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The Fire Hazard of Screwed Electric Contacts Due to Mechanical Vibration at Low Voltage Equipment

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Abstract : There are many electrical connections in the electric apparatus and most fires due to a fault contact result from a failure or misuse of electric apparatus and installation. The fault contact happens between electrical connections by the loose and the mechanical vibration. In this paper, we have investigated thermal and electrical properties of screwed electric contacts due to the mechanical vibration. The exciter was connected to a signal generator and power amplifier that provided the vibration frequency and amplitude. The vibration, temperature and voltage data were sent to a data acquisition system (DAQ). In the case that fault contact took place, the arc happened between the screwed electric contact and electric wire, heat due to the arc was transmitted to the adjacent insulators, for which the oxide could be generated more. In addition, a spark was generated and the insulator began to melt. Thus, the possibility of electrical fire became the highest in this case. Finally, when the fault contact takes place due to vibration, the hazard of an electric accident is very high.

Key words : screwed electric contact, fault contact, mechanical vibration, electrical fire

1. Introduction

Electric wire and many electrical connections at low voltage equipment such as the connection of screwed electric contacts exist in these electrical devices. If connection strength is deteriorated in connection and it is deteriorated by surrounding environment, electrical disaster happens by a local heat generation [1~5]. According to statistical data in 2004, the short circuit accident occupied 78% most in electrical accidents, and the connections caused by fault contact occupied 3.5% (369 cases) in Korea[6]. It is necessary to investigate the accidents cause and to present improvement of structural problems and to suggest prevention at electrical connections.

The connection method of connecting part can be divided into a spring connection, a compression connection and a screwed connection, among them, a screwed connection is used much by divergence of electric wire and purpose of connection. The terminal block is one of screw connection instrument. In the case that several load electric wire is connected to single power wire, correct installation and maintenances are required in standard. In the case that the screw(or the bolt) is not tightened with standard tightening torque, the contacts become poor and oxide substances are generated. Thus, the electrical fire can take place at the connections. However, there are not electrical devices to detect the poor conditions at the connections [7~8]. Electrical accidents due to fault contact occur by the looseness or the deterioration caused by vibration and corrosion at the connections. The cause of the vibration can be; blasting; earthquakes; wind; inside the machine in low voltage equipment. The vibration frequency is very wide and the amplitude is various according to environmental conditions. The vibration frequency covers a wide scope (1~1000 Hz) in the machine inside. Mechanical vibration of electrical devices is induced by unbalance because of the wrong design or an error in manufacturing. These causes can lead to the fault contact in an electrical apparatus, and an electrical fault event can take place, ultimately [9~10]. Thus, accordingly, as an electrical accident happens necessarily, we need to minimize the number of the connections and to maintain a suitable tightening torque.

Therefore, this study aims to improve screw connec-

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tion methods. For this, we simulated accelerated deterioration on screwed electric contacts under mechanical vibration and we investigated to fire hazard of terminal block.

2. Experimental

Fig. 1 shows the composition of a screwed terminal block (30A, 4P) that is used in an experiment and each temperature measurement parts (A, B, C). The terminal block consists of a screwed electric contact (included square washer), bus bar and insulator (phenol resin). An electric wire (thickness of 2.0 mm) with a crimp-type terminal lug is connected between the bus bar and the screwed electric contact. The screwed tightening torque of a terminal block must tighten properly according to a screw diameter of IEC standard (IEC 60947-7-2) as shown in Table 1. In this experiment, however, we simulated a tightening torque of 0 N•m by a torque driver (FDS2-S, Tohnichi, Japan) that did not tighten the electric wire and screwed electric contacts.

Fig. 2 shows a schematic diagram of the experimental setup for the arc and deterioration properties between screwed electric contacts and the electric wire. In this figure, a terminal block is fixed to a jig and an exciter is used to make the screwed electric contacts on the terminal block poor. And, sinusoidal input is provided by a signal generator (2555, Yokogawa, Japan). The amplitude of vibration is adjusted by an amplifier (EA42, Eliezer, Korea). The vibration and temperature data were analyzed by the DAQ system (6071E, 1.2M/s, NI, USA) connected with an accelerometer (sensitivity, 50 mV/g) and K-type thermocouples. In addition, the voltage drop across the terminal block was recorded by the DAQ system. $220V_{rms}$ was applied to the terminal block by using a transformer of maximum output $600V_{rms}$, a lamp was used as load resistance. The arc phenomenon and deterioration progress at poor contact due to vibration were observed by a computer using a high-speed image system (HG-100K, Redlake, USA) which takes photographs available up to 100,000 fps. Material of the specimen was analyzed by using TGA/DSC (SDT-2960, TA.Ins., USA), SEM (JSM6400, Jeol, Japan) and EDX (Ultracool, Oxford, England). The environmental condition was 11.5°C and 38% in temperature and humidity, respectively.

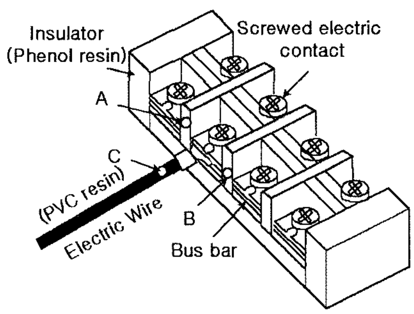


Fig. 1. Temperature measurement and composition of the terminal block.

Table 1. Tightening torque for the verification of the mechanical strength of screw-type clamping units (IEC 60947-7-2).

Diameter of thread mm		Tightening torque N·m		
Matric standard values	Range of diameter	i[a]	i[b]	i[c]
1,6	≤1,6	0,05	0,1	0,1
2,0	>1,6 up to and including 2,0	0,1	0,2	0,2
2,5	<2,0 up to and including 2,8	0,2	0,4	0,4

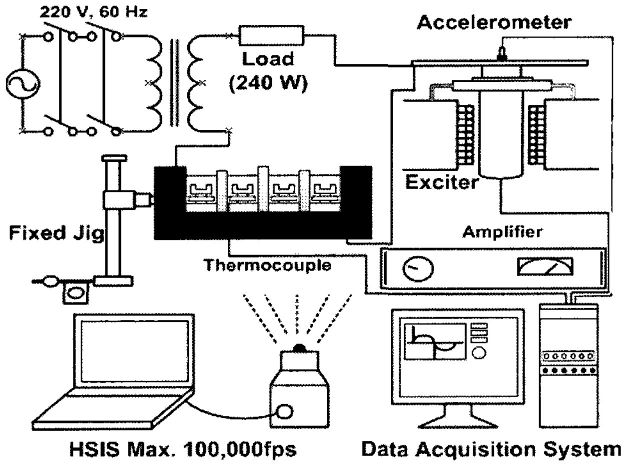


Fig. 2. Schematic diagram of experimental setup.

3. Results and Discussion

The experiment was done for vibration frequency 60 Hz and a variety of vibration amplitude. G is the acceleration of gravity. Vibration is applied for 2,500sec. Fig. 3 shows the temperature variation caused by poor contact between a screwed electric contact and an electric wire at 1 G. As shown in Fig 3, temperature of the PVC resin connected to the screw terminal increased to 100°C at 250 sec and thereafter decreased. The increase in temperature to 250sec was due to the arc, thereafter, the arc and the oxide growth were not observed. The temperature was maintained underpowered.

Fig. 4 shows the temperature variation caused by poor contact between a screwed electric contact and an elec-

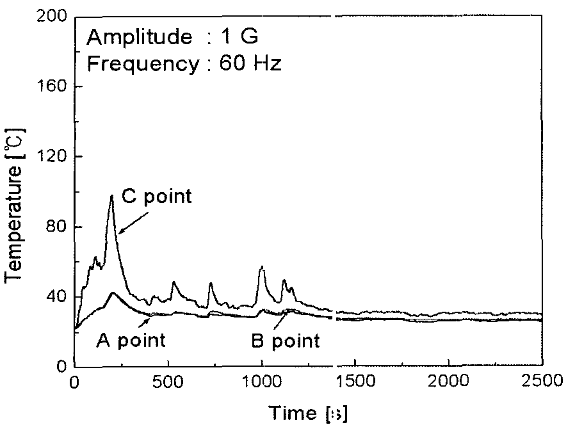


Fig. 3. The temperature variation between a screwed electric contact and an electric wire at vibration amplitude 1G.

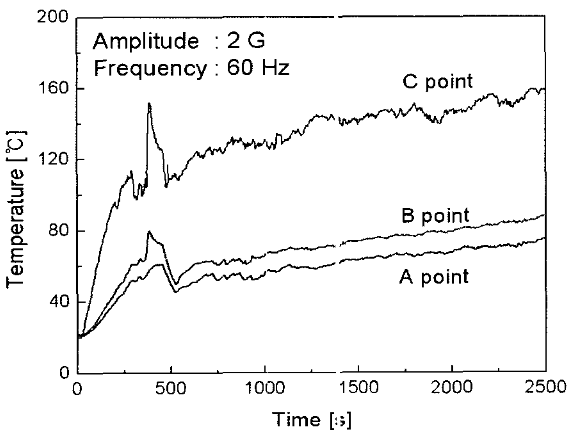


Fig. 4. The temperature variation between a screwed electric contact and an electric wire at vibration amplitude 2G.

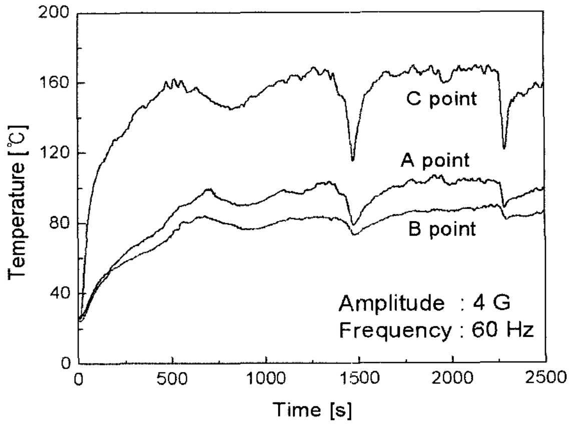


Fig. 5. The temperature variation between a screwed electric contact and an electric wire at vibration amplitude 4G.

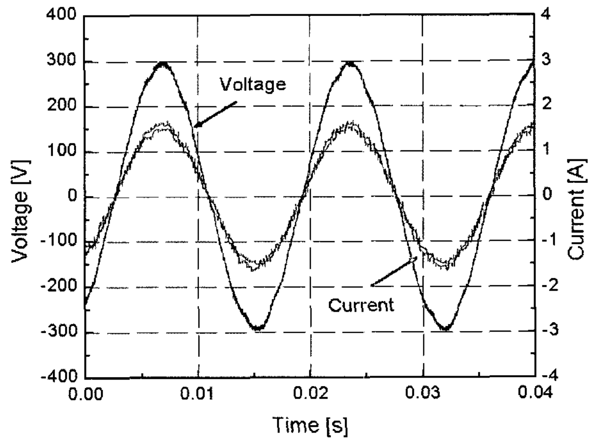


Fig. 6. The voltage waveform (VL) and the current waveform under load around 1,500 sec, (amplitude = 2G, frequency = 60 Hz).

tric wire at 2 G. In this Fig 4, temperature abruptly increased up to 470sec. Hereafter, the temperature increased more due to the intermittent and the oxide generation. Temperature of PVC resin connected to the screw increased more than that of phenol resin of the terminal block. The temperature differences between C point and A, B points(as shown in Fig. 1) are as follows. The heat is directly transmitted to PVC resin by the spark because the electric wire is connected to the screwed electric contact. However, in the case of the phenol resin, heat is indirectly transmitted because there is a small gap.

Fig. 5 shows the temperature variation caused by poor contact between a screwed electric contact and an electric wire at 4 G. In this Fig. 5, the temperature abruptly increased up to 500sec and was saturated at 160°C. There were, however, several peaks in the temperature. Arc was continued at 4G, by which a spark was generated and the phenol resin began to melt. The fire possibility became the highest in this case.

Fig. 6 shows the voltage waveform(V_L) and the current waveform under load and Fig. 7 shows the voltage waveform(Vs) between screwed electric contact and electric wire at 2G. They were measured around 1,500sec. In this Fig. 5, at that moment, there was no distortion in voltage waveform and the current peak was 1.51A. The growth of the oxide generally tends to be activated as the current becomes larger. In this experiment, however, the oxide was easily activated even at low current, which deteriorated the adjacent insulators. After all, electrical accidents could take place.

Fig. 7 shows the voltage waveform measured around 1,500sec. Unique voltage waveforms were measured because of the oxide growth, and the voltage peak was about 10V. However, the electrical circuit breaker was not operated in this case, therefore, a proper countermeasure has to be prepared.

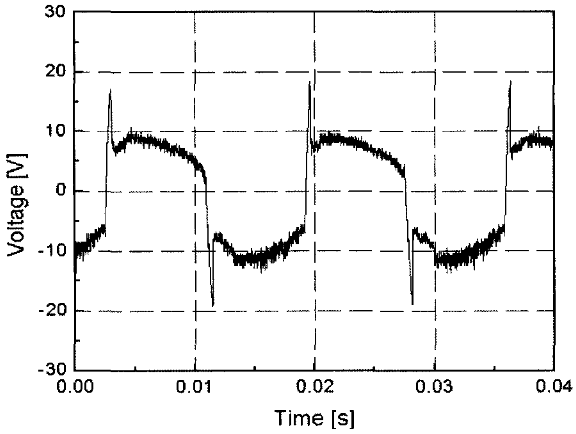
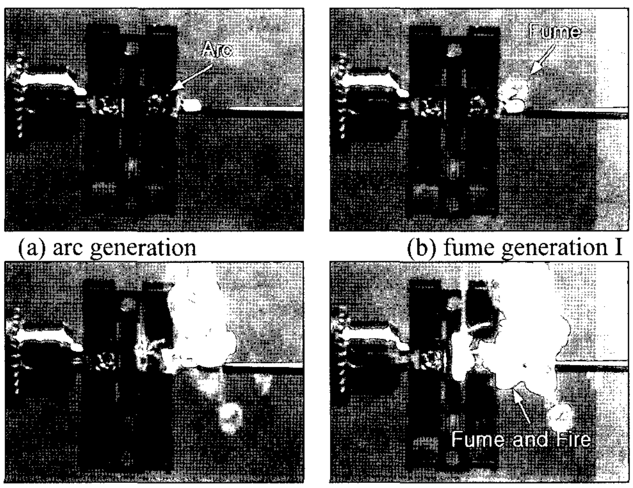


Fig. 7. The voltage waveform (Vs) between a screwed electric contact and an electric wire (amplitude = 2G, frequency = 60 Hz).

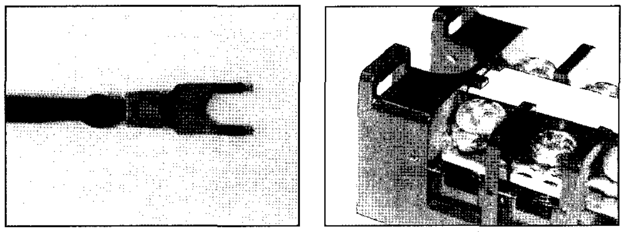
Fig. 8 shows the arc generation and fire progress caused by fault contact in the terminal block at 4G. Photographs were taken by using a high-speed image system(HSIS) at the rate of 500fps. In this Fig. 8(a), if fault contact happened by vibration around 250sec, the arc occurred first, and contact resistance increased, phenol resin and PVC resin were melted by the arc heat. At about 1,200sec, temperature of PVC resin and phenol resin increased by heat, as shown in Fig. 8(b) and Fig. 8(c), fumes were generated. At the same time, it dispersed into the terminal block. As shown in Fig. 8(d), the melted phenol resin was ignited by the spark and progressed to fire. Therefore, it was confirmed that the possibility of the fire by mechanical vibration was very high.



(a) arc generation (b) fume generation I

(c) fume generation II (d) fire generation

Fig. 8. The arc generation and fire progress by poor contact in terminal block at 4 G, 60 Hz.



(a) Crimp-type terminal lug (b) Screwed electric contact

Fig. 9. Damaged shape of electric wire and terminal block.

Fig. 9 shows the shape of the crimp-type terminal lug connected to the electric wire and the terminal block after the experiment. In the case of Fig. 9(a), the oxidization of the crimp-type terminal lug surface and the swell of the PVC resin were observed. In Fig. 9(b), the screwed electric contact discolored to leek-green and it was oxidized, and the phenol resin was carbonized. In particular, the square washer of the screwed electric contact was rotated by vibration, by which it was contacted to the insulator. In the case of the terminal block(30A and less), therefore, it is considered that the square washer is likely to make a short circuit by contacting the adjacent screwed electric contact. After all, it is strongly recommended that the square washer has to be substituted by circular washer, which prevents the electrical failure events.

The element analysis results of the screwed electric contact caused by fault contact are listed in Table 2. In the case of the virgin specimen, iron(Fe) is plated with zinc(Zn) on the screwed electric contacts. The elements of zinc, oxygen and iron were about 66.56%, 30.9% and 2.51%, respectively. In the oxidized specimen, the elements of the specimen were 3.3%, 24.6%, and 59.8 % in zinc, oxygen and iron, respectively. From these results, it was shown that the oxygen element was similar to the normal type specimen, and the zinc element abruptly decreased, but the iron element abruptly increased. The iron element is much detected because the melting point of zinc is lower than iron. Also, the copper(Cu) and tin(Sn) elements were 10.9% and 1.37 %, respectively. It is considered that the elements of the crimp-type terminal lug appeared by the arc, as listed in Table 3. Table 3 shows the element analysis of the crimp-type terminal lug caused by fault contact. Copper

Table 2. Element analysis of the screwed electric contact

%	Zn	Cu	Fe	O	Sn
virgin specimen	66.56	0	2.51	30.9	0
Poor contact	3.33	10.9	59.8	24.60	1.37

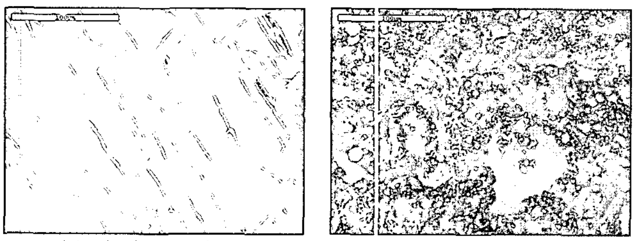
Table 3. Element analysis of the crimp-type terminal lug

%	C	Cu	Sn	Zn	Fe	O
virgin specimen	1.52	1.8	96.6	0	0	0
Poor contact	0	63.7	2.89	10.4	8.82	14.1

is plated with tin in the case of the crimp-type terminal lug. Tin is occupied the most as 96.6%. After a fault contact, the tin element decreased greatly by 2.89% and the copper element increased greatly by 63.7%. This result is similar to the screwed electric contact, and the copper element is detected accordingly as tin is melted. It is thought that the element of the screwed electric contact was transmitted.

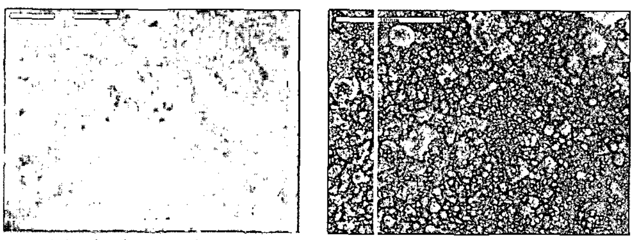
Fig. 10 shows the SEM photographs of a screwed electric contact at 500x. Fig. 10(a) is the surface structure of the virgin specimen. In this Fig. 10(b), because of the arc heat due to the fault contact, the molten marks were observed irregularly. Fig. 11 shows the SEM photographs of a crimp-type terminal lug at 500x, too. Fig. 11(a) shows the surface structure of the crimp-type terminal lug of the virgin specimen. In this Fig. 11(b), however, when it was damaged by the fault contact, the surface was deteriorated and the molten marks were observed. These SEM photographs will be utilized for the data in the investigation of electrical fire.

Fig. 12 shows the thermal analysis of phenol resin in the terminal block. Thermal gravity of the virgin specimen decreased 62.36% from about 464.73°C to 488.14



(a) virgin specimen (b) oxidized specimen

Fig. 10. SEM photographs of the screwed electric contact.



(a) virgin specimen (b) oxidized specimen

Fig. 11. SEM Photographs of the crimp-type terminal lug.

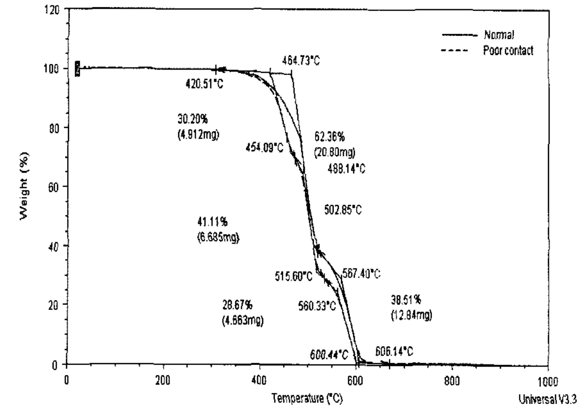


Fig. 12. A thermal gravity analysis of phenol resin in terminal block.

°C, 38.51% to 606°C. After poor contact, however, it is observed that thermal gravity decreased 30.2 % from about 420 to 454 , 41 % to 512°C and 28.6% to 560°C. In the case of carbonized phenol resin, it was confirmed that thermal gravity is greatly changed in 3 points, it is thought that thermal gravity of the main material and filler decreased by the arc. The characteristics in thermal gravity varied around 450°C, which is better than those shown in Fig. 3. The electrical fire probability is, however, still high.

Conclusion

In this paper, we simulated fault contact in the connection accordingly as the screw tightening torque is not fit, and investigated the arc properties and deterioration of screwed electric contacts. The fault contact due to vibration leads to the following characteristics; there was the intermittent arc but no variation in temperature at 1G, which means that electrical hazard possibility is very low. In the case of 2G, heat due to the arc was transmitted to the adjacent insulators, for which the oxide could be generated more. Therefore, the electrical fire possibility is getting higher. The arc was continued at 4G, by which a spark was generated and the insulator began to melt. The electrical fire possibility became the highest in this case. Finally, when the fault contact takes place due to vibration, the hazard of electric accident is very high. Thus, it is important to maintain a suitable tightening torque to prevent an electrical disaster. In the case of the terminal block (30A and less), it is strongly recommended that the square washer have to be substituted by circular washer, which prevents the electrical failure events. These experimental results will be utilized for the data in the investigation and prevention of an electrical fire.

Acknowledgment

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