Characterization of a Metallic Pearl-like Necklace stroked by lightning: *preliminary results*

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***Abstract*— Lightning accidents are frequent in Colombia. In the present investigation, a non-fatal accident is analyzed. For a better understanding of the accident, it was replicated in the laboratory a part of a reported case, in which a soldier, wearing a metallic identification pearl-like necklace, was struck by an indirect lightning current. Different 8/20 µs lightning impulse current amplitudes were applied to similar necklaces in order to determine its electrical parameters, such as dynamic resistance, the absorbed energy and the maximum withstand current. The preliminary experimental data obtained through the application of 8/20 lightning current impulses applied to necklaces is analyzed for a technical insight of the event.**

Keywords- Lightning accidents; Experimental simulation of lightning accidents in Colombia; current impulse in a metallic necklace.

I. Introduction

Colombia is one of the countries in the world with the largest lightning density [1], affirmation supported by several lightning maps indicating flashes per square kilometer per year as the ones shown in [2].

Events reported by the Direction of Integrity Preservation and Security of the Colombian Army (DIPSE), show statistics from 2003 to 2012, in which almost one of two lightning accidents results in mortal consequences [3]. One of these accidents with nonfatal results, identified as Case B in [3], is the object of present study. In Case B an indirect lightning current struck the metallic identification necklace weared by a Colombian soldier. The necklace was overheated and left burning marks around the neck's soldier as it is shown in Fig. 1.

The dynamic resistance of a similar pearl-like metallic necklace as the one wore by the victim during the accident, the maximum energy liberated by the lightning current and the highest lightning current that the necklace can withstand are investigated in the present research work.

II. Background

A lightning flash to ground is defined as an electrical discharge of atmospheric origin between cloud and ground, consisting of one or more strokes [4]. Most of lightning discharges are downward negative ground flashes, initiated by

Figure 1. Injuries in the nape of the soldier caused by indirect lightning stroke [3]

an electrical breakdown in the clouds, forming a column of charge and traveling from cloud to ground [5].

A. *Specific energy*

The liberated energy by the impulse is proportional to the charge transported by the current i and it is defined as the time integral of the square of the lightning current i for the entire flash duration as:

$$\frac{W}{R} = \int i^2(t)dt. \quad (1)$$

B. *Joule Heating*

Joule heating makes reference to resistive heating. It describes the process where the energy of an electric current is transformed into heat when flows through a resistance [6]. Thus, the thermal energy liberated W by the current impulse is therefore the ohmic resistance of the lightning flash through the conductor (the necklace for this study) as follows,

$$W = R\int i^2(t)dt \quad (2)$$

III. Case Scenario

The scenario described in [3] and shown in Fig. 2, reports a Colombian soldier wearing an institutional stainless steel pearl-

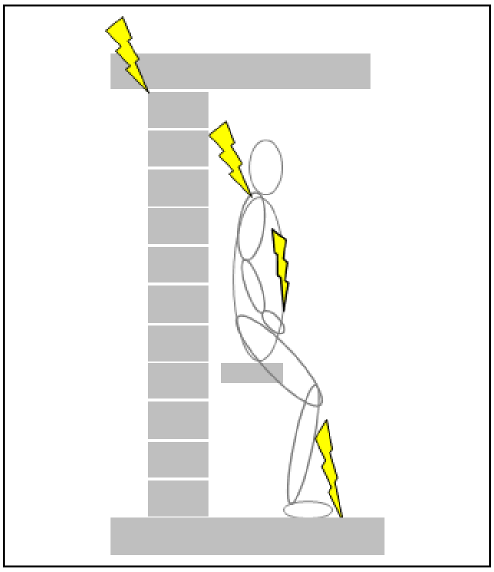

Figure 2. Representation of a man inside a sand-bag sentry box with the possible path of the current stroke [3]

like identification necklace (dog tag in ball chain type), scarf and warm clothes. The victim was inside of a sentry box made of sand bags, which is a high resistance material. The soldier was in a sitting posture in the moment of the stroke. A lightning flash struck the sentry box's roof, which had a metal plate on the roof, which was used as rain protection. The current flowed through the sentry box sand wall, splitting and reaching the soldier necklace. The necklace was overheated and melted, leaving the burning marks around the victim's nape shown in Fig. 1. The surface discharge could have saved the soldier's life, creating a path for the current to flow and avoiding the indirect lightning current to enter in his body.

A. *Structure of the necklace*

The identification metallic ball necklaces (ID dog tag) used by Colombian army soldiers are built by spherical shells and cylindrical junction pins of stainless steel. Each end of every pin has a head of bigger diameter so the holes in the spherical shells have a minor diameter to retain the pins. This design produces a strong but light and flexible mechanical structure but with poor electrical contacts between pins and ball shells.

B. *Flashover along the necklace*

Considering the small contact surface between the necklace pieces and the instable electric contacts, the flow of an indirect lightning current becomes a flashover breaking down the air resistance. The photograph in Fig. 3, taken in the lab during a necklace test, shows how the lighting current produces an external flashover in the necklace. The charge transported to ground by the discharge determines the heating effects at the strike point [4], producing skin burnings when the hot necklace ball shells become in contact with the skin.

IV. METHODOLOGY

Due to its structure and while the necklace is conducting a lightning current, it can be considered as a dynamic resistance.

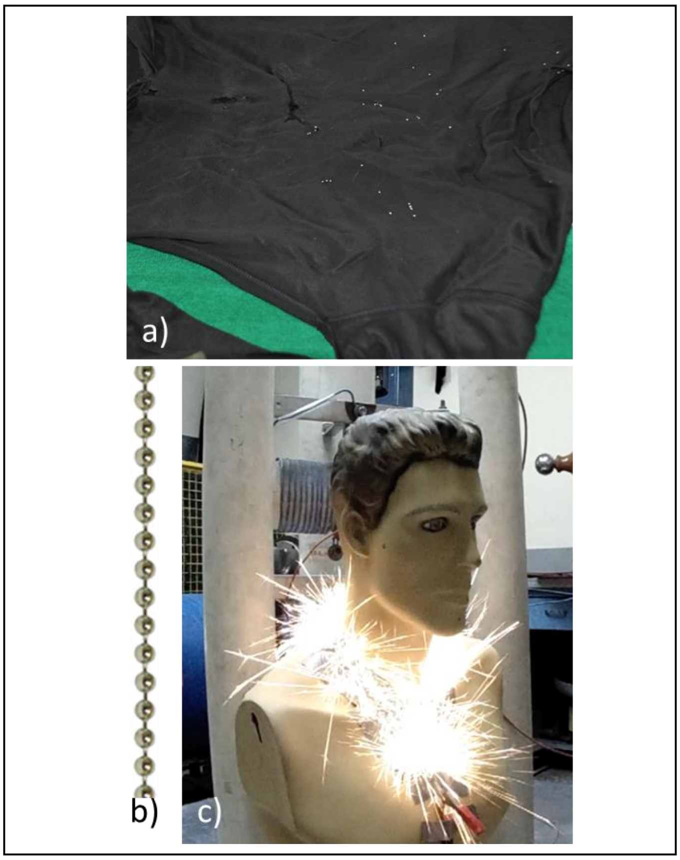

Figure 3. Sweatshirt with necklace remains after lightning struck (a), section of a typical ball chain necklace (b) and a laboratory test with flashover around chain upon a mannequin (c)

In order to understand this behavior, 8/20 µs lightning current impulses were applied to the necklace placed on a mannequin to simulate the actual position in all tests, while current and voltage were measured. This procedure was repeated several times.

A. *Impulse current circuit and measurement system*

Fig. 4 shows impulse generator circuit used to generate 8/20 µs lightning current impulses. The circuit is fed by a voltage source in series with a reversed high voltage diode as a negative high voltage source.

A 8 µF capacitor was the impulse current capacitor while a 6,9 µH inductor was used obtain the 8/20 µs lightning current

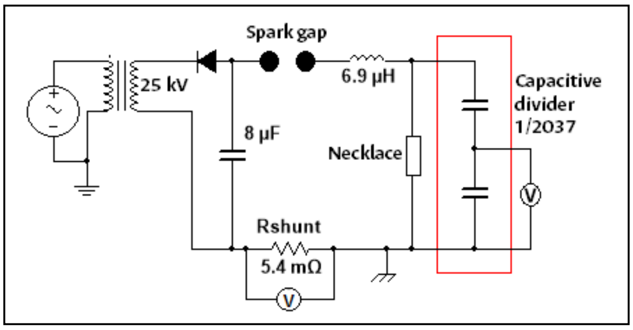

Figure 4. Schematic for the 8/20 µs impulse current generator with its measuring components. Notice the necklace position.

impulse waveform. Current was measured with a 5,4 mΩ series resistor and voltage was measured with a 1/2037 rated capacitive voltage divider. The tested necklace was connected parallel to the voltage divider. The generator discharge was made with a mechanically triggered spark-gap.

A Tektronix TDS1012B digital oscilloscope was used to capture and visualize the measured current and voltage signals. The oscilloscope was fed by an UPS for electric ground isolation from the test circuit.

To avoid measurements problems due to variations in the necklace position, the fiberglass mannequin shown in Figs. 3 and 5 was used to perform the experiments. The necklace was always tested in the same position, remembering the actual location of the necklace in the soldier's neck. In this way, inductance variations were reduced.

B. *Approach to the experimental procedure*

It was observed that the physical structure of the necklace it is modified after receiving certain number of current impulses, altering its mechanical characteristics. The heat produced by the current flow in the points where the current density increases, welded the pins at its contact point with the pearl-like spheres of the necklace. After some tests it was observed that almost all pins were welded to the little balls. This modification resulted in improved electrical contacts in the whole necklace, reducing its resistance.

During the initial experiments it was also observed that a single impulse applied to the necklace is enough to alter its mechanical and electrical properties. Therefore, just one impulse was applied to each single necklace. Five brand new necklaces were tested at different peak current values, while current and voltage signals were acquired.

Fig. 5 is a photograph of a section of the current impulse generator with the mannequin during the experimental process.

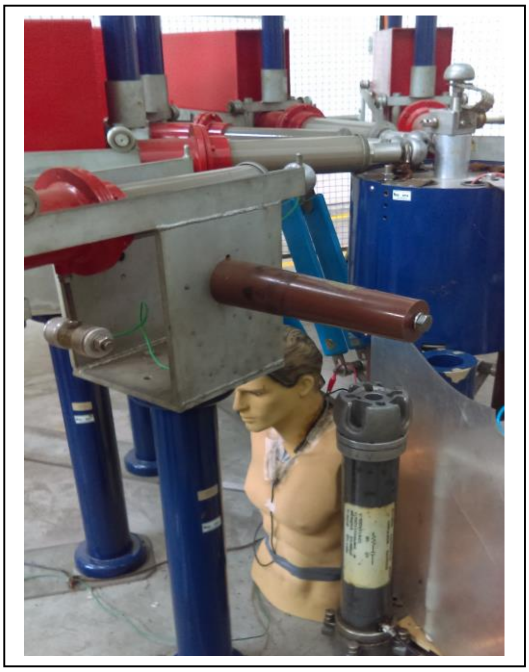

Figure 5 Section of the generator with mannequin during the experimental process

V. RESULTS

A. *Adjustement and qualitative results*

During the experiments it was observed a symmetry effect of the in the necklace connection: If the parallel necklace paths were not equally long with respect to the injection point, the current could follow different path lengths, causing a larger current density to flow in one of the paths producing different physical changes in the necklace. This could cause that one part of the necklace will be more affected by the temperature rise than the other. For example, when a 9,8 kA lightning current impulse is applied to a necklace with differences in the parallel connection, the shorter path shown a corrosion-like color while the longer path shows no appreciable changes. In the case of the 10,3 kA lightning impulse current experiment, one of the pins in the shorter path melted and the necklace broke in that spot, showing again a corrosion-like color in the shells close to the melted pin. A 17,4 kA lightning current impulse breaks down the necklace fragmenting it in pieces due to the molten pins.

B. *Current and Voltage measurement for different levels of peak current*

For the five necklaces analyzed, impulse currents between 9,8 kA and 18,4 kA were applied. Fig. 6 shows the acquired voltage and current signals when a 18,4 kA, 8/20 µs lightning current impulse was applied to the test object. The maximum voltage amplitude was 22,4 kV, corresponding to a resistance value of 1,2 **Ω** at the current crest value at 9 µs. Fig. 7 shows the characteristic resistance of the necklace obtained by dividing the voltage signature by the current. In Fig. 7 it can be observed a continuous reduction of the resistance in the whole event. Also in Fig. 8 the acquired current and voltage waveforms for the 14.5 kA lightning current impulse are presented. The crest of current and its corresponding voltage are highlighted and the resistance calculated for the maximum current is 1,32 **Ω**.

C. *Absorbed Energy and Resistance*

With the collected data, the specific and absorbed energy in the current crest are calculated using equations (1) and (2). The estimation of absorbed energy was limited to the specific energy of the impulse applied to the resistance value calculated at the maximum current amplitude, where di/dt is zero and the magnetic effect is negligible. The synthetic results of current, resistance and absorbed energy as a function of the applied current amplitude are shown in the histogram of Fig. 9.

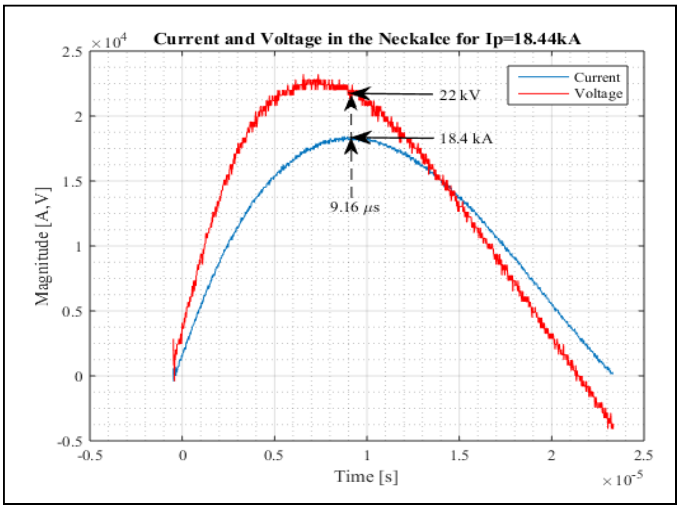

Figure 6. Current and voltage signals for 18 kA peak current test

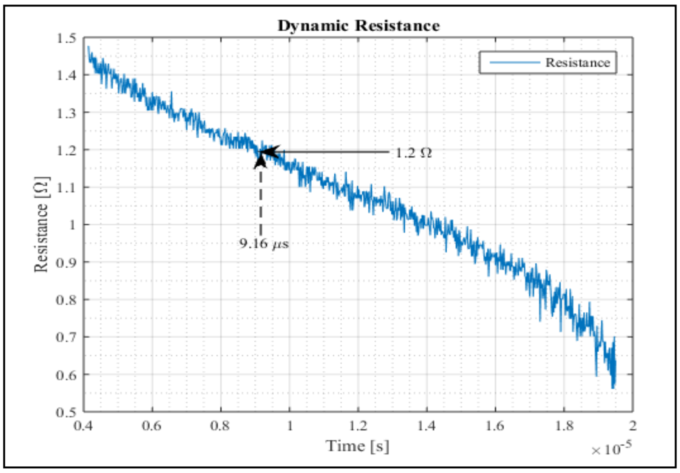

Figure 7. Dynamic resistance for the necklace with corresponding crest current resistance measured when a 8/20 µs current impulse of 18 kA was applied to the stainless steel ball chain necklace

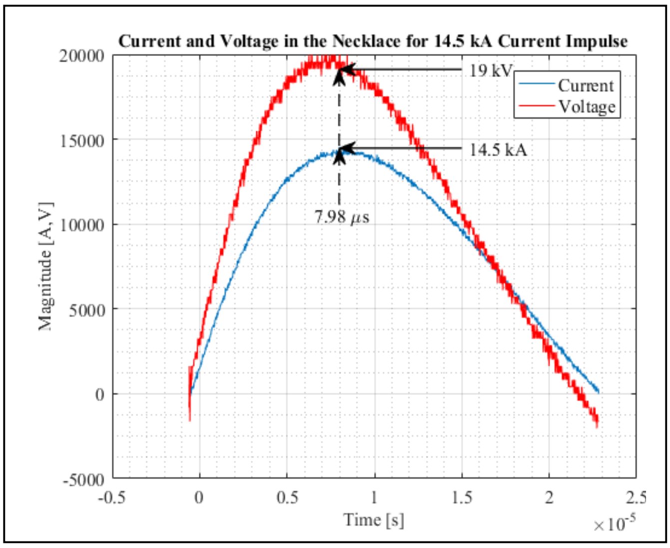

Figure 8. Current and voltage signals for 14,5 kA peak current test

The resistance mean value obtained from all experiments gives 1,3 Ω with a standard deviation of 0.05 Ω. The behavior shown in Figs. 7 - 8 suggests that the resistance at the current peak is independent of the current peak magnitude. The specific energy and the absorbed energy given by equations (1) and (2), should increase as the current increases. Thus, the specific energy varies between 892 J/Ω to 4000 J/Ω proportionally with the absorbed energy as shown in Fig. 9.

Moreover, as it can be seen in the figures 6 and 8 the current lags the voltage, attributable to certain inductive characteristics of the setup and the necklace, however further research about this is needed.

VI. Conclusions

The resistance of a metallic pearl-like necklace involved in a lighting accident was obtained. A dynamic behavior of the necklace resistance was observed, showing that the necklace

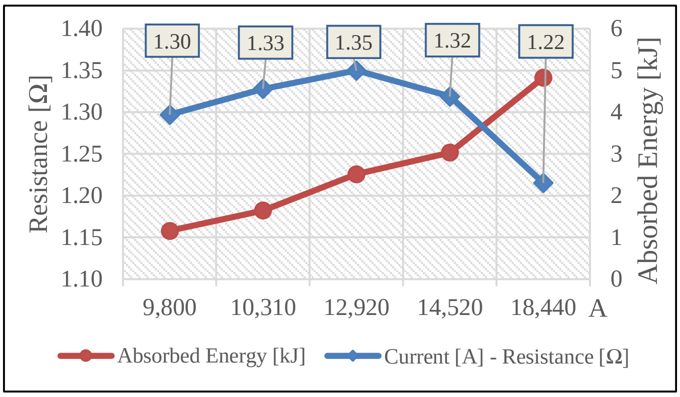

Figure 9. Peak currents for five necklaces (horizontal axis), corresponding resistance with the peak current (left vertical axis) and absorbed energy (right vertical axis). The highlighted value of resistance is related to the peak current presented in each experiment. All reported data is referred to current parallel paths through both sides of the necklace since impact point.

resistance reduces during the whole impulse, reaching a value close to 1Ω.

The presented experiments contribute to the understanding of lightning accidents when lightning currents impact persons wearing a metallic necklace.

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