cigre Turkey

TEPES
TURKISH JOURNAL OF ELECTRICAL POWER AND ENERGY SYSTEMS

DOI: 10.5152/tepes.2025.25028

RESEARCH ARTICLE

Determining the Optimal Copper and Brass Connector Type for High Current Generators Used in Aircraft Lightning Test

Tuğçe Demirdelen[1], Hüseyin Avni Kabasakal[1], Burak Esenboğa[1], Mirzahan Hizal[2]

[1]Department of Electrical and Electronics Engineering, Adana Alparslan Türkeş Science and Technology University, Adana, Türkiye
[2]Department of Electrical and Electronics Engineering, Ostim Technical University, Ankara, Türkiye

Cite this article as: Demirdelen T, Kabasakal HA, Esenboğa B, Hizal M. Determining the optimal copper and brass connector type for high current generators used in aircraft lightning test. *Turk J Electr Power Energy Syst.*, Published online October 20, 2025. doi: 10.5152/tepes.2025.25028.

ABSTRACT

Aircraft in the aviation sector are required to meet stringent certification criteria established by civil aviation authorities. One crucial method to assess this compliance is through high current testing, which evaluates how electrical and electronic systems respond under specific conditions. Modern aircraft are equipped with a wide array of electronic systems, making electromagnetic compatibility (EMC) a critical consideration. High current pulse generators play a key role in conducting EMC tests, ensuring that onboard systems can operate harmoniously with each other and resist interference from external electromagnetic fields. High current tests of electrical and electronic systems evaluate system performance against sudden voltage changes, electrical noise, and other electrical problems that may be encountered under normal operating conditions. High current pulse generators ensure avionics equipment's operational quality and reliability by testing pulses for these systems. This study focuses on the performance of copper and brass fasteners commonly used in high current generators. In the experiments, output signals were observed in contact made using copper and brass connectors with diameters of 10 mm, 5 mm, and 1 mm. The effect of contact type on resistance is emphasized. The study reveals that the contact type provides low contact resistance in metal-metal contacts and contributes to the contacts' longevity by reducing the welding method's oxidation effects. The results show the effects of material selection, contact shape, and type on the contact resistance, increasing the energy transmission efficiency of a low-resistance circuit. It provides important information on how to extend the contact life.

Index Terms—Aircraft, contact resistance, connectors, high current generators, lighting test

I. INTRODUCTION

Multiple lightning strikes pose a risk to various components of an aircraft, including the radome, tail stabilizers, control mechanisms, and surfaces. Factors such as the frequency, altitude, and specific regions of impact are crucial for designing aircraft and defining lightning environments. Statistical analysis reveals that commercial aircraft experience an average of about two lightning strikes per year, occurring approximately every 3000 flight hours. Lightning strikes are most common at cloud level or below, making aircraft more vulnerable during take-off and landing. Reciprocating airplanes, operating at lower altitudes of 10 000 to 15 000 feet, face a higher risk of lightning strikes compared to turbojet and turboprop aircraft [1]. Lightning-induced damages account for over 17% of recorded aircraft damages, making them a significant component of maintenance and repair costs [2]. With aircraft manufacturers increasingly utilizing composite materials in aircraft structures, understanding the potential for composite damage is crucial. The Boeing 787, for example, relies heavily on composites, with a 50% composite structure by weight. Despite the advantages offered by composites, such as fuel and weight savings, as well as extended maintenance intervals due to corrosion resistance, it's essential to recognize the potential risks associated with lightning damage and its implications for maintenance costs over the aircraft's lifespan [3]. Aircraft damage from lightning strikes is categorized as either direct or indirect effects [4]. Direct effects refer to the damage caused directly to aircraft components by the lightning strike itself, while indirect effects pertain to the impact of the lightning's magnetic field generated by the current. It's crucial to assess lightning characteristics and its effects, as well as the resulting lightning environment, considering both direct and indirect effects [5]. As the quantity of electronic equipment aboard aircraft rises, susceptibility to lightning strikes similarly increases. Consequently, there's a growing necessity for protective measures. Initially, to mitigate the indirect effects on avionic equipment, current components were installed while the equipment was linked to

Corresponding author: Burak Esenboğa, e-mail: besenboga@atu.edu.tr

Received: July 8, 2025
Revision Requested: July 9, 2025
Last Revision Received: August 18, 2025
Accepted: August 21, 2025
Publication Date: October 20, 2025

the aircraft. Subsequently, these assessments transitioned to being conducted independently of the aircraft. This evolution brought about benefits such as the ability to design equipment separately from the aircraft and install it in preferred locations [6, 7]. Ensuring accurate outcomes in high-voltage tests involves reducing human error, with the automation of high-voltage systems emerging as an intriguing area of focus [8]. However, it's essential to adequately shield electronic components intended for automation applications due to the potential for significant noise generation resulting from the high voltage and current involved [9].

High current generators are critically important equipment widely used in the defense industry and energy sectors. Fig. 1 shows that a high current generator was used in the arc entry test of the aircraft.

The purpose and focus of this high current testing are to observe the current flowing from the arc point to the aircraft structure. These generators are designed to produce electrical energy at high power and reliably. However, the performance and reliability of these high-power generators may depend on the quality and contact resistance of the fasteners used. Metals such as copper and brass are the main components of fasteners commonly used in high current generators. The properties of these metal alloys can affect the contact resistance and therefore affect the performance and reliability of the generator. Copper can provide high conductivity and low contact resistance. Brass, on the other hand, can provide advantages in terms of both cost and corrosion resistance. Contact resistance is a critical factor for performance and safety in high current generators. High contact resistance can lead to energy loss and reduced efficiency of the generator, while low contact resistance can provide reliable and efficient electrical transmission. Therefore, the correct selection of materials such as copper and brass and regular monitoring of fasteners are important to ensure the long-lasting and reliable operation of the generator.

The contact between high current generators and materials science can be found in a variety of application areas and testing purposes. High current generators are often used in high-voltage testing, especially on electrical insulation. Materials science contributes to the development of more effective insulation materials by studying the properties, durability, and electrical performance of insulation materials under high voltage. Generators used for high-voltage tests often require special conductors and materials. In this context, materials science can work on the development of durable conductive materials that can operate under high voltage. High current generators can

Main Points

- The study highlights the significance of contact surface area, surface smoothness, and connector diameter on resistance values.
- The study examines the electrical and corrosion resistance characteristics of copper and brass, influencing their suitability in high current applications.
- The study analyzes how commonly used materials like copper and brass affect contact resistance in high current generator contact.

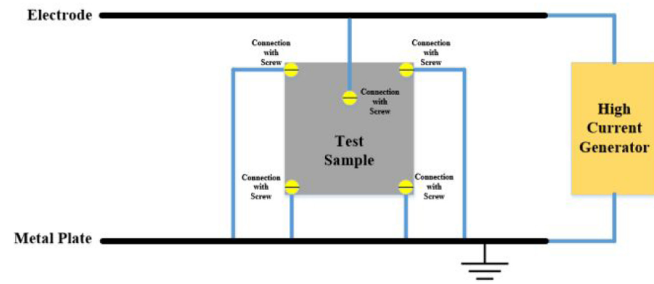

Fig. 1. Arc entry testing setup utilizing the high current generator.

be used to identify failure points of materials and test their durability. Such tests provide materials scientists with the opportunity to understand how materials behave under high current and make improvements. High-voltage generators can be used to evaluate the properties of dielectric materials. This could help materials scientists understand the aging processes of dielectric materials under high currents and improve the long-term performance of these materials. The interactions of electromagnetic fields on materials can be tested through high-voltage generators. This allows materials scientists to evaluate the resistance of materials to electromagnetic fields and make improvements in electromagnetic compatibility issues. At the same time, materials science is also important for the aviation industry.

The use of aluminum and its alloys in the defense industry has revealed the necessity of special designs. Considering the properties of different alloys, it is important to select appropriate alloys to meet the various demands of military vehicles. Additionally, welding processes and joining methods are also important for high-strength aluminum alloys [10]. It is also stated that carbon-based nanomaterials have attracted great attention from the scientific community as a source of high-strength and multifunctional composite materials [11].

Measuring contact resistance is important for testing and developing contact materials required for various operating conditions and applications. The value of contact resistance is a critical factor in the design of a contact system and should be as low as possible to minimize heat loss. The magnitude of the contact resistance is affected by several factors, such as material properties (electrical conductivity), the presence of impurities, oxides, and chemical layers, as well as the form of contact (point, line, and surface) [12]. In contact resistance measurements, two effective methods are used to avoid any mechanical or electrical damage to the surface layer. First, is the crossbar arrangement under very low mechanical and electrical load; the other is gold probe measurements [13]. Copper is widely preferred in fasteners due to its superior conductivity properties. However, in the process of operation, the contact surface of the fasteners can wear significantly, resulting in the deformation of the electrical contacts [14]. Pin-Chun et al. investigated metal-induced gap states (MIGS) at metal–semiconductor interfaces in 2D semiconductors, which cause Fermi level pinning and Schottky barriers. Using a semi-metallic bismuth contact with monolayer MoS_2, WS_2, and WSe_2, they suppressed MIGS, achieved zero Schottky barrier height, a record-low contact resistance of 123 Ω·μm, and a maximum current density of 1.135 µA/µm [15]. Cian Gabbett et al. developed a model to measure and reduce junction resistance in nanowire, nanotube, and nanosheet networks. The method extracts junction and particle resistances from DC and AC impedance data, showing junction resistance ranges from 5 Ω (Ag nanosheets) to 24 GΩ (WS_2 nanosheets). For aligned MoS_2 nanosheet networks, low junction resistance (~2.3 MΩ) enables high carrier mobility (≈7 $cm^2 \cdot V^{-1} \cdot s^{-1}$), while temperature-dependent analysis distinguished phonon-limited transport from hopping conduction [16]. M.F.R. Zwicker et al. highlighted the electrical and mechanical significance of battery cell joining methods in EV packs, examining ultrasonic welding, soldering, laser welding, resistance welding, and less common techniques like friction stir welding. They evaluated how these methods influence performance, capacity, lifespan, and manufacturing considerations [17]. Jordi-Roger Riba and Pau Bas-Calopa studied the effect of contact pressure on joint resistance in aluminum and copper, using measurements, calculations, and simulations to separate resistance component contributions [18].

This article focuses on contact resistance in high current generators, specifically the effect of copper and brass fittings. The main contributions of this article can be summarized as follows:

The effect of copper and brass, commonly used materials in fasteners, on contact resistance was analyzed.

- Electrical resistance and corrosion resistance of brass and copper are discussed.
- Contact resistances of copper are determined using the Holm model.
- The effect of the contact type in terms of affecting the resistance is examined and the importance of surface smoothness and contact area is emphasized. It is emphasized how copper connectors of different diameters can affect the contact resistance under high currents.
- It has been stated that in metal-oxide contact, the oxide layer can increase the resistance and therefore affect the contact resistance.

The study reveals critical factors for electrical engineering applications, highlighting the effects on material selection, contact shape, and type that affect contact resistance. It is emphasized to ensure low contact resistance, increase energy transmission efficiency, and ensure long-lasting and reliable operation of the contact.

II. METHODOLOGY

Analytical models for calculating contact resistance are developed based on the understanding that when current flows between two conductive components, it passes through a specific metallic contact surface with a defined geometry. This contact spot, known as the a-spot, causes constriction resistance (R_c). Several models exist to describe this resistance. A widely accepted one is the ellipsoidal model proposed by Holm [19]. The ellipsoidal model assumes that the contact spot has an elliptical shape, with the major axis being larger than the minor axis. This model considers the dimensions of the contact spot and the material properties of the conductive components to calculate the constriction resistance. By considering the geometry of the contact spot, this model provides a more accurate estimation of the contact resistance compared to other models. The constriction resistance is presented in Equation (1) [19].

$$R_c = p / 2a \tag{1}$$

where p (Ω·m) is the resistivity of the contact material and a is the radius of the contact surface. If metal surfaces are not clean, thin layers of oxides, sulfur and other inorganic substances, which are often found on the metal contact surface, can affect the passage of electric current. This affects the total contact resistance (R_S) of the contact, which is the result of the sum of the constricted resistance (R_C) and the film resistance (R_f). Film resistance defines the resistance resulting from the formation of unwanted resistive material ("film") on the surface of a contact. This usually occurs because of the buildup of oxides, sulfur and other inorganic substances. The total contact resistance and the sum of the constricted resistance are presented in Equations (2) and (3), respectively [19].

$$R_f = \sigma f / \pi x a^2 \tag{2}$$

Where σ_f (Ω·m^2) is the resistance per film area.

$$R_s = R_{c+} R_f \tag{3}$$

In this study, two different materials are analyzed. Stainless steels are used for durable resistors used in high current generators. Stainless steels relate to circuit contact equipment. The material type, contact shape, and contact type are factors that affect contact resistance.

A. Material Type

The copper and brass materials are selected as contact equipment in this study. The importance of using copper as a fastener is based on many factors, and these factors generally focus on properties in electrical engineering and power transmission systems. The specific electrical resistance of copper is quite low (1.68 × 10^8 Ω.m). This means that copper can conduct electric current with high efficiency. The resistance-current-voltage relationship highlights the advantages of copper's low resistance. Low resistance means less energy loss and more efficient energy transmission. Copper has good mechanical strength. This feature increases the resistance of fasteners against physical stress. Copper has high thermal conductivity. This feature means that copper can conduct heat quickly and the heat in electrical contact remains low. High currents convert energy into heat. Therefore, the conduction of heat should not remain at a single point. Otherwise, melting and disintegration may occur. Copper is resistant to atmospheric conditions and resistant to corrosion. This feature ensures the long life of copper fasteners. The electrical conductivity of brass is not as high as copper (0.00000016 Ω.m). This means that brass may be a slightly weaker conductor of electrical current. The thermal conductivity of brass is lower than copper. This causes the temperatures that will occur because of high current to cool down later. Since brass is an alloy of copper and zinc, it has better corrosion resistance than copper. This feature makes brass more durable in various environments. Brass has higher mechanical strength than copper. This indicates that brass has a better resistance to physical stress. The advantages of using brass as a fastener can be particularly focused on properties such as corrosion resistance and mechanical strength. Although it is slightly inferior to copper in terms of electrical conductivity, there are situations where these properties may be more important in certain applications.

The most important criterion in terms of contact resistance is conductivity. Therefore, corrosion and temperature conditions were neglected in the simulation. The contact materials are selected from copper and brass with a diameter of 10 mm. Figs. 2 and 3 present the circuit diagram of these materials.

Contact resistances are expressed that the copper resistance is 1.68 × 10^6 Ω, and the brass resistance is 0.8 × 10^3 Ω. The contact resistance can never be measured exactly in real life. DC may change instantly. But thanks to the Holm model, it can be expressed mathematically.

B. Contact Shape

The shape of the material can affect the contact resistance, and in particular, the shape of the contact points, surface smoothness, and contact area can be decisive on this resistance. The formulas and models used to determine contact resistance are often more complex and may vary depending on the specifics of the application. Contact resistance can be expressed by various formulas and models based on basic principles of electricity and magnetism. Factors affecting contact resistance include many variables such as contact area, contact length, surface smoothness, material properties, and temperature. Therefore, if a specific joint resistance formula is to be used, it is usually determined specific to the application context and material properties. Particularly in electronic devices and microelectronic applications, specific contact resistance formulas and models can be found in the literature and engineering design guides. These models are developed considering material properties and application requirements and are often based on experimental data.

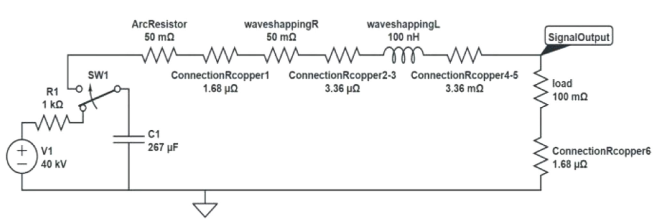

Fig. 2. Circuit diagram featuring copper connector with a diameter of 10 mm.

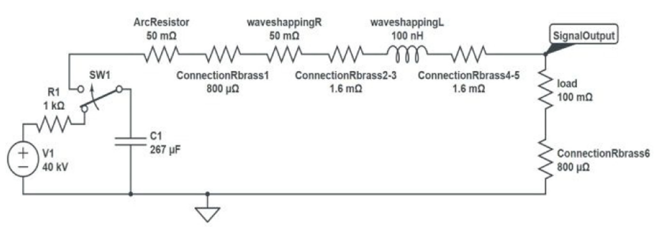

Fig. 3. Circuit diagram featuring brass connector with a diameter of 10 mm.

A flat material surface can generally lead to a larger contact area and lower joint resistance. However, a pointed or rounded material surface may have a smaller contact area, which can increase joint resistance. Additionally, surface smoothness can also affect joint strength; rough surfaces can reduce the contact area, which can increase joint resistance. Therefore, the contact between the shape of materials and the contact resistance plays an important role in material selection in electronic devices and electrical contact. In this case, problems may arise at high currents between a 10 mm diameter copper connector and a 1 mm diameter copper connector. Fig. 4 presents the different size fasteners.

The contact resistance of the first contact equipment (diameter = 1 mm) will be 16.8 × 10^6 Ω, while the contact resistance of the other contact equipment (diameter = 10 mm) will be 1.68 × 10^6 Ω given in Fig. 2. The contact of small space equipment to the circuit is shown in Fig. 5.

C. Contact Type

The type of contact is a factor that determines how contact between two materials is established and maintained. Metal-to-metal contacts generally have low contact resistance because metals are generally good conductors and tend to conduct electrical current well because electrons can move freely. Contact between metal surfaces is generally smooth and tight, contributing to low contact resistance. However, metal-oxide contacts involve the contact of a layer formed due to the oxidation of metal surfaces. This can increase contact resistance because the oxide layer can make it difficult for electric current to pass. However, in some cases, this oxide layer can also function to protect the contact and reduce resistance. The oxide layer can increase friction between fasteners.

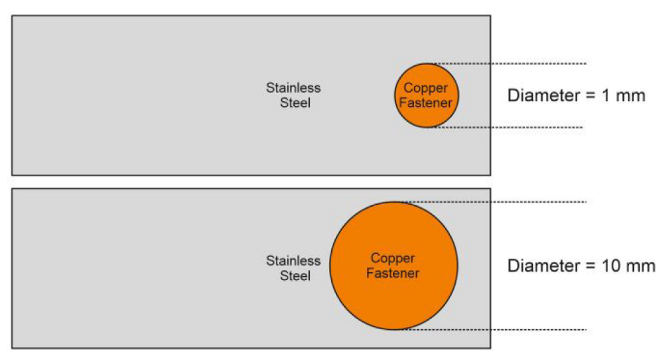

Fig. 4. Different size fasteners.

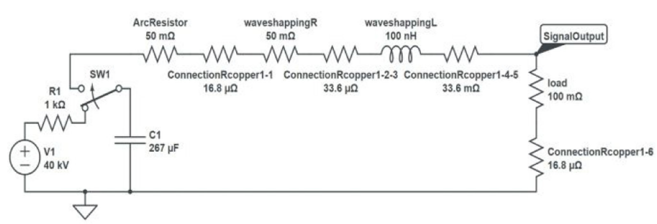

Fig. 5. Circuit diagram featuring copper connector with a diameter of 1 mm.

Friction can increase torque resistance, making it harder for the bolt or nut to turn. Increased torque resistance caused by oxidized surfaces may result in fasteners not being sufficiently tightened. This may cause the contact to be unstable and the contact resistance to increase. Applying excessive torque to the fasteners due to the oxide layer may damage the fasteners or cause them to loosen. When all these problems are taken into consideration, the R_f value begins to increase. Welding has been seen as the best solution to tolerate the oxidation effect.

The welding process usually involves melting the materials being bonded, which helps remove the oxide layer and create a smooth surface. This makes the contact more effective and smoother. Weld joints generally have low electrical resistance because the contact between materials is more accurate and the increase in resistance due to oxidation can be minimized.

III. RESULTS

Contact resistance, distinct from the circuit's internal resistance, arises at points where mechanical contacts are made within the circuit. This type of resistance can occur due to loose contact, improper tightening of bolts in bolted joints, wear on contact surfaces, or contamination and oxidation of these surfaces. Such contact resistance contributes to the total circuit resistance and results in power loss. To prevent issues like spark formation, phase loss, or even fires due to significantly increased contact resistance, regular maintenance of contact is crucial. Frequent tests can cause wear, deformation, or pitting at these contact points, leading to higher resistance and subsequent voltage and current drops.

In this paper, the selection of copper and brass materials as contact equipment was focused on and their effects on the properties of these materials were examined. It has been stated that copper has low electrical resistance, good mechanical strength, high thermal conductivity, and corrosion resistance. The reasons why copper is preferred especially in electrical engineering and energy transmission systems are emphasized. Although brass has lower electrical conductivity than copper, it has better corrosion resistance and mechanical durability properties. When conducting an experiment examining the effects on contact resistance, the copper and brass fasteners were selected with a diameter of 10 mm. The contact resistances are expressed mathematically using the Holm model. According to this model, copper contact resistance is determined as 1,68x10-6 Ω and brass contact resistance is determined as 0.8 x 103 Ω.

The output currents of the high current generator charged at 40 kV DC are given in Figs. 6 and 11.

According to the results, when a copper connector with diameter of 10 mm was used, the output current of the high current generator was measured as 193.1 kA. When the same circuit was installed with brass connectors, the output current was measured as 188.1 kA. This shows that when the output current observed in the circuit is established with brass connectors, the current loss is approximately 5 kA. In practice, this loss is observed in real life as a spark or arc explosion shown in Fig. 12. The results show that connectors can affect the output current depending on the material type and that this effect can be significant enough to be observed in practice.

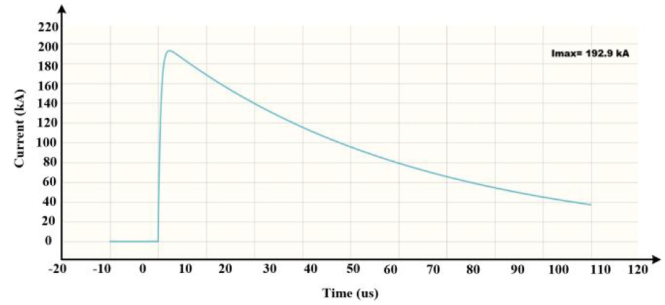

Fig. 6. Output signal of the high current generator using a copper connector with a diameter of 1 mm.

The contact type, surface smoothness, shape of the contact points, and the effect of the contact area on the resistance are important. At high currents, the use of copper connectors of different diameters increases contact resistance. This negatively affects the output current. Small areas of contact elements used in high current generators reduce the output current due to high resistance. The connectors with small areas (diameter = 1 mm) that create more resistance in high current generators have a negative effect on the output current. A loss of approximately 100 A can be mentioned. Additionally, although spikes control the electric field more effectively, they can also create more sparks at higher voltages. It has also been stated

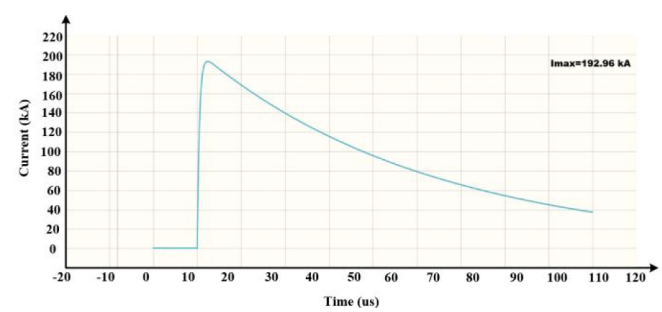

Fig. 7. Output signal of the high current generator using a copper connector with a diameter of 5 mm.

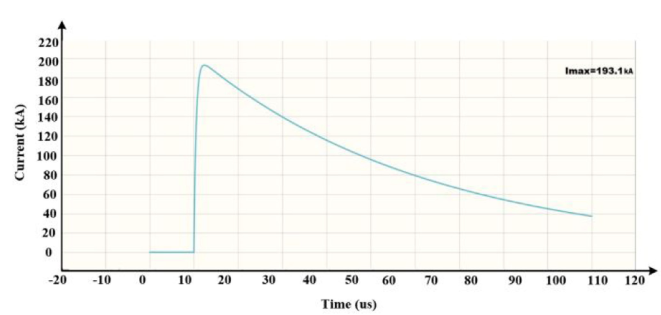

Fig. 8. Output signal of the high current generator using a copper connector with a diameter of 10 mm.

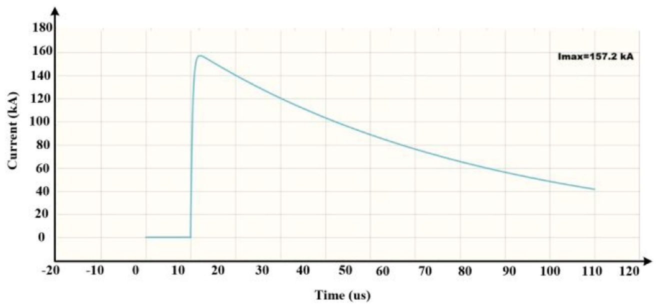

Fig. 9. Output signal of the high current generator using a brass connector with a diameter of 1 mm.

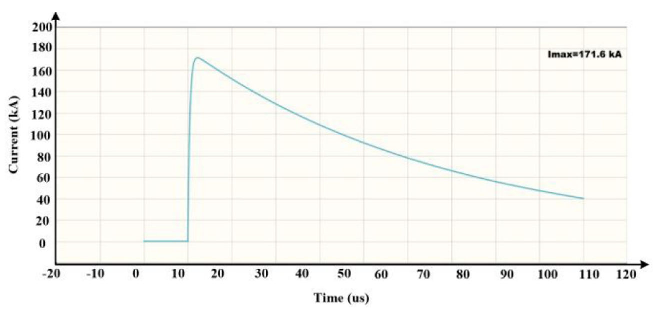

Fig. 10. Output signal of the high current generator using a brass connector with a diameter of 5 mm.

that although spikes control the electric field more effectively, they can create more sparks at higher voltages

It has been stated that the contact type provides low contact resistance, especially in metal-metal contact. Also, in metal-oxide contact, the oxide layer can increase resistance and therefore affect contact resistance. The welding method is a good solution against the oxidation effect, and welded joints are effective in tolerating the oxidation effect.

The effects of material selection, contact shape, and contact type on contact resistance highlight factors that are important in electrical engineering applications. Keeping the contact resistance low is important to increase energy transmission efficiency and ensure the

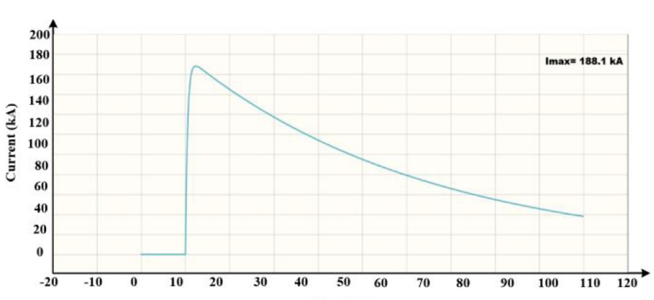

Fig. 11. Output signal of the high current generator using a brass connector with diameter of 10 mm.

Fig. 12. Sparks occurred due to copper contact resistance.

long life of the contact. Considering these factors, a smooth working circuit can be established as in Fig. 13.

While setting up the circuit, processes were carried out for low contact resistance as mentioned in this study. The contact elements used for the contact of the copper bars coming from the high current generator and the stainless steel used as resistance were selected as copper. In addition, the contact surface of the copper bar and the stainless steel were adjusted to be R = 10 mm, 25 π mm^2, thus minimizing the contact resistance. Finally, the copper connector elements were fixed to the stainless steel by welding and, in addition, the copper bars surface was sanded to clean any oxidation that may occur on the surface of the copper bars.

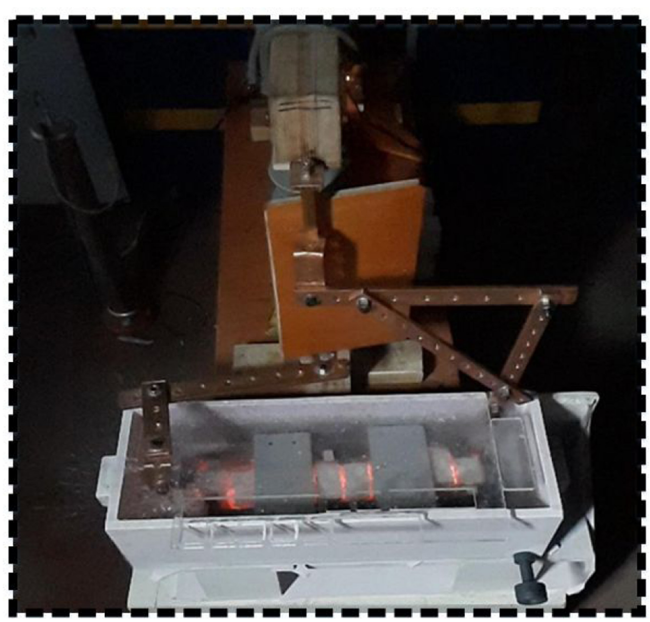

Fig. 13. No sparks occurred by contact resistance.

IV. CONCLUSIONS

This paper presents important results, focusing on high current tests and specifically the performance of copper and brass fasteners. The research highlights the critical role of high current tests in assessing the reliability of electrical and electronic systems and explains how these tests help determine compliance with certification standards in the aerospace industry. The methodology section examines the various factors that affect joint resistance and highlights the importance of material type, joint shape, and joint type. Using analytical models such as the Holm model, contact resistance is expressed mathematically, and the performance of copper and brass fasteners is examined comparatively. The research shows how material selection affects output current by observing the output currents of high current generators. It also focuses on the effects of contact shape, highlighting how fasteners with small areas can cause high resistance, which can reduce output current in high current applications. The research highlights the effects of material selection, contact shape, and contact type on contact resistance, revealing important factors in electrical engineering applications. Consideration of these factors can contribute to the development of optimized and reliable contact systems. This study provides valuable information to inform and guide those working in the field of high current tests and electrical engineering.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – T.D., M.H.; Design – H.A.K., B.E.; Supervision – T.D.; Resources – H.A.K., M.H.; Materials – H.A.K., M.H.; Data Collection and/or Processing – T.D., H.A.K.; Analysis and/or Interpretation – H.A.K, B.E.; Literature Search – H.A.K., B.E.; Writing – T.D., H.A.K, B.E., M.H.; Critical Review – T.D., B.E.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declare that this study received no financial support.

REFERENCES

1. E. Rupke, *Lightning Direct Effects Handbook*. Pittsfield: Lightning Technologies Inc., 2002.
2. E. C. Kiçeci, and E. Salamci, “Uçak-yıldırım Etkileşimi,” *Avrupa Bilim Teknoloji Dergisi*, (Özel Sayı), pp. 177–187, 2020. [CrossRef]
3. J. B. O’Loughlin, and S. R. Skinner, *General Aviation Lightning Strike Report and Protection Level Study*. Office of Aviation Research, Federal Aviation Administration, 2004.
4. B. E. Claveria, “Effects and avoidance of lightning strikes on aircraft”. [Accessed: May 09, 2024]. [Online]. Available: https://zaguan.unizar.es/record/5149/files/TAZ-PFC-2010-220.pdf.
5. D. Djalel, H. Ali, and C. Faycal, “The return-stroke of lightning current, source of electromagnetic fields (study, analysis and modelling),” *Am. J. Appl. Sci.*, vol. 4, no. 1, pp. 42–48, 2007. [CrossRef]
6. Y. Sim, T. Ahn, J. Park, J. Han, and S. Yang, “Development and verification of lightning induced transient protection device for avionics computer,” *J. Adv. Navig. Technol.*, vol. 19, no. 5, pp. 395–402, 2015. [CrossRef]
7. Y. Sim, S. Cho, S. Kim, J. Park, and J. Han, “Design of lightning induced transient protection circuit for avionics equipment considering parasitic inductance,” *J. Adv. Navig. Technol.*, vol. 21, no. 5, pp. 459–465, 2017. [CrossRef]
8. F. Abdolalizadehgharehveran, “An automation of high voltage impulse generator,” M.S. thesis, Graduate School of Science and Engineering, Istanbul Technical University, 2013.
9. H. F. Aydoğan, S. Sungur, O. M. Yücedağ, and H. A. Serim, “Yüksek güçlü geçici elektromanyetik gürültü Kaynağının tasarımı, üretimi ve Ölçümü,” ELECO 2018, Turkey, 2018.
10. S. Ç. Çağan, M. Uğurlu, B. B. Buldum, and İ. Sevim, “Alüminyum ve alaşımlarının asker araçlarda kullanımı,” *II Uluslararası Savunma Sanayi Sempozyumu (IDEFIS)*, Kırıkkale, TÜRKİYE pp. 402–406, 2017.
11. M. M. Harussani, S. M. Sapuan, G. Nadeem, T. Rafin, and W. Kirubaanand, “Recent applications of carbon-based composites in defence industry: A review,” *Def. Technol.*, vol. 18, no. 8, pp. 1281–1300, 2022. [CrossRef]
12. T. Hatakeyama, R. Kibushi, M. Ishizuka, and T. Tomimura, “Fundamental study of surface roughness dependence of thermal and electrical contact resistance,” 15th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), Las Vegas, NV, USA, 2016, pp. 1078–1082. [CrossRef]
13. R. Puyol, and S. Suárez, *A Contact Resistance Measurement Setup for the Study of Novel Contacts*. Montevideo, Uruguay: IEEE URUCON, 2017, pp. 1–4. [CrossRef]
14. V. V. Fadin, M. I. Aleutdinova, and A. V. Kolubaev, “Effect of high-density electric current on wear and average temperature of steel/steel tribo-electric contact,” *J. Frict. Wear*, vol. 39, no. 4, pp. 294–298, Jul. 2018. [CrossRef]
15. P.-C. Shen et al., “Ultralow contact resistance between semimetal and monolayer semiconductors,” *Nature*, vol. 593, no. 7858, pp. 211–217, 2021. [CrossRef]
16. C. Gabbett et al., “Understanding how junction resistances impact the conduction mechanism in nano-networks,” *Nat. Commun.*, vol. 15, no. 1, p. 4517, 2024. [CrossRef]
17. M. F. R. Zwicker, M. Moghadam, W. Zhang, and C. V. Nielsen, “Automotive battery pack manufacturing–a review of battery to tab joining,” *J. Adv. Joining Processes*, vol. 1, p. 100017, 2020. [CrossRef]
18. J.-R. Riba, and P. Bas-Calopa, “Analysing the pressure effect on the contact resistance of electrical connections,” *Eur. J. Phys.*, vol. 43, no. 3, p. 035806, 2022. [CrossRef]
19. P. Kacor, P. Bernat, T. Mlcak, and L. Hrabovsky, “Realization of a test tool for diagnosis of contact resistance and measurement of selected types of conductive materials,” *Sensors (Basel)*, vol. 23, no. 13, p. 5867, 2023. [CrossRef]