

Ultrasound for Crimp Inspection

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ABSTRACT

In copper wire, real time crimp monitoring has traditionally been based on force measurement during the crimp cycle. The force attributed to molding the copper wire into the terminal is a significant portion of the total force needed to form the crimp. Therefore, any wire deviation from the norm is translated into a force pattern aberration that can be detected using basic signal pattern analysis.

As the mobility industry is contemplating replacing copper with aluminum wire, in order to save on weight and material cost, the traditional force monitoring becomes ineffective in detecting wire faults in the crimp. The reason is that aluminum is softer than copper, and most of the force exerted during the crimp cycle is consumed by forming the copper terminal itself. The small force deviation due to an aluminum wire fault becomes much more difficult to detect. Therefore, a new technique is needed to monitor crimped aluminum wires. In this paper, we investigate the feasibility of using ultrasound technology to monitor a crimp press cycle in order to separate a normal from a faulty crimp.

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INTRODUCTION

The crimped electrical terminal remains the most common and the most basic inter-connect in electrical systems. The requirement that the crimp must outlast the life span of the system makes it a critical component and its quality must be assured during production.

The typical electrical terminal is crimped onto a conductor wire by first removing a portion of the insulation in order to expose a prescribed length of stranded wire, and then, using a press, deform the terminal to make a solid contact with the wire. This results in a secure mechanical and electrical connection between the wire strands and the terminal. The crimping press usually has an anvil for supporting the terminal and a ram that moves toward and away from the anvil to crimp the terminal. [Figure 1](#) shows an example crimp press with a close up of the wire, terminal, anvil, and ram.

In a production environment that employs automatic wire stripping, several faults can result in a crimp that is mechanically or electrically deficient, and if not detected, can contribute to a system failure when installed. Therefore, a real time inspection system is desired to monitor the quality of the crimps as they are made.

The class of faults that can occur ranges from an unstripped wire to a crimp that is missing all the strands and can include:

- Wrong strip length.
- Missing strands.
- Wrong wire cross section number of strands.
- Wrong terminal.

- Inconsistent terminal material.
- Insulation in the crimp.
- Wrong insertion depth.
- Wrong crimp height.
- Strands outside of the terminal
- Incorrect wire gauge

By far, the hardest condition to detect is when a small percentage of strands, for instance one or two strands out of a 19 strand wire, are missing in the crimp. Detection of this condition is the focus of this paper.

The absolute quality of a crimped terminal connector is measured by an electrical characteristics test and a pull test to determine its mechanical ability to maintain the wire inside the crimp under specified pull force. Both of these tests are difficult to perform during an automated crimp cycle, and the latter test is destructive. Alternative, nondestructive, *in vivo*, tests are instead adopted by the industry to determine the quality of the crimp. They include measurement of the crimp height and the amount of force required to form it. These measurements are taken during the crimp cycle using position and piezoelectric based force sensors installed inside the press [1, 2]. By comparing the current crimp height and maximum force to the ideal height and force of a particular terminal/wire combination, a fault in the crimp can be immediately detected. A crimp requires a minimum force to form the terminal, and an additional force to crimp the wire to it. The difference between these two forces makes it possible to detect faults, like missing strands, in the crimp. This technique performs well for many applications.

However, for soft wire material relative to the terminal material, like in the case of an aluminum wire, the force required to form the terminal plus the wire is not significantly different from the force required for the terminal alone. As a result, the force measurement technique becomes less effective in detecting wire faults. A proposed new technique that can replace or augment the force measurement is to transmit an ultrasound signal through the crimp as it is being formed [3]. The signature of the received signal can then be analyzed to differentiate between a normal and a faulty crimp.

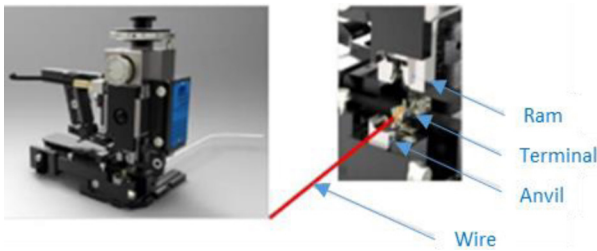


Figure 1. Crimp applicator and Terminal/Wire close up

ULTRASOUND BASED CRIMP INSPECTION

References [3,4,5] discuss an ultrasound energy based method to differentiate between a normal and faulty crimp. The technique presented uses piezoelectric sensors embedded in the crimper tooling to transmit and receive an ultrasonic wave through the crimp as it is being mechanically formed. Upon application of pressure, the jaw of the tooling deforms the crimp ferrule around the wire with sufficient force to press the wire and ferrule surfaces into intimate mechanical contact. As the pressure increases, conformation between the crimper tool jaws, the crimp, and the enclosed wire strands improves, and more of the ultrasonic wave energy propagates through. At this point, it is possible to transmit the ultrasonic wave from the transmitter, through the ferrule, through the electrical wire, and into the opposite jaw of the tool to be received by the ultrasonic receiver.

The justification for this method is that a well formed crimp produces a more continuous medium for the ultrasound wave to propagate through. As a result, fewer reflections are generated and more ultrasound energy is initially collected at the receiver. On the other hand, a bad crimp, with missing wires or other defects, will have more air gaps or a less homogeneous medium, which results in more initial reflections between the crimper and the crimp and less energy being transferred at the receiver. Figure 2 shows the cross sections of a typical normal crimp and a crimp with missing strands and more air gaps.

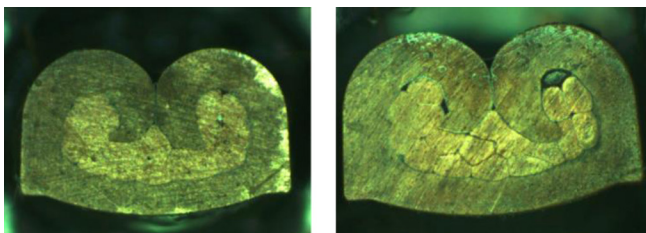


Figure 2. Example of Crimp Cross Sections. (left) Normal, (right) Crimp with two missing strands showing air gaps

Ultrasound Transducer Selection

For selecting the proper transducer, several ultrasound wave propagation fundamentals must be taken into consideration. For instance, the ultrasound energy out of the transducer must be high enough and must be focused on the crimp in order to maximize the signal to noise ratio. The wave beam width must cover the entire width of the crimp in order to detect flaws anywhere in the crimp. In addition, the transducer must be matched to the material of the tooling so as to minimize reflection echoes. In order to simplify the system analysis task, only longitudinal waves are considered in this work. This is accomplished by properly orienting the transducer so the wave travels inside the tooling and intercepts the crimp at a right angle.

When a longitudinal plane wave with energy R_o impinges on an interface of two media at a normal angle, the energy of the incident wave is split between a reflected wave energy, R , and a transmitted wave energy, $T = R_o - R$. The energy in the reflected wave in terms of R_o is given by the expression: [6(chap 2), 7]

$$R = R_o \frac{\rho_1 c_1 - \rho_2 c_2}{\rho_1 c_1 + \rho_2 c_2} \quad (1)$$

Where ρ_1 and ρ_2 are the densities of the material in the two media and c_1 and c_2 are the corresponding wave velocities. The wave velocity is given by:

$$c = \sqrt{(E/\rho)((1-\sigma)(1-2\sigma)(1+\sigma))} \quad (2)$$

Where E is the material Young's Modulus of Elasticity in dynes/mm² and σ is the Poisson's Ratio

Therefore, in order to efficiently transmit ultrasonic energy into the crimp, the transducers must be appropriately coupled to the casting surface of the anvil and the ram.

The transmitted energy can be further reduced by diffraction before reaching the receiver according to the Huygens principle [6, 7]. Diffraction causes the planar wavefront to become spherical, and as a result, only a fraction of the ultrasound energy is captured at the receiving transducer. This implies that careful positioning of the anvil and ram sensors is critical to obtaining a high fidelity signal. As this application deals with longitudinal waves, proper positioning implies that we operate in the *Fresnel* zone of the sensor, or slightly beyond it, where the ultrasound energy is both uniform and has a high intensity [7, 8].

For a circular sensor, the *Fresnel* zone distance is given by $N = D^2/\lambda$, where D is the sensor diameter and λ is the ultrasound wavelength.

Another parameter to consider is the beam spread. The solid angle of beam spread 2θ at 10% (-50 dB) of maximum axial intensity is given by:

$$\sin(\theta) = 1.22\lambda/D$$