

March 2011

ALUMINUM MAGNETICS TECHNOLOGY

Design Principles
Track Record
Material Properties
Industrial Advantages

Aluminum Magnetics Benefits

- Equivalent Performance when compared to Copper
 - Higher Life Expectancy than Copper
 - Field Proven Track Record
 - Cooler Operating Temperatures than Copper
 - Lower Capital Cost than Copper
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Material Price Volatility



Cu prices remain volatile with further increases anticipated, but costs remain in check

LME Cu Official \$/Lb.

Cash	4.6031	Feb. 14, 2011
3 Month	4.5922	Feb. 14, 2011



Al prices show a slower increase

LME Al Official \$/Lb.

Cash	1.1272	Feb. 14, 2011
3 Month	1.1344	Feb. 14, 2011

Historical Perspective

- Reluctance to using aluminum conductors is the result of problems encountered, early on, when making inappropriate aluminum to copper connections in the field. The result was the formation of aluminum oxidizing, a resistive compound, in the connection. Serious overheating of the connection resulted.
 - Problems were also faced when aluminum wire was mechanically inserted into copper fittings, each metal having different rates of thermal expansion.
 - These problems were the result of poor design and installation practices.
 - Aluminum is now standard in utility power transformers, power distribution transformers and high power magnetics.
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Aluminum Design Experience

- Power Quality International, Inc. has over 40 years experience specifying, designing and applying high and medium voltage class power and rectifier aluminum wound transformers.
 - PQI has over 30 years experience supplying aluminum wound medium voltage power transformers and low voltage distribution transformers.
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Industry Examples

- Aluminum is the industry standard in lighting transformers in 90% of commercial and industrial facilities.
 - Aluminum conductors are commonly used in utility industrial transformers.
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Physical Properties and Design Requirements

- Conductivity – 61% compared to Copper

Aluminum conductors require 66% more cross sectional area than copper.

- Density – 30% compared to Copper

Aluminum windings require 66% higher cross sectional area than copper but have half the winding weight of copper.

- Thermal Conductivity – 68% compared to Copper.

Since the aluminum conductor's cross sectional area is 66% larger, the aluminum conductor will have 11% more thermal conductivity than copper.

- Heat Capacity – 2.5 times higher than Copper

For the same heat applied, the temperature rise will be 2.5 times less on a per pound basis. Since the weight of aluminum is only half that of copper, aluminum will have a 16% less temperature rise, resulting in a cooler transformer.

- Coefficient of Expansion – Higher for Aluminum;

Negated by welding connections to like material (i.e. Al wire to Al bus bar) and using absorption connectors.

- Oxidization – AlO_2 is an insulator

No oxide forms when conductive grease is applied. The grease eliminates exposure to moisture or oxygen. In fact, this connection has a better lifetime outcome than a copper bus bar.

- Thermal Cycling – Annealing

In addition to a lower temperature rise, aluminum windings will cool less rapidly than copper. There is no brittling of the conductors due to wide temperature ranges. Wire is annealed not tempered, with no adverse physical affects.

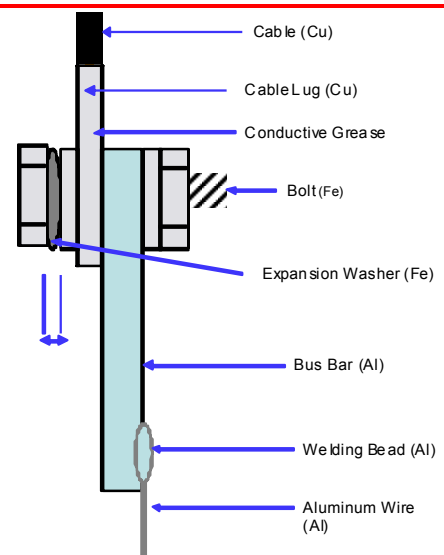
Sound Aluminum Conductor Design Practices

- **Internal Conductor Terminations**

Internal conductor must be welded to aluminum bus bar. This ensures a lifetime connection.

- **Customer Terminations**

Expansion washers (i.e. Belleville) allow any thermal expansion to be absorbed without compromising integrity of the connection.



- **Oxidization**

Application of conductive grease ensures that no moisture or air will come in contact with the connection to produce oxidization.

Cost / Design Perspective

- Aluminum is less than 75% cost of copper per (lb) / weight required is 50% that of copper.
- Conductor cost is roughly 40% - 50% that of copper.
- Magnetics weight is approximately 5-10% less (most of the weight still is in the core).
- Aluminum magnetics will typically operate cooler.
- Aluminum is less reactive to varnishes and many other chemicals used in magnetic production, resulting in a longer life expectancy.
- Volumetrically, aluminum and copper designs are almost equivalent.
- Energy efficiency requirements are identical.
- Design practices now well accepted with units in operation for more than 40 years.