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Technical Paper

Experimental investigation of aluminium–copper wire crimping with electromagnetic process: Its advantages over conventional process

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ABSTRACT

Crimping of lugs to wire strands is a crucial part in electrical power transmission process. Improper design increases the resistance of current flow through terminals and causes problems like power loss, spark and heating in the joint. Which affect many industries like shipping, automobile, aerospace, satellite and communication where cable connections are used in large quantities. Electricity distribution boards faces similar problems during generation due to improper connection. To overcome these problems in conventional crimping process a new novel technique for effective wire crimping has been proposed in this paper. A strong pulsed electromagnetic (EM) field is used in wire crimping of aluminium connector terminal with copper wire. Experiments are carried out at different discharge voltages to demonstrates the feasibility of EM wire crimping process and to study the properties. With developed method, positive results were found from EM crimped samples. The gap between aluminium connector terminal and copper wire was reduced by 70% than conventional process. The electrical resistance of EM process was decreased by 34% than conventional one. Its pullout strength is 978 N higher. The surface finish is improved as mean roughness value of 0.8 μm. The hardness was reached up to 47 $HV_{0.1}$. X- ray diffraction (XRD) technique was used to find the residual stresses in EM and conventional crimped samples. Thermal behavior is improved over conventional crimped process.

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1. Introduction

Reduction of weight with the help of cables and cable systems in a car to further reduce the car weight besides using lightweight car body materials will be a worthy challenge. Since, in a hybrid power car, cables and cable systems can reduce the total weight of the car upto 15 to 45 kg. The average length of copper cables used in light weight cars is approximately 1650 m [1]. To make light weight construction one can make use of aluminum lug instead of existing copper lug in contact sites. This will help in reduction of weight and it is an economical method without compromising the power loss.

Crimping is a process where cable is stripped and the strands of the wire are placed into a common metal terminal. The terminal is then compressed around the wire stands to ensure good electrical contact between the terminal and the wire. Crimping of dissimilar materials in order to achieve a durable joint is a difficult process and important challenges for electricity boards, electrical industries, shipping, automobiles, aviation, satellite and communication.

Crimped connector terminals under various applications are exposed to various types vibrations, temperature gradients and different electrical environment. Study carried out on electrical problems shows that more than 60% problems occurs in contact area of connectors than any other technical problem [2]. The fatigue and fracture failure, wear tear, increase in stress and energy losses are caused on the terminal connectors when exposed to most of the vibrations. Some important sources of vibrations in a vehicle are mostly due to powertrain consisting of engine, differential section and gear box. This severely affects the connector resistance stability and durability [3].

The compression using conventional crimping tool deteriorates the material due to relaxation or partly releasing. This results in increase in resistivity and high amount of losses in wiring system and battery power system [4,5]. An inhomogeneous stress distribution is found in materials thereby increasing the critical notch stresses, which reduces the transferable load [6].

Therefore, there is need to develop a new technique to make contact joints between aluminum and copper in wiring system that can give us a required strength with minimum power loss, more uniform with no radial nor longitudinal misalignment so that it can be beneficial for industries where cable connections are used in large numbers.

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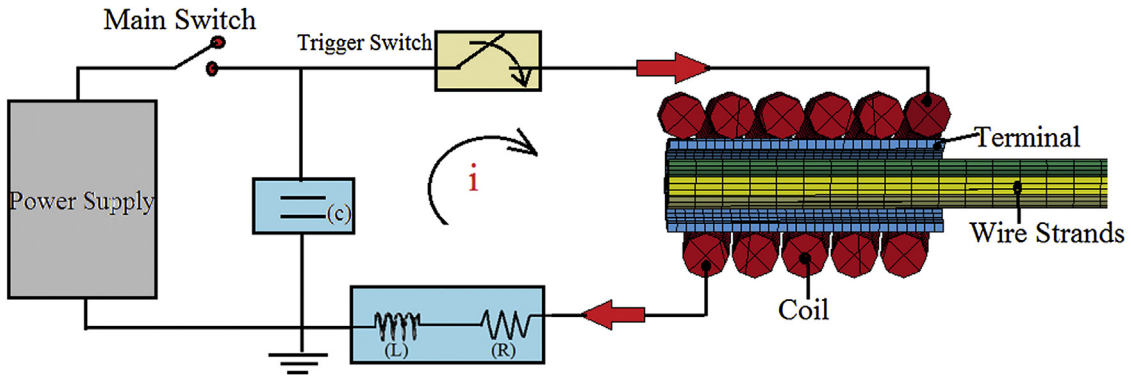

Fig. 1. Equivalent circuit diagram for EM wire crimping process.

Table 1
Geometry set-up and working conditions.

Workpiece	Outer diameter of terminal connector	12 mm
	Inner diameter of terminal connector	10 mm
	Length of terminal connector	27 mm
	Al conductivity	35×10^6 S/m
	Density	2.70 g/cm^3
Circuit condition	Capacitor bank	90 μF
	Maximum voltage	15 kV
	Circuit inductance	20 μH
	Circuit resistance	23 mΩ

In comparison to other widely used joining techniques, like conventional mechanical crimping, electromagnetic crimping shows interesting characteristics which results in uniform forming pressure distribution [6,7]. The advantage of EM process including no contact, low mould cost, no lubrication and less spring back makes it more suitable for materials that are difficult to form [8]. The earliest applications of electromagnetic crimping originate from the electrical industry. Examples are swaging of copper tubes to coaxial cables and joining of metal fittings to ceramic insulators [9]. In 1996 Belvy et al. [10] found that the electrical resistance of EM crimped cable connectors is up to 50% lower than those of produced by mechanical crimping. Since then no further published research paper has been found in this field. Although a large number of studies present EM forming as having a tremendous application potential [8,11], but no research has been carried out in the field of EM wire crimping process.

In this paper EM wire crimping is carried out with different parameters and analyzed with conventional crimping process. The intension of the present work is to develop a new method for wire crimping that can be an alternative option for existing conventional wire crimping method. The aim of this experiment is to give advantages in uniform lug deformation, minimum electrical resistance, high pullout strength, good surface finish, increased hardness number and improved thermal property.

2. Theoretical background: electromagnetic crimping process

A high energy system that can discharge its energy within a very short period of time is required for Electromagnetic (EM) crimping process. This is achieved using a high voltage capacitor bank which is connected in series with the inductor (coil) as shown in Fig. 1. The circuit parameters (the total inductance, capacitance and resistance of the circuit) should be selected such that, the RLC circuit operates in the overdamped condition [12]. The total energy that is stored within the capacitor bank is given by:

$$E_c(t) = \frac{1}{2}CV(t)^2 \tag{1}$$

where $E_c(t)$is the total energy stored in the capacitor bank (Joules) and C is the equivalent capacitance of the capacitor bank (farads) and $E(t)$ is the charge voltage (volts). The stored energy of the capacitors is suddenly discharged by closing the high current switch between the charged capacitors and the inductor. This generates a current $I(t)$, which is a damped sinusoidal oscillation [14]. The current generates an electromagnetic field that can be found according to the first of Maxwell's Equations:

$$\vec{\nabla} \times \vec{H} = \vec{J} \tag{2}$$

where $\vec{J}$ is the current density and $\vec{H}$ is the electric field. In Eq. (2), $\vec{\nabla}\times$ represents the curl operator. According to the second Maxwell's Equations, a current is induced on the workpiece due to the electromagnetic field caused by the high frequency current on the coil. The magnetic flux density can be given as:

$$\vec{\nabla} \times \vec{B} = 0 \tag{3}$$

where $\vec{B}$ is the magnetic flux density and $\vec{B} = \mu\vec{H}$. Also, $\vec{\nabla}$ is the curl operator. The induced current due to the flux density flows in reverse direction to the coil current according to Lenz's law. The induced current generates Lorentz force on the workpiece which may be expressed as:

$$\vec{F} = \vec{J} \times \vec{B} \tag{4}$$

For a particular number of turns (N), length of the coil (l), the developed magnetic field increases with the increase in the discharge coil current as illustrated in equation below.

$$B = \frac{\mu NI}{l} \tag{5}$$

For lesser skin depth magnetic pressure (P) is calculated by the simplified equation as:

$$p(t) = \frac{1}{2}\left(\mu H_{gap}^2(t)\right) \tag{6}$$

Which is deduced from the damped coil current from the sinusoidal current. But when skin depth is considered magnetic pressure (P) is calculated using magnetic field for various discharge voltage using the equation illustrated below:

$$P = \left(\frac{B^2}{2\mu}\right)\left(1 - e^{-\frac{2t}{\delta}}\right) \tag{7}$$

$$\delta = \frac{1}{\sqrt{\pi\sigma\mu f}} \tag{8}$$

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