Copper vs. Aluminum Conductor

At Issue

There is a common misconception that a distribution transformer with copper windings is in some way more efficient, more reliable, or has greater short-circuit strength than a transformer with aluminum windings.

Recommendation

Improvements in technology regarding the use of aluminum in transformers make aluminum-wound Eaton's Cooper Power series transformers an ideal choice for many of today's applications.

The Evidence

It is obvious that, per square inch, copper can carry more amps than can aluminum. To overcome this, Eaton designs aluminum-wound transformers with windings of a larger cross-sectional area than would be used for a copper-wound unit. This larger cross-sectional area results in a lower current density at an equivalent operating temperature. Operating temperature is the key to controlling and predicting losses. **A copper-wound unit is not necessarily a low-loss unit**. By reducing the current density in the windings, a low-loss design may be achieved with either aluminum or copper windings.

Somewhat related to losses are operating temperature and transformer life. **A transformer's life is defined by the life of its insulation system**. Over the life of a transformer, insulation loses its tensile strength and becomes susceptible to breakdown under fault conditions. Insulation can also deteriorate in high temperatures. Temperature is driven by current density. Because Eaton designs of aluminum-wound and copper-wound units run at equivalent operating temperatures, the insulation system for each design ages at the same rate.

Table 1. Example: 2500 kVA, Three-Phase Pad-Mounted Transformer, 13800 Delta - 480Y/277

	All Aluminum Winding	All Copper Winding	Copper Primary Aluminum Secondary
No Load Losses (Watts)	2402	2015	2097
Load Losses (Watts)	14,732	16,558	16,032
Total Losses (Watts)	17,134	18,573	18,129
Efficiency at 50% Load	99.53%	99.53%	99.53%
Efficiency at 100% Load	99.32%	99.27%	99.28%
Dimensions (H x W x D)	81" x 104" x 73"	81" x 94" x 72"	81" x 99" x 70"
Price Difference	Baseline	+13.8%	+8.5%

Whether operating efficiency is a goal or not, aluminum windings are typically less expensive than copper windings. Table 1 shows three equally efficient designs – one with all aluminum windings, one with all copper windings, and one with a copper primary and an aluminum secondary winding.

In this example, while the efficiencies at 50% load are equivalent because of the Department of Energy (DOE) requirements, when compared to the price of the aluminum wound unit, the copper-aluminum-wound transformer is 8.5% more expensive, while the copper-wound transformer is 13.8% more expensive.

Field experience with aluminum connections outside of transformer tanks contributes to the bias against aluminum windings. Aluminum conductor connections are more difficult to maintain in an environment where oxygen is present. Unless sealed correctly, these connections will gradually increase in resistance until the heat generated results in thermal runaway. The connections inside an oil-filled transformer **are sealed from oxygen at the factory** by the insulating fluid. Each connection thus maintains its quality in the field. Connection methods used by Eaton for aluminum conductors have been validated in laboratory tests as well as in over 30 years of experience in building aluminum-wound transformers.

The influence of power transformers on the specifications of distribution transformers also contributes to some misconceptions about aluminum windings. In a power transformer with round coils, the design parameter which dominates the design is the tensile strength of the conductor. Because windings are stretched across spacers, a great amount of tensile force is placed on the conductor during short-circuit testing (tension can reach 1000 psi). The forces present are independent of conductor material; they are based on current level and coil geometry. The tensile strength of copper is higher than that of aluminum, making copper more suitable for a round coil transformer design.

The Eaton **rectangular coil design** makes a short-circuit test a test of core-clamp strength, rather than of conductor strength. The rectangular coil design greatly reduces the amount of tensile stress on the windings. Windings are stacked on top of each other rather than stretched across gaps between spacers. This stacking process allows each layer of windings to rest on the layer inside of it. No windings are bridged across gaps. The 1000 psi tensile force is simply a compressive force across an entire layer of windings. Aluminum or copper windings in a rectangular core design resist this pressure easily.

Conclusion

Eaton designs its aluminum-wound coils using the same thermal, dielectric, and mechanical rules as for its copper-wound coils. In pad-mounted and substation designs, Eaton's Cooper Power series aluminum-wound units and copper-wound units serve their loads equally well.

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Publication No. TC202003EN

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