Aluminium transformer vs copper transformer:

A technical and economic comparison

ABSTRACT

The possible applications for dry-type transformers are multiple and versatile. Together with the choice of the correct technology and execution, it is quite often under discussion which one can be the best solution for a conductor if using aluminium or copper to have the best result in terms of performances. The analysis must be carried on considering different topics we are deepening here.

KEYWORDS:

aluminium, copper, economic analysis, materials, technical analysis, winding

Development of aluminium windings

Historically, copper was the preferred conductor for electrical transmission and machines because it was a very readily available material, easy to work with and, importantly, an exceptional conductor of electricity.

During World War II, the demand from the arms industry led to an acute shortage of copper for other uses. Electrical equipment manufacturers needed an alternative material, and aluminium was an obvious choice mainly because it was (and still is) one of the most abundant metals on the planet, and it has excellent thermal and electrical conductivity.

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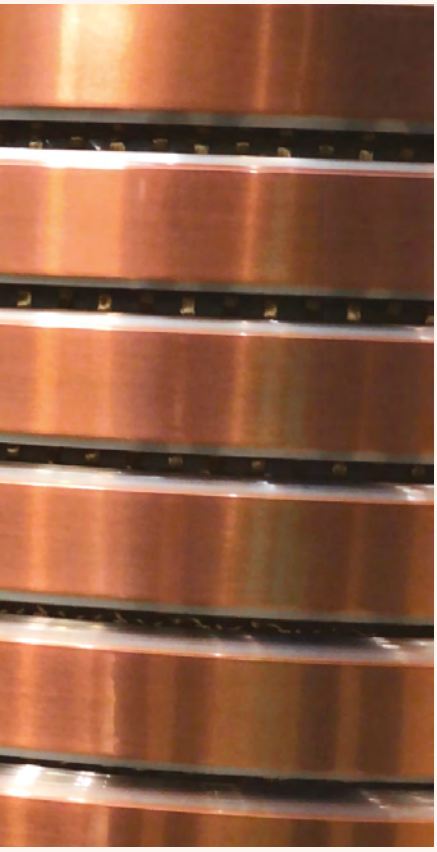


The choice of material – copper or aluminium, mainly depends on the technical project specification or client preference, and both materials have their pros and cons

In the earlier stages, working with aluminium proved more difficult than copper. However, modern manufacturing and metallurgical processes have improved dramatically.

Advances in jointing technology have also made aluminium more suitable as a winding conductor. In the last 50 years, the use of aluminium as a winding conductor in transformers became widespread.

Lower and more stable prices (compared to copper) make it now the preferred material for cast resin transformers manufacturers.

Copper or aluminium?

All the major manufacturers have, for many years, manufactured transformers utilizing both aluminium and copper winding conductors. The choice of material mainly depends on the technical project specification or client preference.

Experienced manufacturers have proper knowledge and experience of the technical "pros and cons" of either conductor material and can advise the best technical solution for any specific project. Both winding materials provide low loss, highly reliable transformers which have identical technical performance. However, there are several key advantages in using aluminium from both the technical and economic points of view.

Transformers: overall dimensions and mass

- For the same current carrying capacity, an aluminium conductor would need to be about 63 % larger in cross-sectional area than the equivalent copper conductor.
- However, the density of aluminium compared with copper means that the mass of the aluminium winding is still 50 % lower than the equivalent copper design.
- The higher volume of the aluminium conductor does increase the dimensions of the magnetic core, with a subsequent increase in core mass of about 10–15 %.
- Overall, the aluminium transformer has a slightly higher volume but lower mass (about 10–12 % less) than the equivalent copper transformer.

FACT: Aluminium transformers have a higher volume but lower mass than copper ones.

Winding conductor for cast resin transformers

- Cast resin transformers have HV windings (and occasionally also LV) encapsulated (cast) in epoxy resin.
- It is important that the thermal expansion of the epoxy resin matches the thermal expansion of the conductor.
- Matching these characteristics will avoid internal mechanical stresses and potential cracking of the resin.
- The coefficient of expansion of aluminium is more closely matched to that of the most commercially available epoxy casting resins than copper.
- This is particularly relevant if the transformer is subjected to rapid changes of load during the duty cycle or significant overloads.

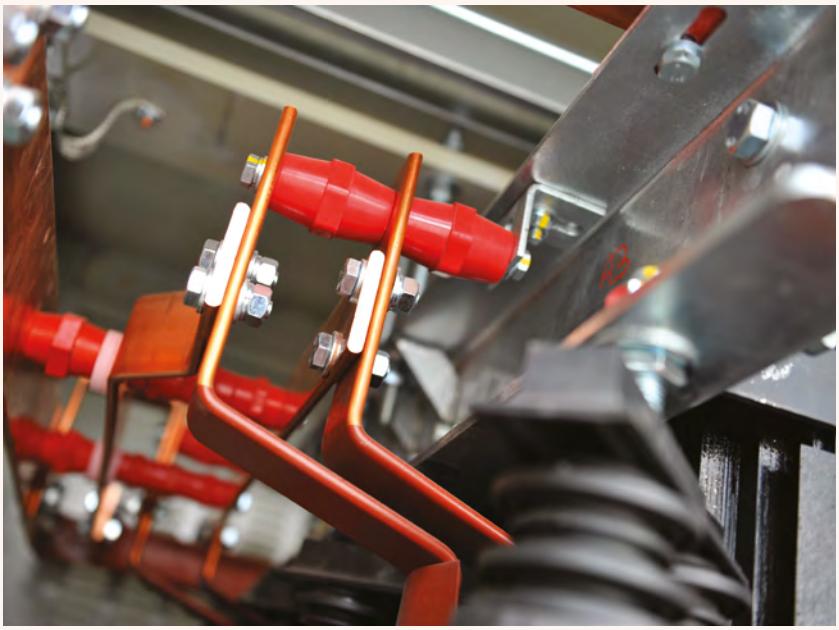
FACT: The coefficient of expansion of aluminium is more closely matched to that of the epoxy casting resin than copper.

Over-temperatures during short term over-loads or system short circuits

- The temperature rises of the winding under these conditions dependent upon:
  1. The specific heat capacity of the conductor material.
  2. The mass of the conductor material.
- The specific heat capacity of aluminium is significantly higher (x 2.4) than that of copper.
- The mass of the aluminium winding is about 50 % lower than that of the copper winding.
- The rise in temperature during overload conditions of the aluminium winding is about 75 % that of the equivalent copper winding.
- This improved thermal time constant results in improved short time overload capability and the subsequent increasing lifetime of the winding insulation system.

FACT: Aluminium windings have better short-term over-load capability than copper.

Aluminium transformers have a higher volume but lower mass than copper ones, also aluminium windings have better short-term over-load capability than copper



Transformer *hot spot* temperatures

- The melting point of aluminium (660 °C) is significantly lower than that of copper (1085 °C).
- However, the winding temperature and, in particular, the *hot spot* temperature is limited by the thermal class of the insulation system.
- For cast resin systems, this is usually Class F (155 °C) or, in some cases, Class H (180 °C).
- *Hot spot* temperatures are no different for aluminium or copper transformers. At these operating temperatures, the mechanical properties of aluminium winding remain unaffected by the temperature of the transformer.

FACT: Aluminium windings have the same hot-spot temperatures as copper.

Dielectric performance

- Most cast resin transformers utilize foil winding technology on the HV and LV windings.
- This is technically very significant for the HV winding.
- The foil winding technology creates a winding coil with a very high series capacitance.
- This provides a more uniform distribution of any transient voltage (switching surge) across the winding and improved transient voltage withstand strength.
- Quality cast resin transformers invariably use foil winding technology - this dictates the dielectric strength of the windings, not the choice of conductor material.
- So, the dielectric performance of foil wound aluminium or copper can be considered identical.
- Theoretically, the larger volume (surface area) of the aluminium conductor results in a higher series capacitance than the equivalent copper winding - so the aluminium winding may be considered stronger - but in reality, the difference is negligible.

FACT: The dielectric performance of both aluminium and copper is to be considered identical.

Losses and efficiency

- The mass of an aluminium winding is about 50 % lower than that of a copper one.
- The higher volume of the aluminium conductor increases the mass of the magnetic core by about 10–15 %.
- This increase in conductor volume potentially increases both load loss and % impedance.
- The increase in core volume potentially increases the no-load loss.
- The design differences between aluminium and copper are closely based on the optimization of the winding geometry, losses, thermal performance, and the relative costs of the active materials.
- From this point of view, there is no difference in efficiency between an aluminium design and a copper design - losses, impedance and dielectric performance can be exactly matched for either material.
- However, as the trend towards more efficient (ECO design) transformers continues, it will be far easier from an economic point of view to achieve lower load losses using aluminium.

FACT: In terms of overall efficiency, there is a negligible difference between a copper and an aluminium design.

FAQ: The choice between aluminium and copper transformers		
Aluminium transformers are **not** as **reliable** as copper ones.		**FALSE**
Aluminium transformers have a higher **volume** than copper ones.	**TRUE**	
Aluminium transformers have a lower **mass** than copper ones.	**TRUE**	
Aluminium windings are more closely matched to the coefficient of expansion of epoxy casting resin than the copper ones.	**TRUE**	
Aluminium windings have better short-term over-load capability than copper ones.	**TRUE**	
Aluminium windings have the same hot spot temperatures as the copper ones.	**TRUE**	
The dielectric performance of both aluminium and copper is to be considered identical.	**TRUE**	
Copper transformers are more efficient than aluminium ones.		**FALSE**
A copper transformer will always be significantly more expensive than the equivalent aluminium design.	**TRUE**	
There is **no** technical difference in performance between aluminium or copper windings.	**TRUE**	

The economic consideration

- London Metal Exchange (LME) (June 2021): copper at US$9,900 / T and aluminium at US$2,500 / T
- Cost ratio of 3.96:1
- But also, an aluminium design has 50 % less conductor mass than its copper equivalent.
- It can therefore be seen that the use of aluminium results in a very significant reduction in the cost of the winding material and therefore in the cost of the finished transformer.
- Commodity prices historically vary from year to year – however, a copper cast resin transformer will always be significantly more expensive than the equivalent aluminium design.
- It is for this very reason that aluminium is the winding conductor of choice for the vast majority of cast resin manufacturers in the world today.

FACT: The copper transformer will always be significantly more expensive than the equivalent aluminium design - with absolutely no technical difference in performance!

Aluminium and copper windings have the same dielectric performance as well as the same hot-spot temperatures, but there is a slight difference in the efficiency in favour of the copper winding transformers

Author

Marco Bianchetti is Area Sales Manager of TMC Transformers S.p.A, one of the leading companies in the market of power transformers of medium and low voltage, using dry-type technology. He is responsible for Northern and Eastern Europe, Russia and CIS countries. Russia specifically is one of the biggest markets for TMC, where the company also has many resellers for their high-quality products.

Before starting his career in TMC in 2017, he obtained a Master Executive degree in Sales Planning at SDA Bocconi, Itally, where in 2020 he also attained another Master Executive degree in Area Sales Management, while working for TMC.

In TMC Transformers S.p.A, Marco has strengthened his skills such as teamworking and team leadership as well as his inclination to improve his personal knowledge. In TMC, it is thought that motivation is the main determinant of success, and just as Marco believes, nothing is impossible if you work with motivation, believing in yourself and trusting in others.