WHITE PAPER

# Applying MAG-MATE Insulation Displacement Connection (IDC) Technology to Aluminum Magnet Wire Applications

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## The switch to aluminum magnet wire is on the agenda of electric motor manufacturers

Many fractional horse power (FHP) motor manufacturers, selling to the appliance, heating, ventilation, and air conditioning equipment industries, are seriously evaluating a switch from copper to aluminum magnet wire. The economics of switching to aluminum are quite straightforward: Copper magnet wire currently contributes up to ten percent to the overall cost of a typical FHP electric motor. At current market prices, switching from copper to aluminum wire can potentially reduce this contribution to less than two percent.

However, to achieve equal conductivity, aluminum wire needs to have a larger cross-sectional area than copper. As a rule the AWG* has to be reduced by two numbers which means that, for instance, a 20 AWG copper wire could be replaced by 18 AWG aluminum wire. Yet, even on an equal conductivity basis, aluminum is one half the weight of copper. For medium and high volume FHP motor manufacturers in particular the reduced material cost and the lower motor weight are equally welcome. Looking at the price development, it also appears that aluminum is not subject to the same price increase that can be seen with copper.

**Advantages of aluminum magnet wire:**

- Aluminum is traditionally 1/4 the cost of copper
- Aluminum is 1/3 the weight of copper
- Aluminum is 1/2 the equal conductive weight of copper
- Aluminum is 1/8 the cost per unit of conductivity vs. copper
- Between March 2010 and March 2011 the copper price increased 30 %
- Between March 2010 and March 2011 the aluminum price increased 12 %

*American Wire Gauge


Between January 1, 2010 and March 31, 2011 aluminum prices increased by roughly 14 percent at the London Metal Exchange.

Source: The London Metal Exchange Limited, www.lme.com, London, EC3A 2DX, UK


During the same time span (January 1, 2010 through March 31, 2011) copper rocketed to above 10,000 USD/ton, before it dropped to around 9,500 USD, which still is an increase of over 25 percent.

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## Wire connection technology has to be on a par with the reliability of copper-based interconnection

The major obstacle to benefiting from the huge potential cost savings has always been finding a way to make electro-mechanical connections to aluminum magnet wire at production and reliability levels equal to that of copper magnet wire. This paper takes an in-depth look at the above opportunities and obstacles and offers solutions to reconcile the two. As aluminum is more brittle than copper, the interconnection needs to be adjusted for its different material properties. Still, the termination technology needs to be fast, efficient, durable and repeat-accurate which more or less excludes sonic welding or soldering from the list of options for medium to large volume production.

## IDC Technology

TE Connectivity (TE) has been successfully driving a superior solution for magnet wire termination over the past 15 years: Many leading FHP motor and pump manufacturers around the world use TE's MAG-MATE product range to terminate copper magnet wire. This product portfolio is based on Insulation Displacement Connection (IDC) technology. IDC has proven to be an effective alternative to stripping and soldering wire in thousands of applications for over 40 years.

Originally the IDC principle provided an effective way to terminate stranded and solid lead wire in the telecommunications industry. Increasing demand for cost reductions in the highly competitive FHP market eventually drove the transfer of IDC technology into these and other magnet wire applications. To meet this demand, TE developed the MAG-MATE IDC interconnection system, which comprises efficient and durable termination products for medium and high volume manufacturing operations. In total the MAG-MATE product portfolio covers a wide range of wire gauges and offers a multitude of possible terminal contact geometries. For applications with space constraints slim-line and mini solutions offer an efficient termination option.

## How MAG-MATE IDC technology works

In the IDC-based interconnection system, box-shaped dual-beam terminals reside on a continuous strip. The manufacturer inserts the terminals into a plastic cavity using either semi or fully automatic insertion equipment. The plastic cavity can be molded onto the customer's existing bobbin or can be part of a separately attached housing. This molded cavity has two slots at opposing sides with a chamfered lead-in at the top of each slot. The magnet wire from the bobbin is pre-positioned into these two slots either manually or by the winding equipment. The wire is supported inside the cavity by means of an integral wire support or "anvil" feature.

The MAG-MATE metal terminal has two IDC slots with chamfered lead-ins at the slot entrances. The terminal is positioned over the magnet wire in the housing cavity and inserted. Specially designed terminal features, called "nickers", clean the insulation film from the wire surface during insertion. Once the terminal is fully seated, the wire is captured within the two insulation displacement slots to provide a reliable termination, Figure 1. The wire deforms to an oblong shape. During this process four gas-tight points of contact (two on each beam) are created between the wire and terminal. The opposing side walls of each terminal slot have residual spring energy that maintains constant pressure on the wire, providing a reliable, long-term connection. Similarly, the molded plastic slots grip the wire on each side of the metal terminal, providing strain relief.

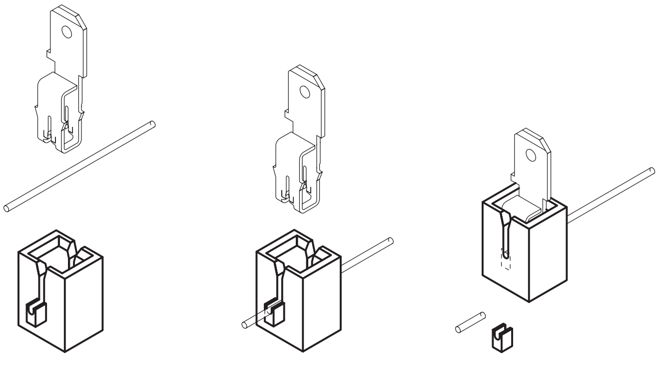

Figure 1:
The IDC termination process. When the magnet wire from the bobbin is pre-positioned into the slots of the plastic cavity, the MAG-MATE terminal is inserted into the cavity. During this the insulation is displaced from the wire surface. The stripped wire deforms to an oblong shape, creating four gas-tight points of contact.

## Terminating aluminum magnet wire

The termination of aluminum magnet wire has presented unique challenges for IDC technology. Environmental and mechanical stresses will cause aluminum to experience creep and stress relaxation to a much higher degree than copper. Magnet wire manufacturers have been able to minimize the creep and stress relaxation characteristics by alloying aluminum magnet wire with iron, but at a higher cost than traditional aluminum wire. Instead, the MAG-MATE IDC termination can be designed to compensate for the material properties of aluminum without impacting the aluminum alloy price, the wire weight – or the termination quality itself.

Therefore TE conducted studies to verify the factors that result in long-term successful IDC termination of aluminum magnet wire. These studies incorporated environmental and mechanical stresses and evaluated the effects of:

- Wire position within IDC slot
- IDC slot compliance
- Terminal plating materials
- Strain relief features

The tests showed a very stable performance of MAG-MATE terminals on aluminum magnet wire as long as manufacturers take certain precautions during the termination process. To ensure a successful termination on aluminum wire, the manufacturer:

- must not over-insert the wire into the IDC slots.
- must incorporate strain relief features in the plastic housing.

## Details on the influence of the wire end position

Table 1 and Figure 2 both illustrate different test samples, grouped according to the depth of wire insertion (ranging from A to C), and the presence or absence of a strain relief feature. Wire end position "A" is the most compliant, providing maximum springback capability and longest termination life on aluminum magnet wire. Wire end position "B" is the standard wire insertion depth used with copper, which results into normal springback capabilities and termination life.

| Group | Wire size, material | Wire position in slot | Strain relief? |
|---|---|---|---|
| 1 | #21 AWG Al | A | Yes |
| 2 | #21 AWG Al | A | No |
| 3 | #21 AWG Al | C | Yes |
| 4 | #21 AWG Al | C | No |
| 5 | #21 AWG Cu | B | Yes |

Table 1:
The test samples covered three options for the wire insertion depth, and showed the influence of a strain relief feature.

Wire end position "C" proved to be the least compliant, providing virtually no springback and leading to a short termination life on aluminum magnet wire. Test data for groups 3 and 4 shown in Table 1 illustrate that over-insertion of the magnet wire into the IDC slot compromises the successful termination of aluminum magnet wire. The absence of a strain relief feature (Group 4) significantly increases the instability of the termination. As a result, TE Connectivity now specifies an optimal insertion depth for the terminal, measured from the top of the plastic cavity to the top of the terminal. This assures proper aluminum wire placement and eliminates the need for destructive inspection.

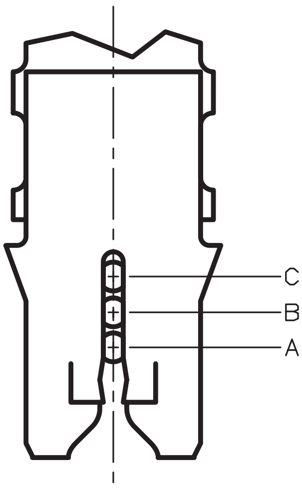


Figure 2:
Testing the possible insertion depth levels A, B, and C revealed the influence of the wire end position on the termination life.



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Figure 3 compares the average resistance levels of the MAG-MATE terminal on aluminum wire and subjected to environmental and mechanical stresses. Some samples provided strain relief by means of an interference fit between the magnet wire and plastic cavity slots. Other samples did not incorporate the strain relief feature. One test group included copper magnet wire as a base line for comparison.

## Evaluating the possible influence of connector design modifications

Analysis of the influence of the wire end position revealed just how important the resilience and long-term pre-loading of the IDC slot beams are for mechanical durability. But what about the electric properties of the interconnection? Would changes in the IDC design improve e.g. resistance? Figure 4 shows a similar comparison of average resistance levels of standard and modified MAG-MATE terminals used with aluminum magnet wire. In this case the groups represent different combinations of slot designs, plating materials, and strain relief, as indicated in Table 2. Indium plating was selected due to its ability to inhibit aluminum oxides.

Results show that the standard connector design (Group 4) offers the best performance. Special indium plating actually diminished termination performance on aluminum magnet wire. The combination of a more compliant slot with the special plating (Group 1) clearly produced unstable terminations. Additionally, enhanced strain relief offered no improvement over a standard interference fit between the magnet wire and the slot in the plastic cavity.

We therefore conclude that the standard MAG-MATE terminal with the wire terminated in the compliant region of the slot and standard strain relief from the plastic cavity offer the best performance for aluminum magnet wire.

## Conclusion

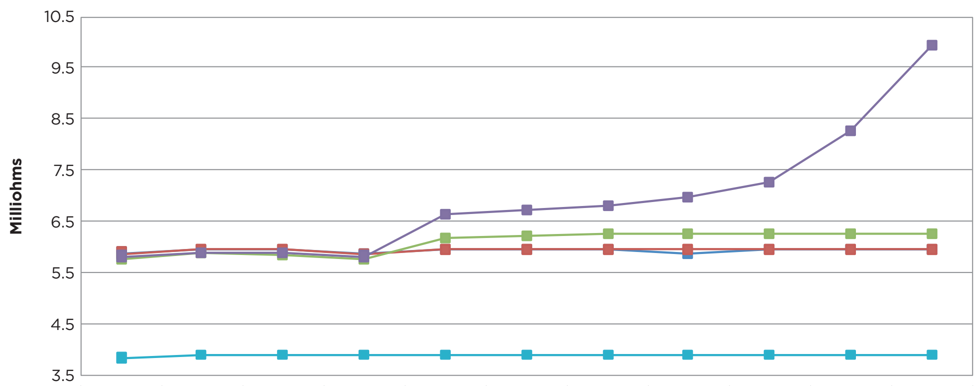
These TE studies indicate that FHP motor manufacturers can switch from copper to aluminum magnet wire and use standard insulation displacement terminals to eliminate labor intensive pre-stripping or soldering.

In order to ensure that the termination process leaves the wire in a compliant region of the connector slot, the TE engineering team will specify an optimum insertion depth for an application. In addition to that, a strain relief mechanism is required. However, tests have shown that the interference fit between magnet wire and plastic cavity slot can provide an adequate solution. Finally, TE does not recommend the use of single-beam IDC terminals for aluminum magnet wire terminations because they do not provide the robustness and control needed for such a dynamic conductor as aluminum wire.

Customers considering replacing copper magnet wire by aluminum wire are welcome to contact TE engineering for design-in support. Based on 15 years of experience with IDC interconnection technology for magnet wire, and the portrayed in-house studies, TE can optimally apply the principal benefits of IDC technology to aluminum magnet wire termination.

Figure 3:

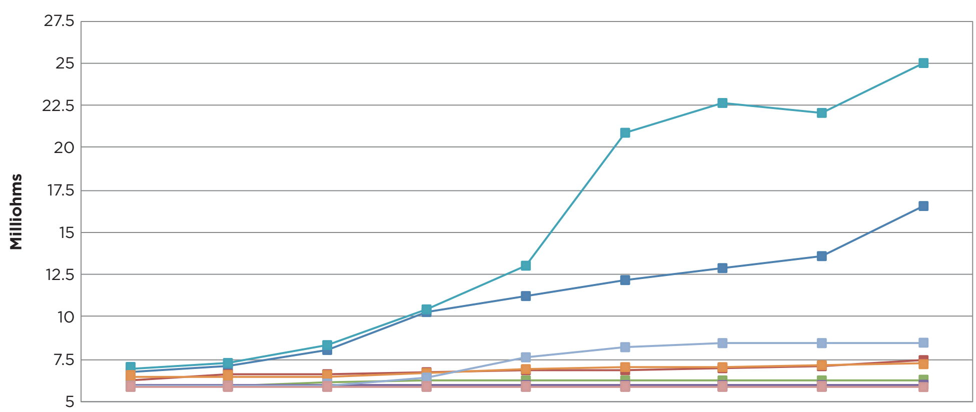
Average resistance levels of the MAG-MATE terminal on aluminum wire, and subjected to environmental and mechanical stresses.




| | Initiale | T-rise #1 | Tempera-ture Life | Humidity-Temp Cycling | Thermal Shock | Vibration Axis #1 | Vibration Axis #2 | Vibration Axis #3 | Vibration Axis #4 | Vibration Axis #5 | Vibration Axis #6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Group 1 | 5.8845 | 5.96475 | 5.92725 | 5.8795 | 5.927 | 5.9245 | 5.93675 | 5.91575 | 5.92925 | 5.941 | 5.942 |
| Group 2 | 5.888 | 5.9485 | 5.929 | 5.86775 | 5.9465 | 5.95725 | 5.969 | 5.942 | 5.94075 | 5.94475 | 5.953 |
| Group 3 | 5.77975 | 5.861 | 5.83325 | 5.771 | 6.14625 | 6.213 | 6.251 | 6.23225 | 6.243 | 6.259 | 6.2695 |
| Group 4 | 5.8135 | 5.88475 | 5.863 | 5.84575 | 6.648 | 6.722667 | 6.808667 | 6.958 | 7.246 | 8.243 | 9.956667 |
| Group 5 | 3.834 | 3.88825 | 3.8815 | 3.85625 | 3.88375 | 3.89675 | 3.89625 | 3.8935 | 3.876 | 3.8785 | 3.882 |

Figure 4:

Average resistance levels of standard and modified MAG-MATE terminals to aluminum magnet wire.




| | Initiale | T-rise #1 | Tempera-ture Life | Humidity-Temp Cycling | Thermal Shock | Vibration Axis #1 | Vibration Axis #2 | Vibration Axis #3 | Final T-Rise |
|---|---|---|---|---|---|---|---|---|---|
| Group 1 | 6.758 | 7.071 | 8.023 | 10.307 | 11.192 | 12.14 | 12.852 | 13.513 | 16.57 |
| Group 2 | 6.263 | 6.534 | 6.633 | 6.736 | 6.818 | 6.848 | 6.951 | 7.095 | 7.463 |
| Group 3 | 5.924 | 5.933 | 6.074 | 6.184 | 6.231 | 6.257 | 6.239 | 6.235 | 6.261 |
| Group 4 | 5.893 | 5.887 | 5.906 | 5.918 | 5.958 | 5.974 | 5.963 | 5.952 | 5.987 |
| Group 5 | 6.941 | 7.234 | 8.239 | 10.401 | 12.987 | 20.872 | 22.601 | 22.08 | 25.026 |
| Group 6 | 6.467 | 6.499 | 6.569 | 6.615 | 6.843 | 6.928 | 7.023 | 7.125 | 7.277 |
| Group 7 | 5.94 | 5.943 | 6.078 | 6.457 | 7.535 | 8.21 | 8.41 | 8.443 | 8.47 |
| Group 8 | 5.877 | 5.874 | 5.887 | 5.886 | 5.932 | 5.918 | 5.92 | 5.9 | 5.925 |

Table 2:

Parameters for testing redesigned IDC terminals for aluminum.

| Group | Wire size | Beam design | Plating | Strain relief |
|---|---|---|---|---|
| 1 | #21 AWG Al | More Compliant Beam | Indium | Standard |
| 2 | #21 AWG Al | More Compliant Beam | Tin | Standard |
| 3 | #21 AWG Al | Standard Beam | Indium | Standard |
| 4 | #21 AWG Al | Standard Beam | Tin | Standard |
| 5 | #21 AWG Al | More Compliant Beam | Indium | Enhanced |
| 6 | #21 AWG Al | More Compliant Beam | Tin | Enhanced |
| 7 | #21 AWG Al | Standard Beam | Indium | Enhanced |
| 8 | #21 AWG Al | Standard Beam | Tin | Enhanced |

## FOR MORE INFORMATION

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