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Magnet Wire Bonding Basics
By David Steinmeier

Magnet Wire

Magnet wire is solid copper wire, ranging in diameter from less than 25 microns (.001 inches) to over 1.5 mm (.060 inches). Magnet wire is typically coated with polyurethane, polyester, or polyimide insulation, depending on the required operating voltage and temperature. Nylon is often added to polyurethane to decrease insulation cracking and improve lubricity when the wire is wound around a tight bobbin or special form.

The combination of polyurethane-nylon is the most commonly used insulation. It melts at 155°C, making it easily removable by hand soldering, solder pot dipping, and automated solder wire feed using a constant temperature soldering iron or diode laser for the heat source. Applying heat causes the insulation to shrink back from bonding area, allowing the solder to flow over the newly exposed copper wire.

Automotive applications involving operating temperatures higher than 155°C are pushing manufacturers to use more polyimide wire. Since polyimide chars around 600°C, the most commonly used solders and brazing alloys will not remove polyimide insulation.

Bonding Polyimide Insulated Magnet Wire

To reliably resistance weld, braze, or solder polyimide insulated magnet wire to a contact or terminal, the polyimide insulation must first be removed by mechanical, chemical, or Excimer Laser methods. Mechanical methods depend on the wire diameter. For magnet wire diameter greater than 120 microns (.005 inches), abrasive wheels effectively remove the polyimide insulation.

Below a wire diameter of 120 microns (.005 inches), micro sandblasting is employed. *Caution*: micro sandblasting is uneven, weakening the copper wire and leaving it susceptible to fracturing when terminated.

Chemical striping is the best way to remove polyimide from very small diameter magnet wire and does not harm the copper wire. However, the chemicals required to strip off polyimide are very toxic and have a tendency to migrate up the wire and into the wound coil on small transformer or telecom coils, causing insulation voltage failures when tested.

Excimer Laser removal of polyimide insulation is the only method capable of removing a precise amount of insulation without damaging the copper wire. Excimer Lasers, though, are very expensive, typically costing more than USD 100,000 and require extensive protection to shield the machine operator from any laser radiation.

"Fusing" Polyurethane-Nylon Insulated Wire

Reliably bonding polyurethane-nylon insulated magnet wire greater than 120 microns (.005 inches) in diameter to a contact or terminal requires establishing an electric current path around the insulated wire.

Figure 1 shows how the magnet wire contact can be designed to hold the wire in place as the weld force is applied and at the same time create a weld current path that flows through the contact. The electric current flowing in the electrodes and contact generate sufficient heat to displace the insulation and create a bond between the magnet wire and contact.

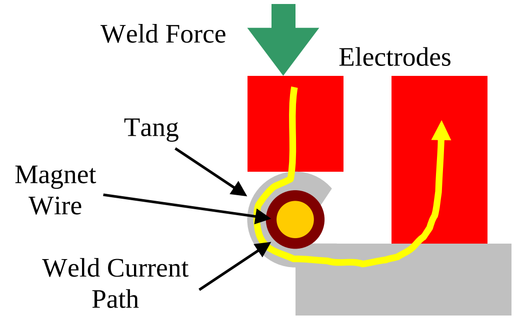

Figure 1 – Cross section of motor armature contact and "Tang"

This highly reliable technique is called "Fusing" in the motor armature industry and the wire gripping mechanism is called a "Tang". If the tang is not solder plated, then the resulting joint will be a solid state bond. If the tang is solder plated, then the joint will be a reflow braze. For a thorough discussion on bond joint physics, download the microTip on "Laser and Resistance Welding Bond Types" at: http://www.microjoining.com/microTip_Library.htm

A second variation on the "Fusing" technique employs the use of a component lead to create the weld current path around the insulated magnet wire as shown in Figure 2.

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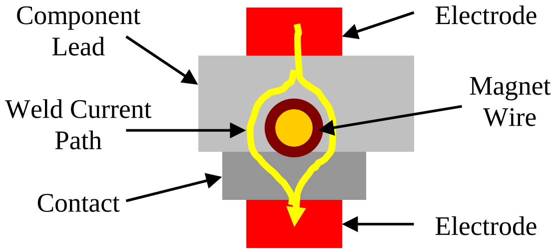

Figure 2 – Cross section showing magnet wire squeezed between component lead and contact.

The weld force squeezes the insulated magnet wire between the component lead and contact surface. This technique only works with soft or pliable component lead material like solder or tin plated copper and a small diameter magnet wire. Hard component lead materials like steel or nickel do not conform very well and tend to shear the magnet wire, creating an open circuit.

Thermocompression (TC) Bonding
Use thermocompression bonding to create a solid state bond between polyurethane-nylon insulated magnet wire smaller than 120 microns (.005 inches) and a gold plated printed circuit board (PCB) pad.

TC bonding uses a very small molybdenum, nichrome, or tungsten heater element that is pulse heated in less than .010 seconds. This heater element or "Thermode" can easily reach over 1000°C. See Figure 3.

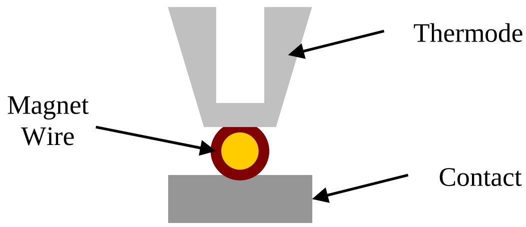

Figure 3 – "Thermode" bonding magnet wire to contact.

The advantage of TC bonding lies in its ability to remove the insulation and join the copper wire to the copper PCB pad without the need for a third element such as solder or a brazing alloy.

The downside to TC Bonding includes deformation of the wire, inconsistency in attachment strength caused by a gradual decrease in thermal energy transfer due to insulation residue buildup on the face of the thermode, and a thermode life as little as 100 process cycles.

Hot Bar Reflow Soldering
Hot Bar Reflow Soldering is very similar to TC Bonding in that both processes utilize a thermode for the heat source. A constant temperature thermode can make a million or more bonds without being replaced. A pulsed heated thermode may only last several hundred thousand bonds due to the stresses caused by thermal cycling.

The major difference between TC and Hot Bar Reflow Soldering is the operating temperature. TC Bonding requires pulsed heating to 1000°C or more while the Hot Bar typically operates at less than 400°C. The bonding mechanisms are also very different. TC Bonding produces a solid state bond while Hot Bar Reflow Soldering creates a reflow solder joint using the solder plating on the PCB pad as the joining element.

Penetration Bonding
The concept of using a large weld force and a sharpened or chisel shaped electrode to mechanically "crack" through the insulation as shown in Figure 4 has great appeal. In practice, however, this technique produces several bonds before quickly becoming ineffective due to the dulling of the chisel shaped electrode, inconsistent weld current area, and most importantly, a very rapid buildup of the insulation residue on the face of the chisel shaped electrode, preventing future weld current flow.

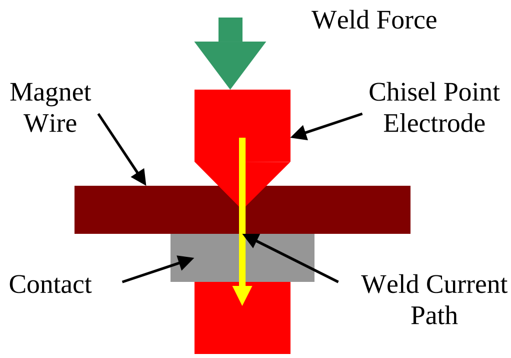

Figure 4 – "Chisel" point electrode penetrating magnet wire insulation.