

Joining Challenges in the Manufacture of Motors for Electric Vehicles – Stator Winding Assemblies

Stator Windings in Electric Vehicle Motors

Traction motors for electric vehicles are largely designed around “bar-wound” stators. These assemblies incorporate large-cross-section, rectangular copper wires to maximize the conductive metal area within the motor stator channels. To build the stator windings, individual pieces of copper wire are bent into “hairpin” shapes and inserted into stator lamination stacks. These hairpins must be joined together to create the required electrical circuit.¹ Joining of copper can be complicated by its very high thermal conductivity, making it difficult to concentrate sufficient energy at the joint position to produce fusion without overheating adjacent areas.

Gas tungsten arc welding (GTAW) has been used to join the stator wires, as illustrated in Figure 1. This process provides an adequate joint for oxygen-free, high-conductivity (OFHC) copper, but oxygen-containing, tough-pitch copper has tended to exhibit porosity associated with the combination of hydrogen (in the arc) and oxygen (in the substrate) to produce water vapor at the joint.² In addition, the temperatures and heating times associated with GTAW both excessively soften the copper and damage the insulating coatings employed on the wires. Alternate processes for joining copper are needed that offer improved process robustness, reproducibility, joint durability, and decreased degradation of adjacent wire insulation systems.



Figure 1. Gas tungsten arc welding (GTAW) used to join stator wires. (Image courtesy of General Motors)

Resistance-forge Welding Approaches

One candidate approach recently investigated is resistance mash welding (RMW). This technology employs conventional resistance spot welding systems to effectively heat and subsequently forge the joint. In this application of RMW, a multistep force and current regimen is used to manage the temperature and deformation of the wires during the joining process. Initially, the joint area is heated under a relatively low load, so that the parent metal becomes sufficiently soft to enable significant deformation of the joint interface. The electrode force is then rapidly increased to produce local strain at the wire-to-wire (faying) interface. This causes surface oxides to fracture and expose nascent copper so that metallurgically clean copper surfaces are brought into contact at elevated temperature to form a strong joint.³ In order to achieve a strong, low resistance, clean copper-to-copper joint, the process parameters must be optimized to ensure significant solid-state joining

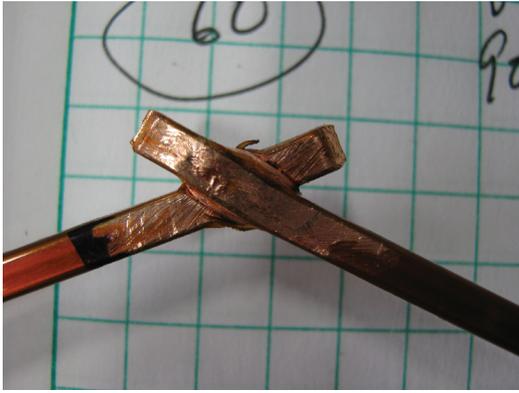


Figure 2. Joint using cross-wire arrangement.

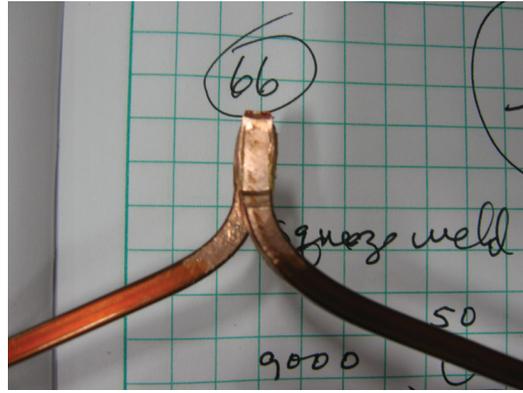


Figure 3. Joint using parallel-wire arrangement.

without overheating the copper and expelling it or causing it to stick to the electrode faces. Two types of weld joints, cross-wire and parallel-wire arrangements, were demonstrated and investigated in this study (Figures 2 and 3). The first joint (Figure 2) uses the contact area between two intersecting wires (cross-wire joint) to concentrate weld current and produce metal displacement. Large-diameter flat-faced electrodes are used for this joint type. The second joint welded a set of wires placed parallel to one another (Figure 3). The electrodes were contoured to provide concentration of weld current and displacement needed for bonding. A typical cross section of one of these joints is shown in Figure 4. Welds show a complete solid-state character with significant deformation along the residual bond line.



Figure 4. A typical cross section of a joint using parallel-wire arrangement.

Capacitive Discharge Methods

More recently, capacitor discharge (CD) welding has been investigated for such stator winding assemblies. CD welding is a stored energy technology, creating high intensity current pulses as short as a few milliseconds.⁴ These compare to previous efforts using resistance-forge welding where cycle times can be as long as 100 ms. With respect to stator winding assemblies, these short cycle times offer two advantages associated with the limited heat penetration that results from the short cycle times. These include localized forging (improving joint consistency) as well as minimizing insulating any thermal damage to the coating (minimizing strip-back lengths).

Summary

Stator windings in traction motors for electric vehicles are created by the joining of multiple short copper wire sections. Current approaches (GTAW) provide good joint quality, but lack the productivity for high-volume manufacturing. In addition, the extended thermal cycles require long strip-back lengths, increasing the required copper for the assembly. Further, these thermal cycles soften the copper, reducing the strength of the joint. Two emerging technologies for stator winding assembly have been described here. These include resistance-forge and capacitor discharge (CD) welding. Resistance-forge welding has been demonstrated with two geometries, including cross and parallel orientation of the wires. CD welding offers potential for creating joints with significantly reduced thermal cycles, minimizing strip-back lengths and enhancing component strengths.

REFERENCES

- [1] Agapiou, J.S. and Perry, T.A. Resistance mash welding for joining of copper conductors for electric motors. *Journal of Manufacturing Processes*, Vol 15:549-557 (2013), Elsevier publishing.
- [2] Hook, I. T. The welding of copper and its alloys. *Welding Journal Research Supplement*, pp. 321-s-337-s. (July 1955).
- [3] Peterson, W. A., Gould, J. E., Agapiou, J., Perry, T. A., and Schroth, J. G. Resistance spot mash welding of Cu wires for electric car batteries and motors. *Sheet Metal Welding Conference XVI, AWS Detroit Section, Detroit, MI. Paper 5B-4. 2014.*
- [4] Gould, J. E. and Lewis, S. Development of an open architecture capacitive discharge welding system. *Sheet Metal Welding Conference XVII, AWS Detroit Section, Detroit, MI. Paper 3B-5. 2016.*

Get Started

EWI is currently pursuing Internal Research and Development projects focused on maturing sensing technology while bringing them together as a collective group to quantify weld strength. If this is something you would like to learn more about or find out how to participate, please contact us at:

[614.688.5152](tel:614.688.5152) (or) info@ewi.org

For more information regarding our capabilities and services, visit EWI.org

EWI.ORG→