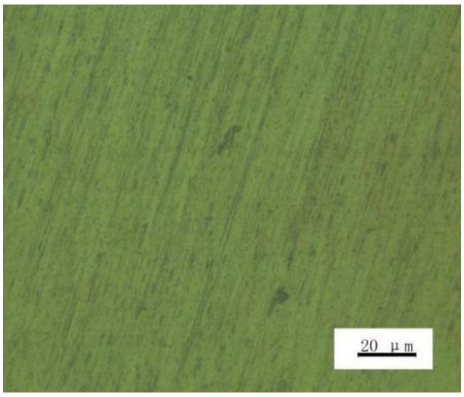

Figure 3. Metallographic structure of contact springs in good surface state

2.2. Unqualified material composition

During overhaul, it was found that the fixed bolts and nuts of a moving iron core of the opening coil of 444 circuit breaker in a 500KV substation were broken.The alloy composition of the fractured parts is analyzed, and the results are shown in Table 1.Comparing the chemical composition range of lead brass in GB/T 5231-2012 "Designation and Chemical Composition of Wrought Copper and Copper Alloys" standard, it is found that the content of Cu element in the sample is lower than the standard requirement value, while the content of Pb element is far beyond the upper limit of the standard requirement value. Therefore, material of thefixed bolts and nuts for inspection is unqualified.

Table 1. Results of chemical composition analysis of the fracture fixed bolts. Similar alloy brands in GB/T 5231-2012 are also listed for comparison.

Species	Grades	Chemical Composition/%					
		Cu	Fe	Pb	Sn	Zn	Impurity
Lead Brass	HPb62-3	60.0~63.0	0.35	2.5~3.7	-	Allowance	0.85
	HPb60-3	58.0~61.0	0.3	2.5~3.5	0.3	Allowance	0.80
	HPb58-3	57.0~59.0	0.5	2.5~3.5	0.5	Allowance	1.00
	HPb57-4	56.0~58.0	0.5	3.5~4.5	0.5	Allowance	1.20
Fixed Bolts and Nuts	Unknown	52.01	0.56	5.95	0.79	40.35	0.34

The samples were further analyzed and the results are shown in figure 4. Metallographic pictures of the polished unetched samples are shown in figure 4(a). The black island in the figure is free element Pb. Metallographic structure after etching with $FeCl_3$ hydrochloric acid solution are shown in figure4(b). The main constituent phases are equiaxed α phase and matrix β phase, and the obvious third phase element Pb is with black island shape[4].

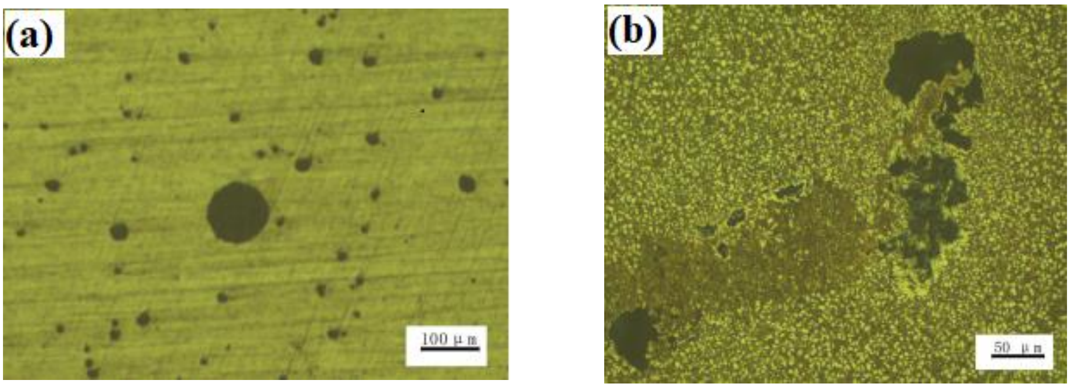

Figure 4. Microscope of the fracture fixed bolts and nuts (a) unetched after polishing (b) etched

The solid solubility of Pb in copper-zinc alloy is very small, and it mainly exists at the grain boundary of solid solution. The hardness of the element Pb is very low, it has strong lubrication and friction reduction, and it can make the alloy have very high cutting performance. However, if the content of Pb in the alloy is too high, the distribution of Pb in the grain boundary will be continuous network, leading to the weakening of the grain boundary and even the island distribution of the precipitated Pb in the matrix, as shown in figure 4. All of these will lead to the decrease of mechanical properties and the increase of brittleness of the alloy, which will easily lead to fracture[4]. Therefore, the chemical composition of the alloy does not meet the requirements of the standard, especially the excessive lead content in the alloy is the direct cause of the breakage of the fixed bolts and nuts in the moving iron core of the circuit breaker opening coil.

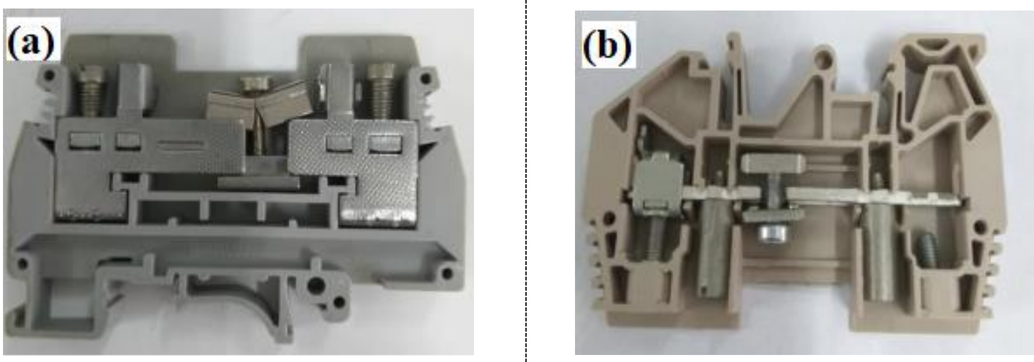

Figure 5. Terminal row (a) fractured (b) intact

During overhaul, it was found that there were a lot of fractures in one type of terminal row, as shown in figure 5(a), while other types of terminal row were intact under the same conditions, as shown in figure 5(b). Further analysis shows that the material of the broken terminal row is lead brass, and the lead content is far beyond the upper limit required by the standard, which will lead to brittleness of the terminal row. Thus, it is easy to cause cracking in the process of installation and screw hole processing.

Table 2. Chemical composition of the intact terminal row

Species	Grades	Chemical Composition/%				
		Cu	Fe	Pb	Zn	Impurity
Ordinary Brass	H66	64~68.5	0.50	0.09	Allowance	0.45
Intact Terminal Row	-	67.79	0.16	0.08	31.78	0.19

Analysis shows that there is a tin plating layer on the surface of intact terminal row. The base alloy grade is ordinary H66 brass, and its composition is shown in Table 2. The H66 brass has high content of Cu, low content of Pb and impurities, and good plasticity. So it is more suitable for terminal row material than lead brass. In addition, we also found that the terminal rows made of aluminium alloy and tin plated copper have much better durability.

3. Corrosion Caused by Environmental Factors

Terminal of the secondary cable core in terminal box of a substation is corroded, and the number barrel made of polyvinyl chloride is green. When unplugging the number barrel and unlashing the terminal, it is found that the cable core has been corroded seriously, and it almost falls off from the terminal row. The corrosion location of copper wire is just at the interface of insulating layer, but there is no obvious corrosion at a distance, as shown in figure 6. XRD and XPS analysis showed that the corrosion product of copper wire was $Cu_2Cl(OH)_3$, which was a typical corrosion product of copper and copper alloy in marine atmospheric environment.

Further analysis shows that Cl^- can be dissolved from the number barrel and dominates the whole corrosion process. When the external humidity increases, thin liquid film is formed on the surface of copper wire, copper will react with oxygen in air to form Cu_2O film, and the corrosion rate decreases. In the meantime, a thin liquid film will be formed around the number barrel, and the chlorine elements in it will dissolve in the form of chloride ions, which will increase the concentration of Cl^- in the surrounding environment. Then, Cl^- gradually invades into Cu_2O film and replaces O element in it to form soluble $CuCl_2^-$, which is further oxidized to soluble $CuCl_2$ under the action of oxygen. Whereafter, $Cu_2Cl(OH)_3$are formed by coordination reaction and redeposition process between Cu^{2+}, Cl^- and OH^-. The whole process can be expressed as follows:

$$Cu_2O + Cl^- + 2H_2O + 1/2O_2 \rightarrow Cu_2Cl(OH)_3 + OH^- \qquad (1)$$

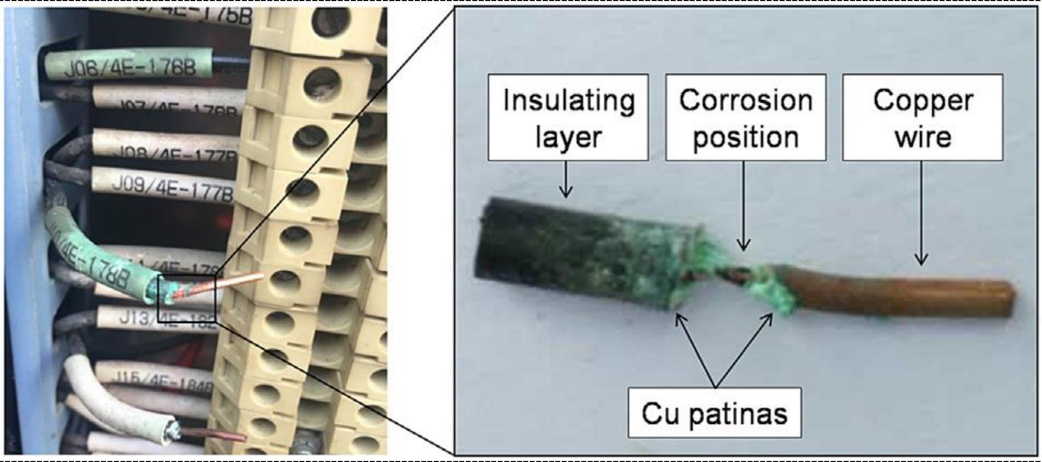

Figure 6. The damaged copper wires in outdoor terminal boxes[5]

From the above discussion, it can be seen that Cl^- dissolved from the number barrel and higher air humidity are the main environmental factors accelerating the corrosion process of copper conductors. In order to avoid the corrosion of copper conductors, it is suggested to replace the dehumidifier with independent control and evaluate the dehumidification effect regularly and the number barrel should be replaced with the material which does not dissolve the harmful ions such as Cl^- andSO_4^{2-}.

The above cases show that the influence of environment, including temperature and humidity, harmful ions, and potential galvanic corrosion or crevice corrosion, should be fully taken into account when selecting metal materials for secondary components.

4. Conclusions

Due to improper selection of materials, unqualified materials and unfavorable environmental factors in the long-term service process, failures of the metal parts of secondary components emerge in endlessly. In order to ensure the reliability of secondary components in service and to reduce or even eliminate the control circuit faults caused by the metal parts failures of secondary components, it is suggested that the following work be carried out:

(1) Technical standards such as guidelines for selection of metal materials and quality acceptance criteria for secondary components should be formulated as soon as possible, and the quality acceptance of secondary components into the power grid should be strengthened.

(2) In the design stage, material with excellent comprehensive properties such as aluminum alloy, nickel-plated brass and tin-plated copper should be preferred, while material with insufficient corrosion resistance such as galvanized steel, 200 series stainless steel and poor mechanical properties such as lead brass should be avoided.

(3) In order to ensure the reliability of secondary components in service life, effects of temperature, humidity, harmful ions and other environmental factors on the metal parts of secondary components should be studied in detail. Meanwhile, it is necessary to establish a method for evaluating the service life of different metal materials under various environmental conditions.

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