

## Experimental investigation of the effect of inrush current created by LED drivers on switching elements

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### Abstract

The demand for lighting technology is increasing rapidly with the increasing population and the advancement of industrialization. Significant developments are taking place in the field of lighting to meet this demand. LED lighting technology, which is the most current of these developments, is preferred to a high degree as it is more efficient, long-lasting, and advantages compared to conventional lighting technologies. However, this technology is still in its development stage and problems may be encountered that need to be solved. In this study, the problems that caused by inrush current and damage to the switch contacts of LED armatures using different protection classes as a result of multiple switching were observed with switching elements complying with IEC 60669-1 standards. The damage on these two switching elements was tested by connecting them with 69 LED armatures of 12A-36W and starting-stopping 10000 times, 40 times per minute. As a result of the test, corrosion/damage that could cause major fires was observed in the LED switching elements and pictures were taken with the help of Scanning Electron Microscope (SEM). The study shows the importance of creating a special international material standard for LED switching systems and ensuring that manufacturers comply with this standard.

**Keywords:** Lighting, LED, Inrush Current, SEM

### Introduction

The need for lighting energy is increasing day by day with the increase in the population around the world and parallel industrialization. There are developments in lighting technology due to increasing needs. LED lighting systems are among the best examples of these developing technologies. These systems are preferred because of their long life, high efficiency, controllability, ease of installation, mercury-free, and color variations. Although they have many positive aspects, they also have certain problems as they are new and developing lighting systems [1-4]. In many studies, it is stated that the most important problem occurring in LED lighting systems is inrush currents, also known as input currents. The inrush current is the maximum instantaneous current that the electrical device draws when it is started, in other words, when it is connected to a power source. As the input condensers are suddenly charged during the operation of a power supply, they draw a great inrush current. A large inrush current may significantly force the fuse of the power converter and input rectifiers. The input current may limit the operation of other power devices on the line, and of other elements including the power line, switches, contactors, relays, circuit breakers, etc., and it may even cause loss of life and property [5]. When the literature studies were examined, the tests performed with the driver LED armature showed that inrush current in the power supply system could affect fault protection devices, and solutions to prevent the inrush current problem were proposed [6]. In another study, it was stated that although each armature was connected to the same AC grid circuit with a single circuit breaker or switch, arrangements such as multiple lines and multiple grid switches may cause unwanted inrush currents, and inrush current protection was required [7]. In the other study, a new approach to inrush current limitations in LED power applications was discussed. Accordingly, it was demonstrated how the cost of the inrush current, which adversely affected the circuit, could be effectively reduced [8]. In a different study, it was concluded that there were many conventional resistors to limit the inrush current in the LED circuit topology. So switched transistor inrush current controller, without resistor, both inrush current could be

limited and efficiency could be increased [9]. In another different study, the measurement and analysis of power quality in public lighting with LED technology was performed. An extraordinary curve was found in the LED lamps' power quality measurement results. Power peaks arose as inrush current five days in a week. Thus, it was assumed that the LED driver was unable to restrict the inrush current [10]. In the study [11], experiments to eliminate harmonic distortions in the input inrush current showed that converters were the most suitable solution for LED lighting applications. In the study [12], a closure delay-controlled discharge circuit for a TRIAC dimmable LED driver was suggested. This closure delay operation prevented the faulty closure of TRIAC, and it was observed that it decreased the inrush current. In the study [13], in comparative analysis tests of the effects of lighting elements on electrical systems, it was observed that LED lamps may be affected by inrush currents arising from the electrical source. The study [14] performs tests with LED lamps of different powers to examine the causes of failures in LED drivers. In tests performed with a LED lamp load of 1 kW, 1450 A inrush current was measured. In the study [15], this study, which was designed and applied for verifying the feasibility of HF noise reduction with a prototype of an LED streetlamp with a 60-Hz (Ferro resonance transformer) FRT and AC line voltage damping, a low-frequency transformer was suggested for protecting the LED streetlamps from the damage causes by inrush current. In the study [16], a Butterworth low-pass active harmonic filter model filtering the inrush current, over current, and voltage harmonics of different types of LED drivers were designed. In the study, to examine the total harmonic distortions (THD), harmonic analysis caused by this inrush current and voltage was performed with tests performed with different types of LED drivers. In the study [17], in order to increase the reliability of LED driver circuits and power electronic circuits, inrush current tests were performed to determine the appropriate value by calculating fuse melting points. Moreover, it was explained how the inrush current may be measured and a suitable value for the power circuit may be found. In the study [18], it was observed that the inrush current was being restricted by the application of a boost converter design formed with a new soft starter method on LED drivers negatively affected by the inrush current. In the study [19], for restricting the inrush current in LED circuit systems, an actuator based on an electromechanical relay and a load actuator based on an optocoupler and TRIAC were compared with tests. As a result of experimental tests, it was observed that the actuator based on the combination of an optocoupler and a TRIAC restricts the inrush current by 97%. In the study [20], the fact that the inrush current, drawn by the switching of numerous LED lamps, was at worrying levels for electromagnetic compatibility on the power electronics converter systems, and was indicated through simulations. In the study [21], soft starter technology was proposed for LED power supply to prevent LED lighting equipment from affecting the normal operation of power supply equipment on ships due to excessive inrush current. In the study [22], the effect of LEDs driven by magnetic ballast and electronic ballast fluorescent driver on the same switching element was investigated. While the minimum level of deformation was determined on the switching element of the magnetic ballast fluorescent circuit, excessive deformation was determined on the LED driver circuit. In the study [23], after performing the start-stop test of a LED driver, the arise of a significant inrush current was measured with the test device.

In all studies in the literature, it is observed that the sudden current drawn by the LED lighting circuit affects the circuit elements and lighting systems. In the study, the effects of inrush current on the contacts of the circuit elements during the switching of the LED lighting circuit were examined with SEM. As a result of the test observations, it was determined that there was excessive deformation on the contact surface. According to the results obtained in this study, it was concluded that the amount of deformation is high and fire and system malfunctions may occur.

## Materials and Methods

The effects of LED armatures on standard switching elements were tested in accordance with IEC 60669-1 standards. Moreover, according to these standards, the loads between 6 A and 10 A, 10.000 times switching with 30 switching per minute, and the loads between 10 A and 20 A, 5.000 times switching with 15 switching per minute were tested [24]. In the study, 1 unit of a switch, 2 units of push-pull solenoid, 1 unit of flasher time relay, 1 unit of AC-DC power supply, 2 units of contactors as being 12 A of AC-5A class and 7 A of AC-6B class, and 69 units of driver LED armature of 12 A and 36 W, and driver with an input value of 220 V AC and the output value of 60 V, 900 mA were used. In the study, the automatic switching system given in Figure 1 was designed for actualizing the specified number of switching operations as per the IEC standards [25].

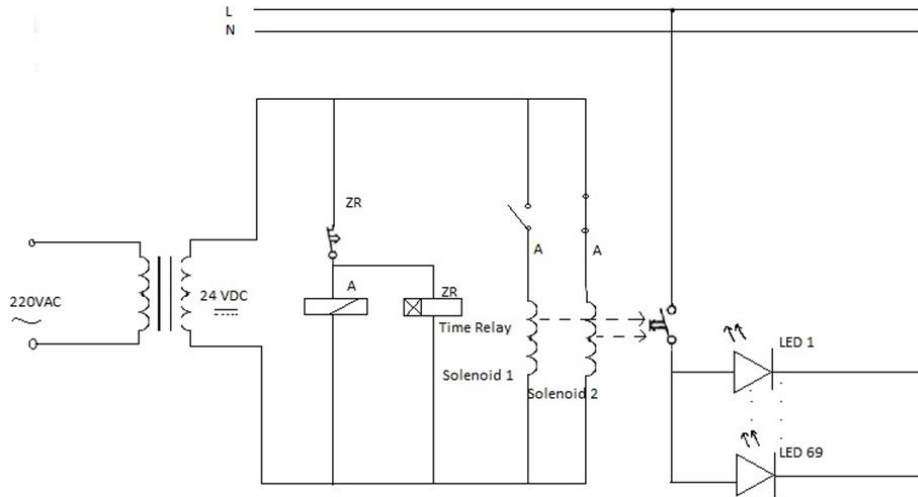


Figure 1. Test System Electric Circuit Scheme.

## Implementation

### Experimental Setup

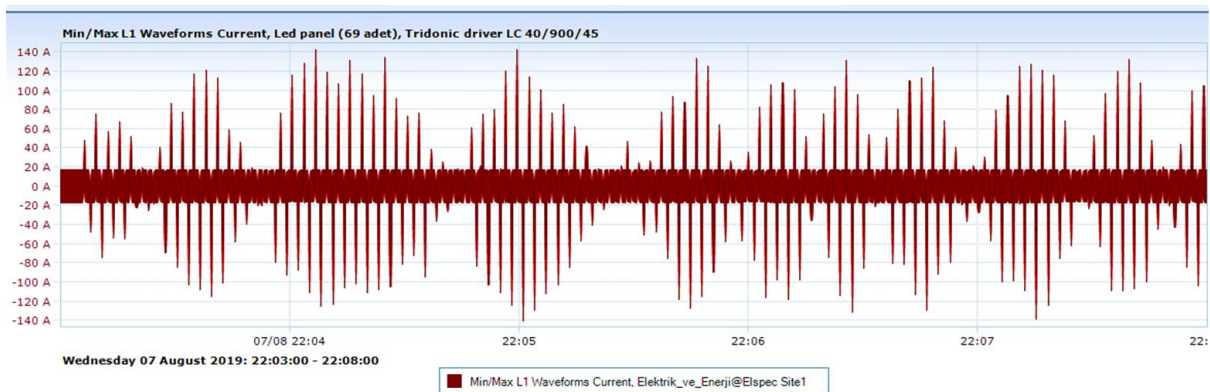
The experimental setup that consisted of an external driver LED armature circuit and an automatic switching circuit was shown in Figure 2 below.



Figure 2. Experimental Setup.

Approximately 7 A to 12 A current was obtained from 69 LED armatures used in the experimental setup. For the LED load, an external LED driver, 2 contactors, and a standard switching element were used. In addition, a one-time relay and two push-pull solenoids were used for continuous start-stop operation.

The tests were carried out with a total of 10.000 repetitions on an open and closed switching mechanism 40 times per minute. As a result of the tests, the damage on the surface of the switching elements was observed after a certain number of open and closed switching against the overcurrent that created a pulse at each start. Since the standard switching elements used in the study were 10 A, 69 pieces of 36 W LED panels were used and as a result of the test carried out for a total of 8.5 hours for 3 days, approximately 12 A current was obtained. An overload current with a nominal current of approximately 12 A was applied in all tests. Under nominal load, the value of the inrush current caused by the drives reaches about 140 A, as shown in Figure 3 below.

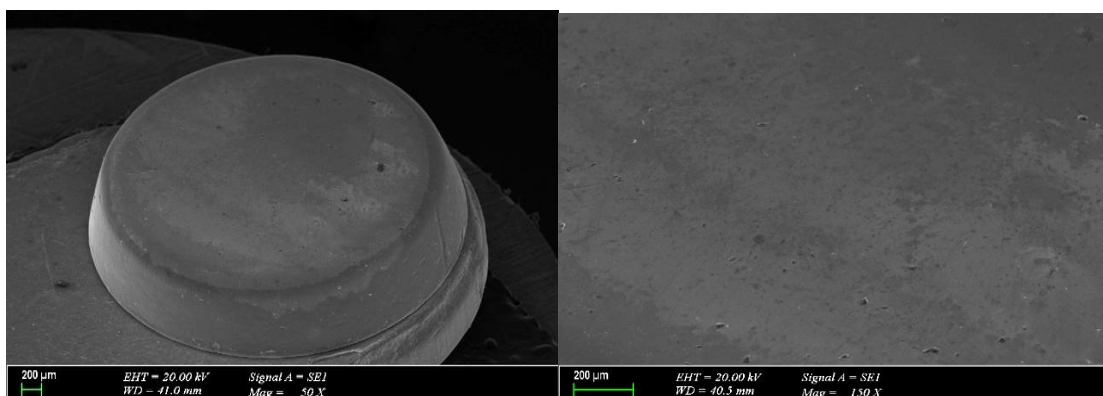


**Figure 3.** Inrush currents during the switching of the contactors.

The contactors were connected individually to the circuit to perform measurements. The switching operation was resumed until the switching elements reached the determined number. After the switching operations were completed for all three switches, the contactors were broken and the damage to the contact constructions was examined using secondary electrons (SE) by scanning electron microscope (SEM).

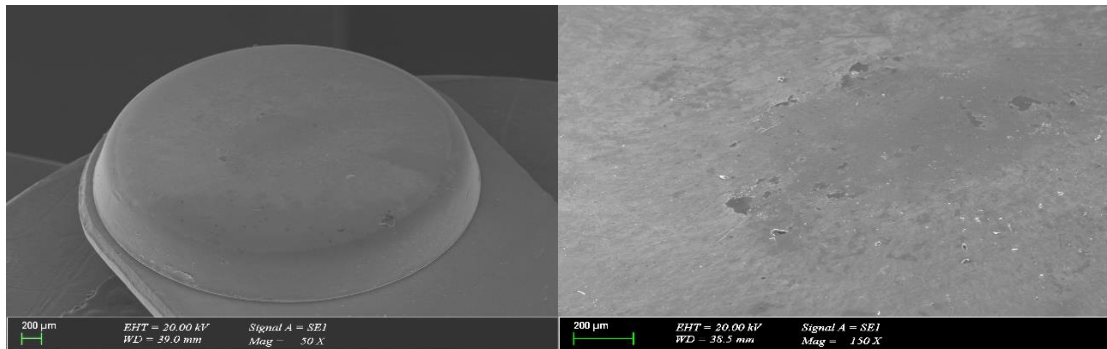
### SEM Examination

The moving and fixed parts of the switching elements were examined with SEM at 20 kV acceleration voltage and 50X to 150X magnifications. The damage conditions of the fixed and movable contact parts of the contactors were investigated in the examinations carried out on the surface area of approximately 8 mm<sup>2</sup> of two different brands of contactors.



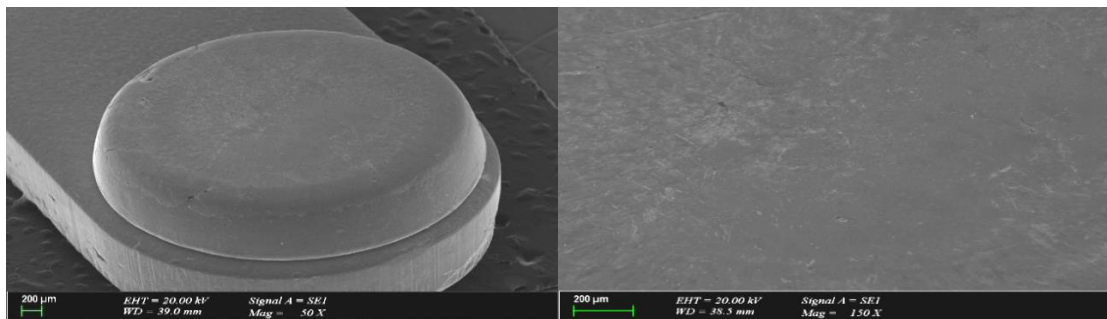
**Figure 4.** SEM image of the fixed contact of a new contactor of the first brand.

As seen in Figure 5, the mobile contact of the new contactor of the first brand was undamaged.

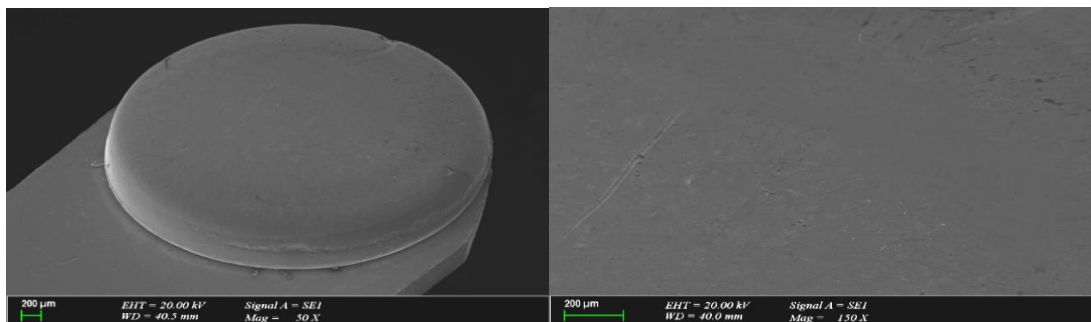


**Figure 5.** SEM image of the mobile contact of a new contactor of the first brand.

As seen in Figure 6 and Figure 7, the mobile contact of the new contactor of the second brand was undamaged. For the first brand, at the end of 10.000 repetitive switchings, the contactor was broken and damage was detected on the mobile contact surfaces and the body. SEM images of the destruction of the mobile contact part of the contactors are shown below in Figures 8 and 9 separately.

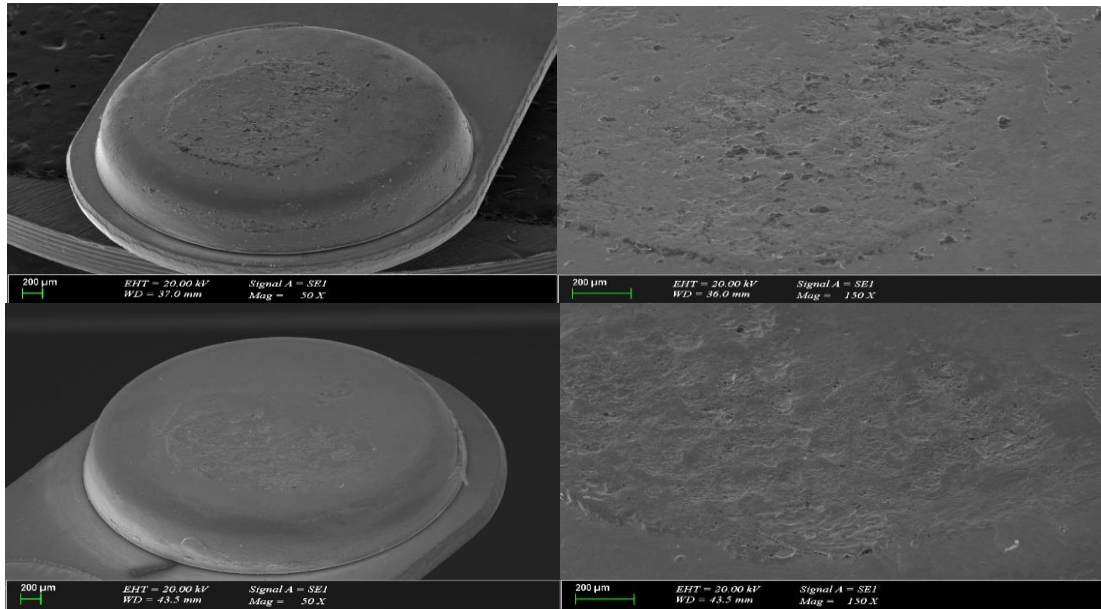


**Figure 6.** SEM image of the fixed contact of a new contactor of the second brand.

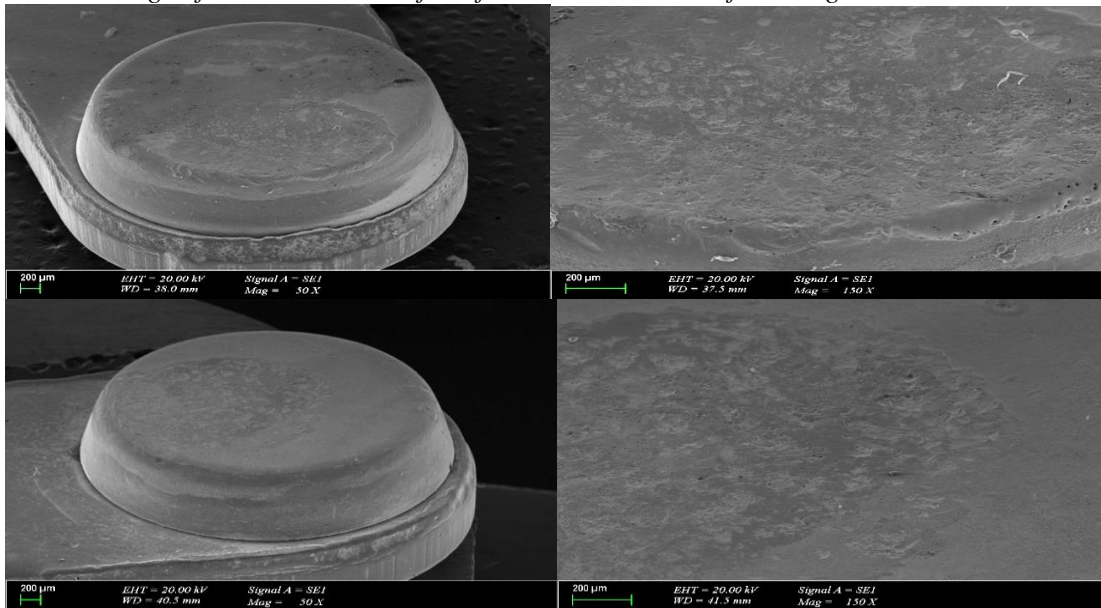


**Figure 7.** SEM image of the mobile contact of a new contactor of the second brand.

In Figure 8, the mobile contact of the new contactor of the first brand was damaged after 10.000 times of on-off. In Figure 9, the fixed contact of the new contactor of the first brand was also damaged after 10.000 times of on-off. For the second brand contactor, 10.000 switchings were made and the contactor was broken as a result of the test lasting 255 minutes. In Figure 10-11, it was seen that the mobile and fixed contacts were seriously damaged after 255 minutes of on-off.

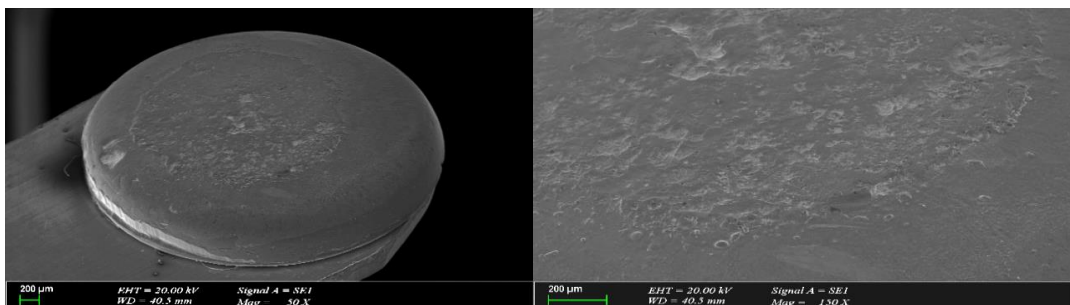


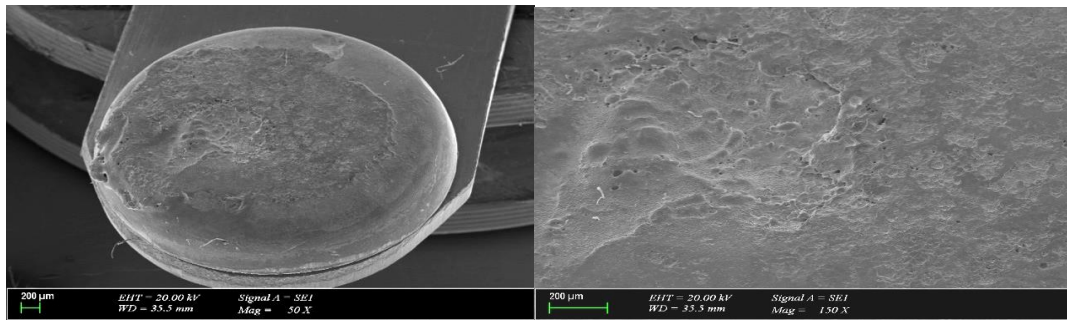
**Figure 8.** SEM image of mobile contacts of the first brand contactor following 10.000 times switching



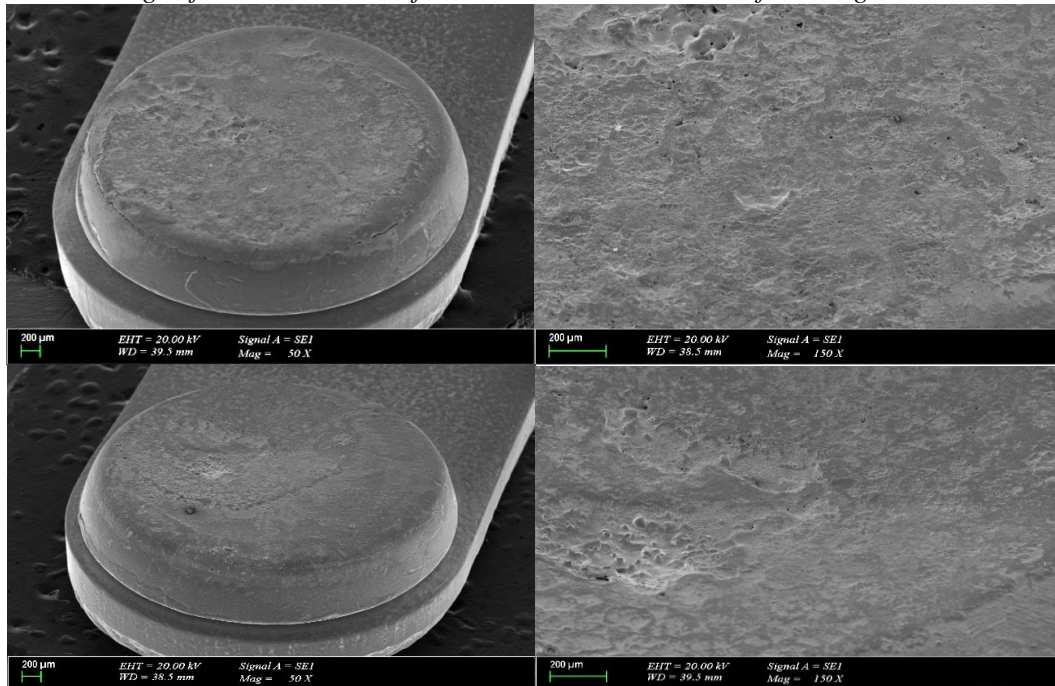
**Figure 9.** SEM image of fixed contacts of the first brand contactor following 10.000 times switching

For the second brand contactor, 10.000 switchings were made, and the contactor was broken as a result of the test lasting 255 minutes. SEM images of the damage on the contact surfaces and the body are shown below in Figures 10 and 11 separately.





*Figure 10. SEM image of mobile contacts of the second brand contactor following 10.000 times switching*



*Figure 11. SEM image of fixed contacts of the second brand contactor following 10.000 times switching*

## Results and Discussion

As a result of tests of 10.000 cycles carried out under the same conditions, it was determined that damage occurred in both contactors of different brands. It was observed in SEM images that the damage to the second brand contactor was more than the first brand contact, both in terms of fixed and mobile contacts. The damage to two different brands of contacts is different in tests under the same conditions, meaning that the contact materials vary from manufacturer to manufacturer. This means the conductor materials are not produced according to a certain standard. The lifetime of LED armatures also varies due to this difference. For example; if the same LED armature is used with two different contactors used in this study, one contactor will be used for a longer time than the other. This situation is also against the LED armature manufacturer and will reflect on the quality of the armature it produces.

### Suggestions for Solutions Based on the Results of the Experiment:

According to the results that we obtained from the experiments, serious problems such as contact burnout may occur during parallel connection of driver-driven LED panels along a single line and switching them with contactors on the line. Therefore, when choosing the driver, the current limiting driver should be selected or the circuit and circuit elements mentioned below should be used together with the driver.

### ***Current limiting using PTC And NTC resistor***

LEDs, like any other semiconductor device, generate heat. Temperature control is required as high temperatures drastically shorten the life of an LED and adversely affect its brightness. It is also possible to provide temperature control in an LED lighting system with NTC (negative temperature coefficient) and PTC (positive temperature coefficient) thermistors. These thermistors are connected in series between the utility line and the LED drivers.

### ***Current-limiting using PFC converter***

PFC (power factor correction) converters are integrated circuits that contain active switching semiconductor transistors such as MOSFET, FET, IGBT specially designed to drive LEDs. The power factor, which has a value between “0-1” values, approaches “1” when used together with special PFC circuit topologies of LED drivers. This reduces the harmonics that occur in the lighting system due to reactive power and enables the system to operate more efficiently.

### **Conclusions**

LED armatures draw a short-term high current at the first start. The fires or system failures arising due to such high inrush currents can cause significant physical and non-physical damages, such as loss of life and property. This study examined the effects of inrush current on the switching elements present on the driver circuit of LED lighting systems. The destruction forming on the contact surfaces as a result of the high currents experienced by the contactor was examined by SEM. As a result of the tests carried out, the power of the LED system, the first start current, and the destruction as per the quality of the materials used on the switching elements of different brands was determined. In terms of LED usage, which will become more widespread as a result of increasing needs, high inrush current problems need to be solved. This study would contribute to the establishment of a separate international material standard for LED switching systems and the compliance of manufacturers with this standard.

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