



A Study on the Electric Shock Risks of Automatic Wheel Washers in Construction Sites and the Mandatory Application of Earth Leakage Breakers

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Abstract

Purpose: This study empirically analyzes the electric shock risks caused by the conventional use of molded case circuit breakers (MCCBs) in automatic wheel washers at construction sites and proposes institutional improvements to enhance worker safety. **Research design, data and methodology:** Field measurements of leakage currents were conducted in control panels of automatic wheel washers at construction sites in Daejeon, Republic of Korea. A TK-61L leakage current clamp meter was employed to verify the hazards of current MCCB installation practices under operational conditions. **Results:** Despite leakage currents reaching 1.07A (approximately 35 times the lethal threshold for humans) under specific fault conditions, the installed MCCB failed to operate, revealing a critical safety gap in current protection systems. Initial baseline measurements also detected persistent leakage currents of 3.80mA, indicating deteriorating insulation conditions. **Conclusions:** It is imperative to mandate earth leakage breaker (ELB) installation for wheel washer control panels and strengthen safety certification standards at the manufacturing stage to prevent electric shock accidents. Policy recommendations include revising safety certification requirements, updating construction specifications, and implementing IoT-based monitoring systems.

Keywords : Automatic wheel washer, Earth leakage breaker (ELB), Molded case circuit breaker (MCCB), Electric shock, Leakage current

JEL Classification Code : L74, I18, K32, Q53, O33

1. Introduction¹

1.1. Background and Necessity of Research

The domestic construction industry serves as a core driver of national economic development; however, it

remains classified as a high-risk industry that accounts for the largest proportion of industrial accident fatalities. According to the Ministry of Employment and Labor's (2023) analysis of industrial accident status, construction industry fatalities in 2022 constituted 48.7% of all industrial accident deaths nationwide. Among these, electrical hazards demonstrate exceptionally high fatality

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rates relative to their occurrence frequency.

With the recent strengthening of environmental regulations, the installation of automatic wheel washing facilities (hereinafter referred to as wheel washers) has become mandatory under Article 43 of the Clean Air Conservation Act to suppress fugitive dust emissions. Wheel washers operate in inherently humid environments due to their use of high-pressure water jets for vehicle cleaning and contain sedimentation tanks mixed with sludge and soil, thereby exposing electrical equipment to severely harsh conditions.

Article 304 of the Occupational Safety and Health Standards explicitly mandates the installation of earth leakage breakers (ELBs) in humid locations. Nevertheless, field investigations frequently reveal installations of molded case circuit breakers (MCCBs), which lack human electric shock protection capabilities. This practice stems from economic considerations aimed at cost reduction, coupled with erroneous field perceptions seeking to avoid ELB malfunction caused by moisture.

However, MCCBs are specialized devices for overcurrent protection and possess a critical technical limitation: they do not respond to leakage currents in the tens of milliamperes (mA) range that are lethal to humans. This means that workers may be exposed to lethal current levels without any protective measures when insulation breakdown causes electrical leakage.

This study analyzes the operational status of electrical facilities in construction site wheel washers and seeks to clarify the electric shock risks inherent in MCCB installation practices through actual measurement data. Furthermore, it diagnoses gaps in relevant laws and regulations to propose specific institutional and technical improvement measures that can effectively mandate the installation of high-sensitivity ELBs in wheel washer power circuits.

1.2. Scope and Methodology of Research

This study targets the electrical safety systems of automatic wheel washing facilities operating at domestic construction sites. The spatial scope is limited to outdoor humid locations where wheel washers are installed, and the technical scope encompasses low-voltage (below 600V) induction motor drive systems and analysis of protective device operating characteristics. Research methodologies include theoretical background review through literature research, leakage current measurement through field testing, and derivation of institutional improvement measures through legal analysis.

2. Literature Review

2.1. Operating Principles of Electrical Protection Devices

One fundamental cause of electric shock accidents at construction sites is that managers and workers do not clearly recognize the differences in protective purposes and operating principles between MCCBs and ELBs.

2.1.1. Molded Case Circuit Breaker (MCCB)

The primary purpose of MCCBs is to protect electrical circuits and load equipment. Operating principles are classified into thermal and electromagnetic types. The thermal type utilizes bimetallic elements that bend when overload current exceeding the rated current flows continuously, thereby opening the circuit. The electromagnetic type immediately interrupts power when the strong magnetic field formed by large current generated instantaneously during short-circuit accidents attracts the plunger.

The critical limitation of MCCBs is their inability to detect leakage current. For example, if a 50A capacity MCCB is installed and 1A (1,000mA) of current flows to ground due to insulation breakdown, this represents only 2% of the rated current, and the circuit breaker will not operate. However, since 100mA can cause immediate human death, MCCBs are structurally incapable of preventing electric shock accidents.

education and related communication (Schwatka and Rosecrance 2016; Hosseini et al., 2021). However, from the perspective of managers, they think that safety training provided to workers has sufficient work relevance and specificity, but from the perspective of workers, they tend to think that the training is abstract or does not reflect the specificity of actual work and field (Namian et al., 2020). Each of these tendencies leads to a lower level of awareness of safety in the workplace, but the causes are different, so it is important to identify these differences in perception to prevent safety accidents

2.1.2. Earth Leakage Breaker (ELB)

ELBs are human protection devices that, in addition to MCCB functions, detect and interrupt leakage current flowing outside the circuit. The core component is the zero-phase current transformer (ZCT), which monitors the vector sum of input and output currents in real-time according to Kirchhoff's current law. Under normal conditions, input and output currents are equal, resulting in a vector sum of zero. However, when leakage occurs and imbalance is detected, induced electromotive force is generated to energize the trip coil and disconnect power.

High-sensitivity ELBs for human protection typically have characteristics of rated sensitivity current of 30mA and operating time within 0.03 seconds. While MCCBs

can withstand tens of thousands of mA, ELBs immediately disconnect power with only 30mA of minor leakage, thus dramatically reducing the probability of electrocution death.

2.2. Physiological Effects of Human Electric Shock

The International Electrotechnical Commission's (IEC) IEC 60479-1 standard classifies the effects of alternating current on the human body into four zones according to current magnitude and duration. Zone AC-1 (below 0.5mA) is at the threshold of perception, while zone AC-2 (0.5-10mA) causes muscle contraction but is not dangerous. Zone AC-3 (10-30mA) induces strong muscle contraction and breathing difficulties, and zone AC-4 (exceeding 30mA) causes ventricular fibrillation leading to death within minutes.

Human body resistance decreases drastically in humid environments. While dry skin has resistance exceeding several k Ω , wet skin resistance drops to 500-1,000 Ω . Applying Ohm's law, based on wheel washer ground voltage of 220V, in wet conditions (1,000 Ω), 220mA will flow, reaching immediately fatal levels. Since MCCBs do not respond even in this situation, the absence of ELBs in humid locations can directly result in fatal accidents.

for fair pressure was the lowest at 0.041. The correlation coefficient between the degree of margin for fair pressure and the degree of recognition that the work environment at the site was safe was 0.682, and the strength of the correlation was relatively high, although it was less than 0.7. The strong correlation between the degree of awareness of safety education and the degree of awareness of the Serious Accident Punishment Act means that managers who periodically conduct education smoothly are highly aware of safety education, and that they are better adhering to obligations under the Serious Accident Punishment Act at the site. The correlation between the degree of margin for process pressure and the degree of recognition of the work environment at the site is relatively higher for managers who do not express the burden of work speed on the process to workers.

2.3. Status of Electrical Accidents in Construction Industry

According to Korea Occupational Safety and Health Agency statistics, electrical accidents in the construction industry over the past five years (2018-2022) averaged 42 cases annually, with electrocution accounting for over 70% of fatalities. Notably, the proportion of electric shock accidents in humid locations was highest at 58.3%,

suggesting the urgent need for electrical safety management of water treatment facilities such as wheel washers.

3. Conclusion

3.1. Experimental Environment and Measurement Equipment

The field investigation targeted automatic wheel washing facilities operating at apartment construction sites in Daejeon Metropolitan City. The control panel of the facility was installed outdoors, exposed to high humidity and vibration, with soil dust infiltrating internal terminal blocks and wiring.

For precise leakage current measurement, a TK-61L leakage current meter manufactured by CHEKMAN was employed. This equipment can measure zero-phase current without circuit separation under live conditions through a clamp method and is capable of measuring currents from 0.1mA up to a maximum of 300A.

3.2. Leakage Current Measurement Results

Measurements were conducted by simultaneously clamping the power line and neutral line of the submersible pump circuit, which is the core load of the wheel washer, to detect zero-phase current.

3.2.1. Initial Leakage Current Measurement

Measurement of leakage current in the pump circuit during wheel washer standby revealed that 3.80mA of leakage current was constantly flowing. While this is below the 30mA human electric shock protection threshold and not an immediately dangerous level, it suggests that a leakage path has formed due to cable insulation deterioration or terminal block contamination. According to prior research, persistent leakage current exceeding 3mA can be considered a precursor symptom of tracking phenomena, with high probability of leading to rapid electrical leakage accidents when humidity increases.



Figure 1: Initial baseline leakage current measurement showing 3.80mA



Figure 2: Critical leakage current measurement showing 1.07A

3.2.2. Critical Threshold Exceedance Situation

When abnormal conditions occurred during wheel washer operation, leakage current measurement recorded 1.07A (1,070mA). This measurement provides the core implications of this study.

First, the measured 1.07A is approximately 35 times the human ventricular fibrillation threshold (30mA). According to IEC 60479-1 standards, when current exceeding 50mA flows for more than 0.1 seconds, ventricular fibrillation probability exceeds 50% (IEC, 2018), and 1,070mA represents an extremely dangerous level capable of causing instant death.

Second, the circuit had a 30A-50A rated MCCB installed. From the MCCB's perspective, 1.07A represents only a small fraction (approximately 2-3%) of the rated current, so it recognizes this as normal load current and does not interrupt. This empirically proves that MCCBs are structurally useless for preventing human electric shock accidents.

3.3. Engineering Interpretation of Measurement Results

The 1.07A leakage current confirmed in this experiment has the following engineering significance.

Electrical Risk Analysis: Applying Ohm's law ($V=IR$), when 1.07A flows through human body resistance of $1,000\Omega$ (wet condition), the voltage applied to the human body reaches 1,070V. This is approximately five times the nominal voltage of 220V, meaning workers can suffer immediate fatal injury upon contact with exposed live parts.

Insulation Resistance Estimation: According to KS C IEC 60364 regulations, insulation resistance of low-voltage circuits must maintain a minimum of $1M\Omega$ or higher. However, the occurrence of 1.07A leakage current in a 220V circuit means insulation resistance has deteriorated to approximately 205Ω ($220V \div 1.07A$), which is 0.02% of the standard value, indicating severe insulation breakdown.

4. Results and Discussion

4.1. Current Legal Regulations

Article 304 of the Occupational Safety and Health Standards explicitly mandates ELB installation in humid locations. Article 304, Paragraph 1 states that employers must install ELBs on portable electrical machinery and equipment used in humid locations to prevent electric shock hazards.

Furthermore, Korean Electrical Equipment Code (KEC) 232.62.2 recommends using high-sensitivity ELBs of 30mA or less for electrical facilities in humid locations, and Article 67 of the Electric Utility Act mandates safety assurance according to electrical equipment technical standards.



Figure 3: Control panel with initial MCCB installation

4.2. Blind Spots in Legal Regulations

However, current laws and regulations contain the following blind spots.

First, ambiguity in application scope: As Article 304 emphasizes portable machinery and equipment, wheel washers classified as fixed facilities occupy an ambiguous position regarding regulatory coverage.

Second, absence of manufacturing stage verification: Under the voluntary safety confirmation reporting (KCs) system, wheel washers are reported as complex machinery

including conveyors, but verification of circuit breaker types inside control panels is relatively neglected. Manufacturers ship MCCBs instead of ELBs as standard specifications for cost reduction, which fosters field safety insensitivity.

Third, field malfunction avoidance practices: When leakage current like the 1.07A confirmed in this study occurs, ELBs immediately trip and halt work, but MCCBs do not operate, ensuring work continuity. This represents a typical case of safety insensitivity that neutralizes safety devices for work convenience.

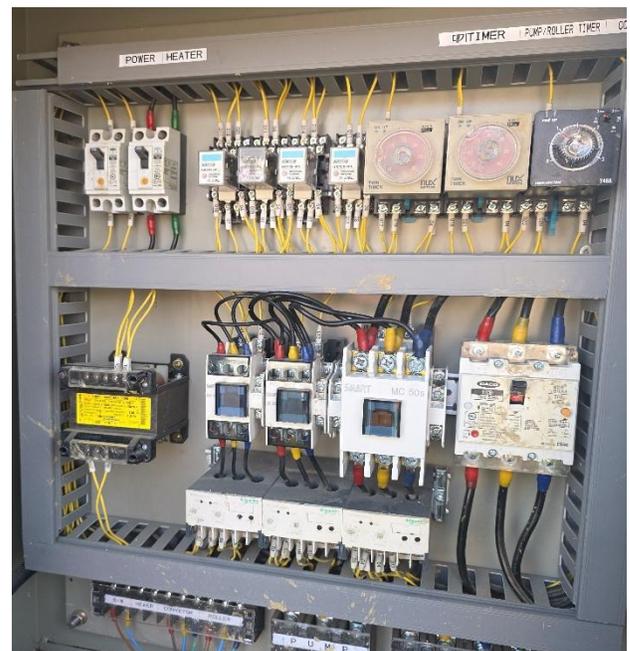


Figure 4: Control panel after ELB installation

4.3. Overseas Regulatory Cases

The U.S. Occupational Safety and Health Administration's (OSHA) 29 CFR 1926.404(b)(1) regulation mandates GFCI (Ground Fault Circuit Interrupter) installation for all electrical equipment in humid locations at construction sites. Additionally, the European Union's IEC 60364-4-41 regulation mandates ELBs of 30mA or less in TT grounding systems and imposes strong sanctions for violations.

5. Conclusions

5.1. Summary of Research Results

This study identified that the practice of installing MCCBs in construction site wheel washers constitutes a serious safety issue threatening worker lives. Through theoretical analysis and field empirical experiments, the following conclusions were derived.

First, field measurements at Daejeon construction site wheel washer control panels revealed persistent leakage current of 3.80mA and lethal leakage current reaching 1.07A (1,070mA) under abnormal conditions. This is 35 times the IEC 60479-1 standard ventricular fibrillation threshold.

Second, even under such high-current leakage conditions, MCCBs designed for overcurrent protection did not operate at all. This empirically proves that MCCBs are structurally useless for preventing human electric shock accidents. Only ELBs can protect workers by disconnecting power within 0.03 seconds.

Third, institutional blind spots including current law's focus on portable machinery and equipment, absence of manufacturing stage verification, and field malfunction avoidance practices perpetuate these risks.

5.2. Policy Recommendations

Based on research results, the following policy recommendations are proposed.

Institutional Aspects:

Establish mandatory inspection items for ELB-equipped control panels in wheel washer voluntary safety confirmation reporting (KCs) standards. Codify provisions for installing ELBs rated 30mA or less in architectural and civil engineering construction standard specifications. Increase fines for Occupational Safety and Health Act violations (from 5 million won to 30 million won) and explicitly include in Serious Accidents Punishment Act application.

Technical Aspects:

Establish selective interruption systems by installing individual ELBs for each load branch circuit. Mandate control panel protection rating of IP55 or higher and apply waterproof cable glands. Introduce IoT-based real-time leakage current monitoring systems.

5.3. Research Limitations and Future Tasks

This study is based on measurement data from a single site, limiting generalization. Future research should address the following.

First, extensive sample surveys of wheel washer electrical safety conditions at major construction sites nationwide are necessary. Statistical analysis of leakage current distribution by region, site scale, and equipment age should be performed to conduct risk mapping.

Second, economic analysis of cost-benefit ratio for ELB installation versus electric shock accident prevention effects is needed. Comprehensive cost-benefit analysis should prove economic validity of policy implementation by considering initial investment costs (approximately 100,000 won for ELB price differential) against life value, workers' compensation, and construction interruption losses.

Third, research on technical measures to minimize ELB malfunction (false leakage detection) is necessary. Since frequent tripping by minor leakage current is a factor causing field ELB avoidance due to humid location characteristics, the applicability of time-delay type ELBs or advanced circuit breakers with automatic reclosing functions should be examined.

5.4. Research Significance

This study holds academic and practical significance as the first domestic research to empirically identify electrical safety issues in construction site wheel washers. Particularly, the field measurement data demonstrating that MCCBs do not operate even when current 35 times the human lethal dose leaks provides powerful scientific evidence to correct erroneous field practices.

We expect that the empirical data and institutional improvement measures proposed in this study will serve as reference materials for policy formulation to strengthen electrical safety standards at construction sites and ultimately contribute to achieving zero electric shock accidents.

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