



# **FOHAMA**

## **ALUMINUM WINDINGS FOR DISTRIBUTION TRANSFORMERS**

### **INTEGRATED SOLUTIONS**

**As manufacturers of dry and oil-filled transformers, we offer the most suitable technology for each application, providing technical advice to customers to ensure safety, reliability, and efficiency throughout the entire service life of the equipment.**

#### **1 – Introduction and history**

#### **2 – Myth vs reality**

#### **3 – Technical advantages**



## 1 – Introduction and history

The lack of technology for welding aluminum was one of the reasons that initially led to the use of copper in transformer windings.

However, during World War I (1914-1918), faced with great difficulties in obtaining copper, aluminum began to be used in the construction of the windings of some transformers, a measure that, for the same reason, intensified greatly during World War II (1939-1945).

It was the imperative of scarcity in wartime situations that precipitated and imposed the replacement of copper with aluminum in the construction of transformers and in other fields of electrical engineering, but the reality is that even then there was a need to be able to use a substitute for copper as an electrical conductor on an industrial scale, mainly due to the instability of the price of this metal, which, because it has special military applications, is subject to very large fluctuations in its price on world markets as soon as a war breaks out or, simply, a tense political situation arises.

The need to replace copper with another more abundant and stable-priced metal drove the development of welding technologies, making this metal the most suitable for the manufacture of transformers, as it combines the optimal mechanical and electrical characteristics in relation to its cost and guaranteed supply.

In 1950, aluminum began its evolution as a conductor for the manufacture of electrical transformers. It can be said that in North America, 95% of distribution transformer production currently uses aluminum windings, and copper is only used in small-power, high-voltage transformers, where the reduced diameter of aluminum is not a problem.

In Europe, French, German, Italian, and Swiss manufacturers, as well as those in the Nordic countries, generally build transformers with aluminum windings.

## 2 – Myth vs. Reality

*Today, aluminum strip winding consists of simultaneously winding an aluminum sheet the width of the coil itself and diamond-patterned insulating paper with thermo-adhesive epoxy resin, leaving, as in all windings, the necessary channels for the circulation of the cooling liquid, resulting in a coil with one turn per layer, which is extremely robust and compact. As there are no false turns, it has a balanced geometry, giving it great resistance to electrodynamic stresses and making better use of the space occupied by the conductor, which partly compensates for the greater volume of the aluminum winding compared to copper.*

<p><b>Myth 1:</b> Transformers with aluminum coils will be less efficient than their copper counterparts.</p>	<p>There is no technical argument to show that transformers with aluminum coils will be less efficient or have greater losses than their copper counterparts, and while it is true that the material has lower conductivity, this is considered in the design and cross-section of the conductor: it is simply increased to compensate for this shortcoming.</p>
<p><b>Myth 2:</b> The aluminum transformers heat up more than the copper ones.</p>	<p>This is not the case, because temperatures are limited according to specifications through design. The design and project of a transformer is obviously conditioned by a series of technical characteristics that it must comply with (power, transformation ratio, losses, no-load current, impedance, temperature, etc.), with the determining factors ultimately being the dimensions of the winding, thermal requirements, or dynamic stresses.</p>

### 3 – Technical advantages

#### **Advantage 1: Better thermal behavior in case of overloads or short circuits.**

For the same characteristics and technical guarantees, and due to aluminum's higher specific heat and lower conductivity, the following always applies:

**Mass Al · Specific heat Al > Mass Cu · Specific heat**

This means that the heat capacity of an aluminum winding is always approximately 17% higher than that of a copper winding in an equivalent transformer.

This allows aluminum windings to withstand transient overloads for longer before reaching a temperature that is dangerous for the insulation.

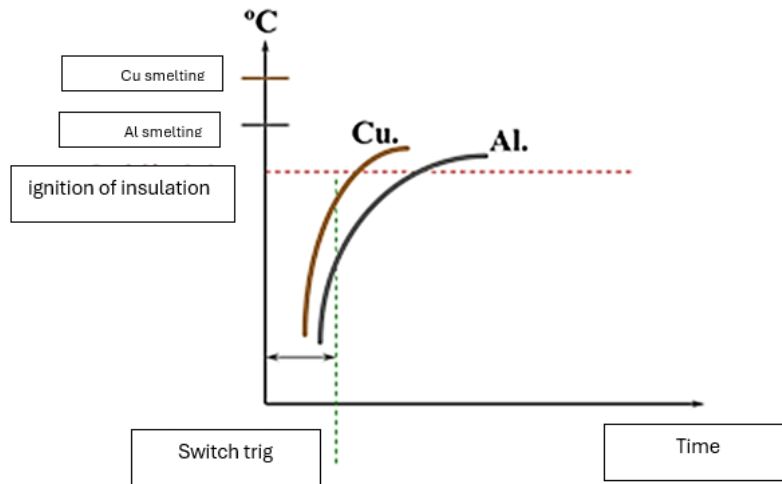
The graph in Figure 3 clarifies this idea about the thermal behavior of transformers with aluminum windings.

By plotting the two curves representing the heating of the copper and aluminum windings, respectively, in a short-circuit situation, we observe that:

- When the switch is turned off, the temperature reached by the aluminum winding is lower than that of the copper winding.
- If the switch was not activated due to a failure of the protection system, the ignition temperature of the insulation would be reached sooner in the copper winding.
-



# FOHAMA



## Advantage 2: Better dynamic performance in the event of a short circuit

Given the lower conductivity of aluminum compared to copper, the cross-section of the aluminum conductor, and therefore its dimensions, are considerably larger than when copper is used, This leads to higher resistance modules, proportional to the cube of the dimension ratio, which compensate for the lower elastic limit of aluminum compared to copper, thus offering aluminum conductors superior resistance to the radial and axial stresses resulting from a short circuit.

Where  $R_{Cu}$  is the strength modulus of Cu and  $R_{Al}$  is the strength modulus of aluminum;  $C_{Al}$  and  $C_{Cu}$  are the corresponding conductivities, the following applies:

$$\frac{R_{Cu}}{R_{Al}} = \left[ \frac{C_{Al}}{C_{Cu}} \right]^{\frac{3}{2}}$$

Short-circuiting causes a bending moment  $M$  to act on the conductor, developing a maximum working stress  $\sigma$ , which is a function of the conductor's dimensions, satisfying the following:

$$\sigma \cdot l = \text{maximum winding force} = \frac{M \text{ (maximum winding force)}}{R \text{ (section modulus)}}$$

Establishing the relationship in both cases, we get:

$$\frac{\sigma \cdot l_{Al}}{\sigma \cdot l_{Cu}} = \frac{\frac{M}{R_{Al}}}{\frac{M}{R_{Cu}}} = \frac{R_{Cu}}{R_{Al}} = \left[ \frac{C_{Al}}{C_{Cu}} \right]^{\frac{3}{2}}$$

This means that, for a given short-circuit situation, the stresses on the conductors, depending on whether they are copper or aluminum windings, are in the same ratio as their conductivities raised to the power of 3/2.

Numeric comparison:

	Aluminum Al99,5	Copper
Yield point	10	12
Conductivity	35,4	57

$$\sigma \cdot l_{Al \text{ normal}} = \sigma \cdot l_{Cu} \left[ \frac{36}{57} \right]^{\frac{3}{2}} = 0,502 \sigma l_{Cu}$$

$$\sigma \cdot l_{Al 99,5} = \sigma \cdot l_{Cu} \left[ \frac{35,4}{57} \right]^{\frac{3}{2}} = 0,489 \sigma l_{Cu}$$

Indeed, assuming that the  $\sigma l$  of copper corresponds to the elastic limit, the  $\sigma l$  we would obtain for aluminum would be:

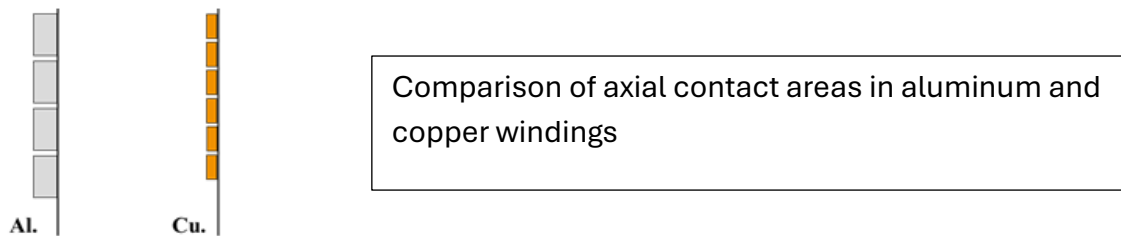
Elasticity limits:  $\sigma \cdot l_{Al 99,5} = \sigma \cdot l_{\text{m}ax.Cu} \cdot 0,489 = 12 \cdot 0,489 = 5,87 < 10$

This indicates that the 99.5 aluminum conductor is operating well below its elastic limit.

### Advantage 3: Less aging of insulation: longer life

International standards for transformer construction, IEC, ANSI, etc., specify the maximum transient temperature that can be reached by the conductor in the event of a short circuit as 200°C for aluminum and 250°C for copper.

International standards for transformer construction — such as IEC, AINSI, etc.— specify that the maximum transient temperature a conductor can reach in the event of a short circuit is 200 °C for aluminum and 250 °C for copper.



This temperature limitation, combined with the higher heat capacity of aluminum windings, results in less aging of the insulation—which determines the transformer’s service life—so it can be stated unequivocally that, under identical conditions, the service life of a transformer with aluminum windings is longer than that of an equivalent transformer with copper windings.

### Advantage 4: Lower additional losses in the presence of high harmonic content

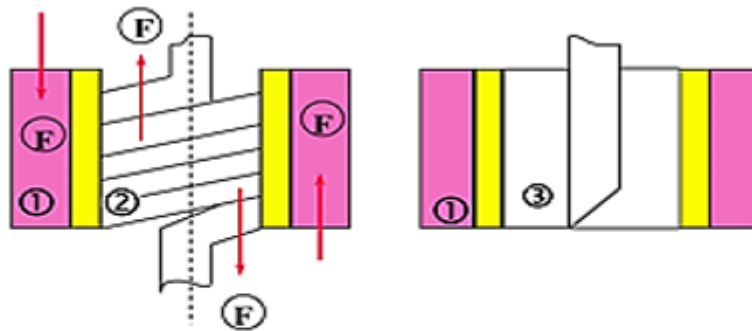
Due to its higher resistivity, eddy currents are significantly lower than those found in copper, which is why it is the most recommended material for installations operating with high harmonic content—a factor that causes increased losses and temperature rise in transformers.

### Advantage 5: Slower oil aging

Aluminum has no catalytic effect on oil; that is, it does not chemically react with it, as copper does. Consequently, oil ages more slowly, reducing maintenance and upkeep costs.



# FOHAMA



- 1- Winding of A.T.
- 2- Spiral winding of B.T.
- 3- Slit winding of B.T.
- 4- Axial forces.

Comparison of a spiral-wound low-voltage coil subjected to axial stresses with an aluminum-strip coil not subjected to such stresses.

### **Advantage 6: Non hot spots in the winding**

The overlapping windings have a large mutual contact surface area separated by a thin insulation layer, which need only withstand the stress per winding, thereby providing rapid heat dissipation in the radial direction and completely preventing the formation of hot spots inside.

Naturally, the windings are subjected to greater thermal stress at the top; the strip winding greatly mitigates this effect, as the same conductor occupies the entire length, thereby better equalizing the temperature.

This condition also helps to delay the rise in temperature during short-circuit conditions.