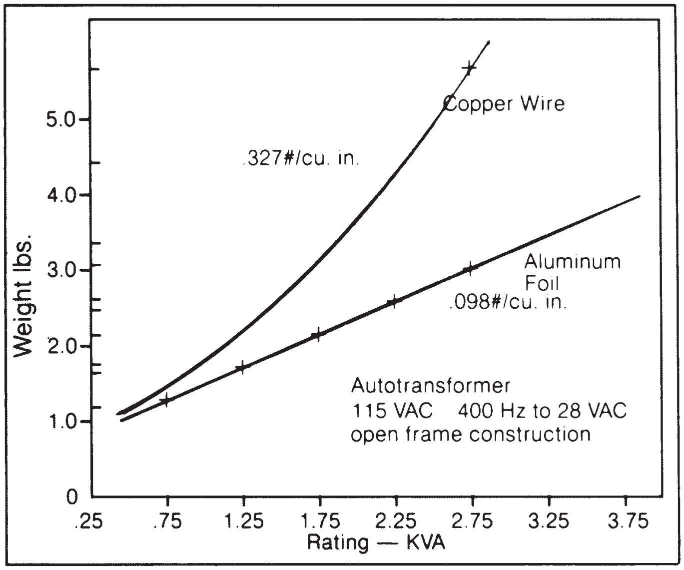
ALUMINUM & COPPER FOIL TRANSFORMERS

Electrocube designs and manufactures transformers and inductors using aluminum or copper foil in place of the standard copper wire traditionally used for coil windings. As the result of a company-funded development and testing program, Electrocube introduced this unique construction technology, providing practical and economical aluminum foil-wound transformers in the 25 VA through 50 KVA power range.

For over thirty-five years, these foil transformers have been used in commercial and military applications exhibiting exceptional reliability and efficiency. The use of aluminum or copper foils result in a transformer with many advantages over conventional wire-wound versions:

- Increased reliability
- Reduced size and weight
- Higher ambient temperature operating capability
- Improved electrical efficiency
- Increased electrical stress resistance
- Better overall regulation



Weight comparison - copper wire versus aluminum foil coil transformers

The basic transformer construction consists of electrical grade aluminum or copper foil, temperature suitable interwinding insulation, fiberglass and nomex sheet insulation. The complete unit is vacuum impregnated with a specially formulated epoxy resin developed to assist in heat transfer and to bond the components into a stable, dense unit. Units are produced as isolation or autotransformers in all standard mechanical configurations (open frame or enclosed), using stamped or "C" core laminations to operate within the following parameters:

SINGLE OR MULTIPHASE

Frequency:	300 Hz to 10 KHz
Power:	25 VA to 50 KVA and up
Voltage:	Fractional volts 110 to 600V (higher voltages available)
Temperature:	-50° C to 250° C ambient (fully rated)

Of the hundreds of available designs, a sampling is listed here to indicate typical sizes and weights. The efficiency of all transformers listed exceeds 95% with regulations of 2% to 5%. Specific, qualified designs are available as OEM or replacement parts for all major commercial and military aircraft as well as many land-based facilities.

SPECIFICATIONS

Aluminum Foil Transformers

SINGLE PHASE 400 HZ (OPEN FRAME)

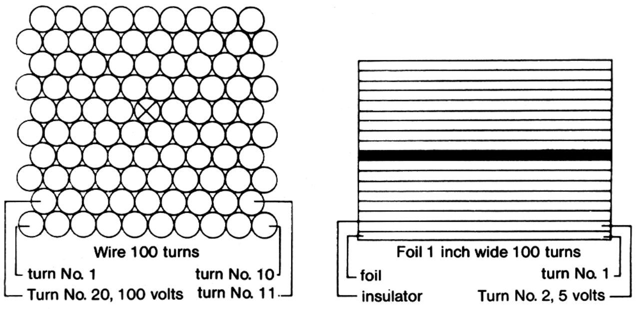
Rating	Type	Primary	Secondary	Width	Length	Height	Weight	Part Number
25VA	Auto	115	5	1.70 (43)	2.50 (63.5)	2.80 (71)	.71(.32)	FT1135
55VA	Iso	115	17.5	1.65 (42)	1.81 (46)	3.63 (67)	.54 (.24)	FT1149
100VA	Auto	115	27.5	1.70 (43)	2.50 (63.5)	2.70 (68.5)	.60 (.27)	FT1133
300VA	Auto	115	28.0	2.75 (70)	3.10 (79)	2.90 (74)	.81 (.37)	FT1134
350VA	Auto	114/110	28/24/21	2.20 (56)	3.00 (76)	2.56 (65)	.80 (.36)	FT1107
500VA	Auto	118/114/110	48/39	2.20 (56)	3.00 (76)	2.56 (65)	.91 (.41)	FT1164
750VA	Auto	118/114/110	28.0	2.20 (56)	3.00 (56)	3.05 (77.5)	1.30 (.58)	FT1046
1.75KVA	Auto	115	200/280/350	3.50 (89)	3.50 (89)	3.75 (95)	2.40 (1.08)	FT1003
2.5KVA	Auto	115	28.0	3.50 (95)	3.75 (95)	4.00 (102)	2.90 (1.32)	FT1001
6.0KVA	Auto	120	240	3.62 (92)	3.63 (92)	4.85 (123)	6.0 (2.72)	FT1238

MULTIPHASE TRANSFORMERS

Rating	Type	Freq	Primary	Secondary	Width	Length	Height	Weight	Part Number
750VA	YY	400	115	230	3.00 (76)	3.09 (78)	3.18 (81)	1.35 (.61)	FT1235
2.0KVA	YΔ	400	208	21.0 ΔY	5.10 (129)	5.15 (131)	2.86 (73)	5.2 (2.35)	FT1241
3.0KVA	ΔY	400	200 Δ	73 Y	3.30 (84)	5.95 (151)	3.70 (94)	6.5 (2.95)	FT1210
5.0 KVA	ΔY	400	115 Δ	31.0 Y	3.897 (98)	4.91 (125)	5.43 (138)	8.2 (3.72)	FT1322
6.0KVA	YΔ	400 (ISO)	208 Y	208 Δ	3.25 (83)	7.20 (183)	4.75 (121)	8.3 (3.76)	FT1240
7.5KVA	YY	400	208Y	208 Y	3.25 (83)	7.10 (180)	4.75 (121)	8.6 (3.90)	FT1329

Dimensions are in inches (mm); Weight is in pounds (kg).

This technical presentation primarily addresses aspects of Electrocube's aluminum foil transformers technology. Transformer designs utilizing copper foil may be optimally designed for applications where electrical efficiency aspects for performance are most critical. Copper foil designs will be heavier than the aluminum foil equivalent. However, attributes of physical size and weight will be reduced in comparison to a copper wire-wound equivalent. In addition, these transformers will enjoy the same performance enhancements, as described for the aluminum foil units.



(A)
Wire Wound

(B)
Foil Wound

Figure 1

The use of strip foil conductors in large, high power transformers, to replace the conventional round or rectangular magnet, wire has been commonplace for many years. Technical problems, however, had not encouraged the use of foils in small transformers.

For example, the principal advantage to using aluminum foil rather than copper in transformers is the reduction in weight. The density of copper is .32117 lbs. per cubic inch while that of aluminum is .09765 lbs. per cubic inch. For a given winding volume, the aluminum winding would weigh one-third the weight of the copper. However, aluminum has only 60% the conductivity of copper. If the winding volume is increased by 40% to raise the aluminum conductivity to that of copper, it still leaves the aluminum coil weighing only 42% of the equivalent copper coil.

Unfortunately, one cannot simply increase the winding volume of a transformer to make use of the aluminum foil. Increasing the winding volume or area necessitates increasing the magnetic path length and, therefore, the amount of magnetic material used. The physical geometry changes; the core losses change; the efficiency, regulation and temperature rise all change, thus making the change from copper to aluminum a fairly complex operation.

By suitable design techniques, the problems indicated above can be obviated. First, consider the space factor. The most efficient use of winding space is to layer wrap using magnet wire as shown in Figure 1A. Depending upon the size of the wire used, there is a percentage of the winding area which cannot be used for the conductors.

This lost area is made up of the space between the wires and the insulation with which each wire is coated. As the voltage stress of the winding is increased, it is often necessary to add inter-layer insulation creating more lost space, thus decreasing the available conductor area. The foil-wound coil illustrated in Figure 1B can be designed to make optimum use of the available winding area. Each turn of the foil extends edge-to-edge of the coil and is separated from the next turn by one thickness of insulation. There is no lost winding space which means that foil with the same circular mil area as wire will fit into a smaller winding area, or conversely, more circular mils of foil may be wound into the same winding area.

Secondly, consider the operating temperature of the transformer which effects its rating, efficiency and voltage regulation. The allowable operating temperature is the major factor in determining the size, weight and performance of a transformer. As in any other electrical device, current flowing through the resistance of the coil wire results in heat generation. This generated heat plus the losses associated with the magnetic material will cause an increase in temperature. How high the temperature will rise depends on how much and how fast the heat is generated and also how fast and efficiently this heat is wholly or partially removed. Figure 2 shows to what surface temperature a black body would rise above ambient as a function of watts power square inch of surface area of heat being dissipated into still air. The assumption is that all internal losses appear at the surface to be radiated to the ambient air.

Temperature Rise vs. Watts/in^2 Surface Area

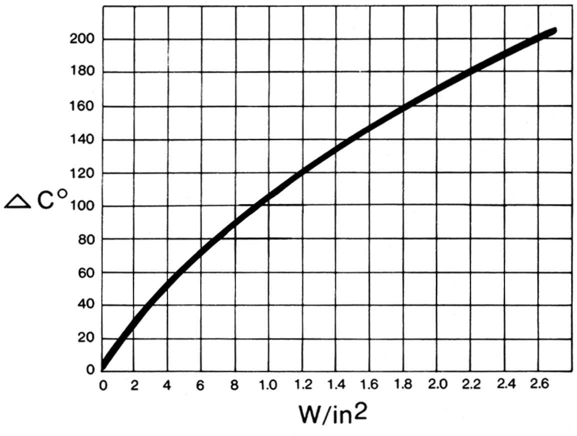


Figure 2

PRODUCT INFORMATION

If the heat transfer from the center of the transformer is restricted, then the internal temperature will be hotter than the exterior and will seriously effect the efficiency, regulation and power rating. It is apparent then that any transformer design that reduces the rate of heat generation and/or increases the rate of heat transfer can result in:

- A unit that is smaller and lighter with the same ratings.
- A unit that has the same size and rating but a lower operating temperature.
- A unit that is the same size, operates at the same temperature, but can have a higher rating.
- A combination of any of the above.

Referring to Figure1A, consider the same initial current flowing in each turn of the coil, and each turn starting with the same resistance, and that an equal amount of heat will be initially generated by each turn. Since all of the heat generated must make its way to the outer surface of the coil before it can be dissipated, a temperature gradient starting from the outside turn (the coolest) to the center turn (the hottest) is immediately established. Further, the temperature of this central inside turn will be very high since the path the heat must travel to get to the coil surface is through many layers of wire insulation which in themselves are very poor thermal conductors.

To further complicate the situation, the resistance of each turn of wire will now increase slightly due to its increased temperature. This in turn will increase the heat generated and this cycle will repeat until a temperature stabilization level for each turn is reached.

Analysis of Figure 1B shows the unique advantage that a foil-wound unit has relative to the problem of dissipating the generated heat. Each turn extending the full width of the coil has two edges in contact with the surrounding air. The tremendous advantage of the solid metal conducting path that each turn has for getting the heat directly to the outer surface of the coil is very apparent. The net result for an aluminum foil design, even with its higher resistivity figure (and consequently more heat generated per unit increment), is a sharply reduced temperature gradient from the outside to the center of the coil.

Thus, in the example described, the use of the aluminum foil winding is such that there is a smaller percentage of increase in the resistance from no-load to full-load (high I^2R) than with a wire wound coil. This then reduces the need for the aluminum foil to have the same conductivity of the copper wire to produce the same results.

A third advantage of the foil wound transformer is the voltage stress between adjacent turns. In the wire wound unit, the insulation on the wire must withstand a higher voltage gradient than the foil insulation. For instance, assume both coils in Figure 1 to be made of 100 turns with 500 volts on the coil. Then, each coil will have a 5-volt drop per turn. In the continuous wound wire coil, turn number 20 is in direct contact with turn number 1 and therefore, the insulation must be capable of withstanding 100 volts. If the coil was random wound, the actual voltage difference between adjacent turns can be in the order of several hundreds of volts. This could not only cause dielectric breakdown but also corona degradation. In the foil wound unit (Figure 1B), each turn is only 5-volt different from its next turn and can never be more than 5 volts between any two turns.

One further advantage occurs in the mechanical strength of the foil unit. Abrupt electrical stresses or mechanical vibrations and shock can cause the wire wound coils to fail because of the friction and abrasion between turns unless solidly cast in an epoxy resin. The expansion and contraction of the foil wound unit, because of mechanical or electrical extremes, causes no movement between the turns, thus eliminating any degradation.

SUMMARY

The design of any transformer is a compromise wherein the designer can optimize for one of many characteristics at the expense of the others. Designing for minimum weight will up the operating temperature and lower the efficiency and regulation. However, the judicious use of foil can produce a lightweight transformer without compromise of the other characteristics.

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