Issue 03 | November 2020

Hot Application
e-Mobility - Hairpin Welding

THIS ISSUE
Hairpin Welding

THE CHALLENGE

Problem:

Electric motor manufacturers are tasked with building increasingly smaller, lighter, more powerful motors that not only maintain but also improve electro-conductivity. Keys to success include:

- Optimize the amount of copper used in the stator core slots
- Increase throughput and reduce cycle time
- Lower assembly costs
- Improve overall quality

Solution:

This manufacturing problem has been solved by replacing the traditional wound wire core with the use of rectangular bars of copper formed into something resembling a hairpin. These hairpins, however, bring new manufacturing challenges to which we will highlight solutions in this document.

Electric Motor Technology

To meet the growing demands of the current e-mobility market, design and manufacturing engineers are tasked with building more powerful, higher performance, electric motors that are also more efficient.

Figure 1

Traditional electric motors used heavy, round-wire motor windings, but newer, electric motors utilize solid, preformed rectangular bars (Figure 1) that are intertwined and locked into place (Figure 2). These formed bars are often called “hairpins” because of their resemblance to the personal care accessory, however, their function is quite different. These hairpins result in improved stator cavity fill (Figure 3) and an end product that is smaller, weighs less, can withstand greater thermal stress, exhibits improved torque, higher power density, and produces less heat.

It sounds simple, but assembling these hairpin motors requires several steps.

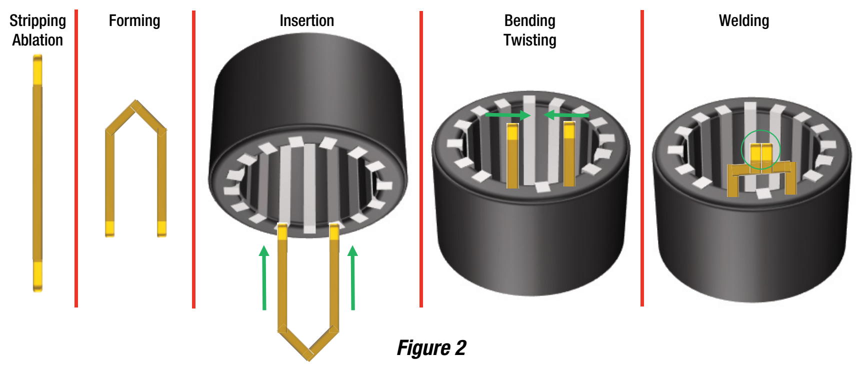


Figure 2

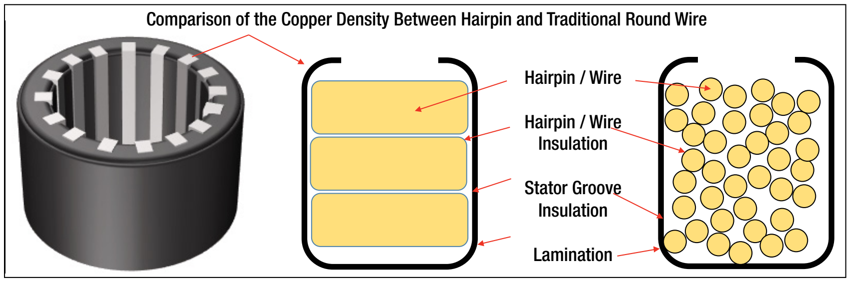


Figure 3

AMADA WELD TECH’s solutions focus on two of these steps:

1. **Laser Ablation.** Strip or clean the ends of the hairpin wires quickly, without removing too much of the copper itself.
2. **Welding.** Successfully weld the ends of the hairpins together with enough contact area to ensure adequate electrical conductivity without introducing so much heat that it destroys the insulating material or creates spatter from the weld that might adhere to the stator and create an electrical short in the motor.

Removing Insulation from the Hairpins

There are two main techniques for removing the insulation from the ends of the hairpins: mechanical stripping or laser ablation.

Mechanical stripping (Figure 4) is typically achieved by rolling the wire between four metal brushes or blades. This technique is relatively slow and prone to leaving particulates behind which can result in expulsion, porosity, poor weld strength and, ultimately, a reduction in electrical conductivity. The process also actually removes a small amount of the copper, which is costly in high volume production applications.

Laser ablation (Figure 5) is achieved by scanning a laser beam over the surface of the hairpin to remove coatings or insulation. The two laser sources most commonly used are CO_2 and fiber. Both CO_2 and fiber lasers tend to leave some residue behind, however, process parameters are constantly evolving making these processes cleaner and more desirable.

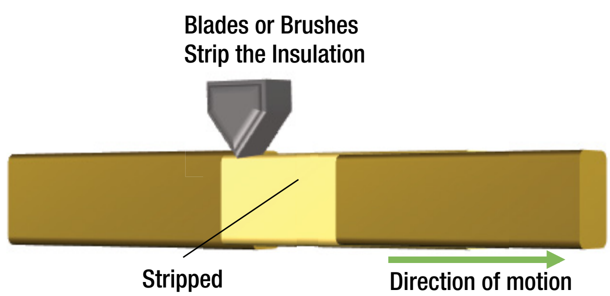


Figure 4

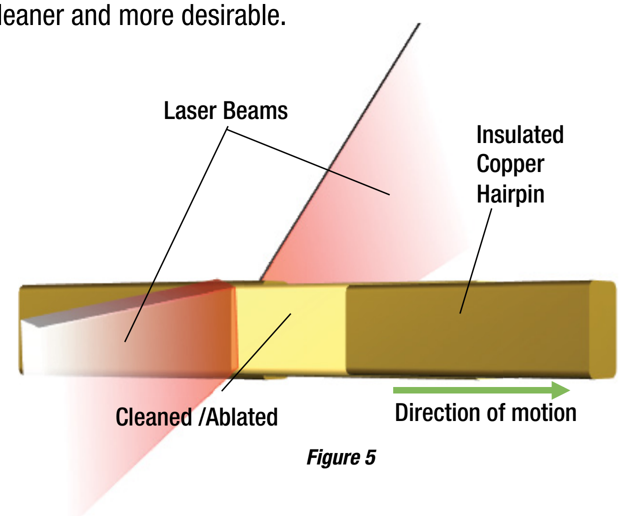


Figure 5

Hairpin Welding

After stripping or ablating the two ends of the copper bars need to be connected to provide the electrical circuit. The joining of these ends occurs after the bars are bent and twisted placing the ends in close proximity. The goal in hairpin welding itself is to achieve a high-quality joint with minimal heat input and spatter. There are several challenges to achieving a high quality weld - including hairpin alignment and delivering enough energy to melt the copper material, but not so much as to damage the coating. Additionally, if the energy is input too fast, the process may create spatter. Successful hairpin welding can be achieved using laser or micro TIG welding, or, resistance brazing.

When considering which technology best fits the application one should consider:

- Hairpin alignment
- Fixture/tooling
- Part access
- Cycle time
- Quality of the hairpin end trimming

Hairpin Alignment / Tooling / Access / End Trim Quality

Figure 7 shows many of the various alignment conditions often found in production. Figure 6 shows an example of poorly finished ends which will cause a problem when welding – particularly for Micro TIG and Laser which address weld from the top, directly onto those surfaces.

Figure 6

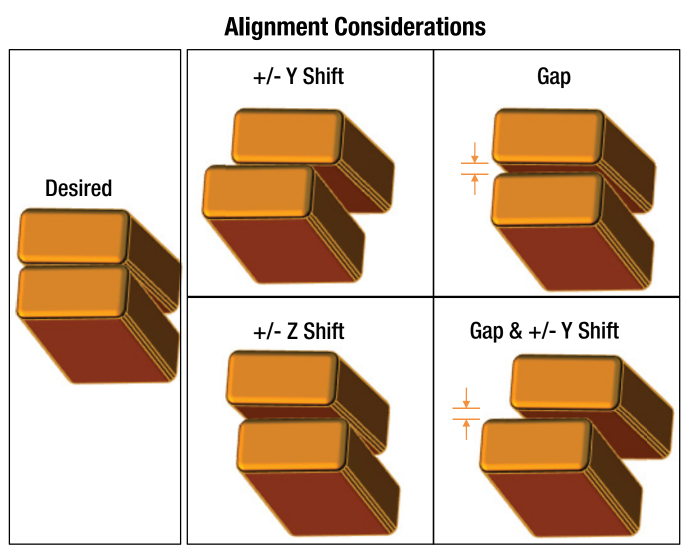
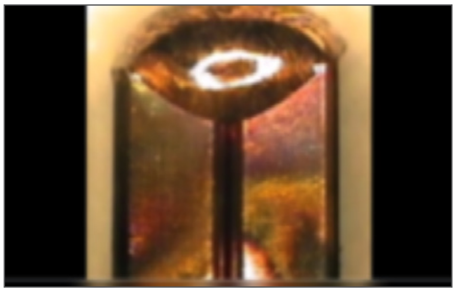
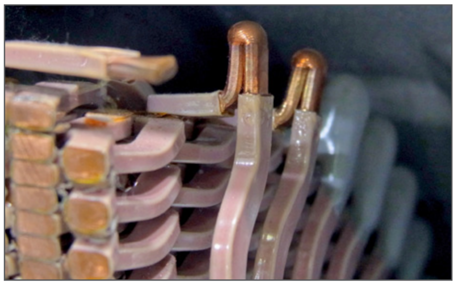


Figure 7



Laser Welding

The difficulty in laser welding hairpins is primarily in the alignment and tooling. As seen in Figure 7, there are a variety of alignment conditions encountered in hairpin welding which, because laser welding is a non-contact process, must be resolved with the development and use of custom tooling. This in turn, can make joint access more difficult. Vision systems are often utilized to help identify the location of the weld joint and ensure the hairpins are aligned and within acceptable positional tolerance for processing. Vision systems can also be used to adjust the power, beam path and speed of the laser; parts that fall outside the acceptable welding tolerances can be flagged for repair. Additionally, because the laser interacts with the top surface layer of the part first, excessive variations in the end trim (burr) plays a role in how the laser couples with the material and can cause spatter resulting in inconsistent welds and potential short circuits.



Micro TIG Welding

As with laser welding, successful micro TIG welding relies on well aligned parts with a negligible gap. While part fit up for this process may be more forgiving than laser welding, it is less forgiving than resistance brazing. As with laser welding, accessibility to the weld joint is from the top of the hairpins and it is therefore a good process to consider when the spacing does not allow for resistance brazing, pincer type heads. Because the micro TIG strikes an arc between the electrode and the top surface first, excessive variations in the end trim (burr) plays a role in where the arc interacts with the material. This can cause spatter and the potential for inconsistent welds.

Resistance Brazing

Resistance brazing can be an ideal solution for hairpin connections because the pincer action draws the parts together correcting for many gap/alignment issues, however it also necessitates access to both sides of the hairpins. Proper tooling is required to insure that there is no X-Y-Z shift. As motors become smaller and more compact, access may become increasingly difficult. Creative tooling and the use of multiple heads can improve the overall cycle time for the resistance brazing process. The quality of the end trimming does not affect the brazing process results.

	Laser Welding	Micro TIG Welding	Resistance Brazing
Hairpin Alignment	Very important	Important	Less important
Fixture/Tooling	Very important	Important	Less important
Access	Top side	Top side	Sides
Cycle time / Speed	Fast	Medium-slow	Medium
Quality of end trim	Very important	Very important	Not important (from welding perspective)

When defining a process it is important to account for such above variations within the process. Well thought out tooling and vision systems can increase the probability of success.

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