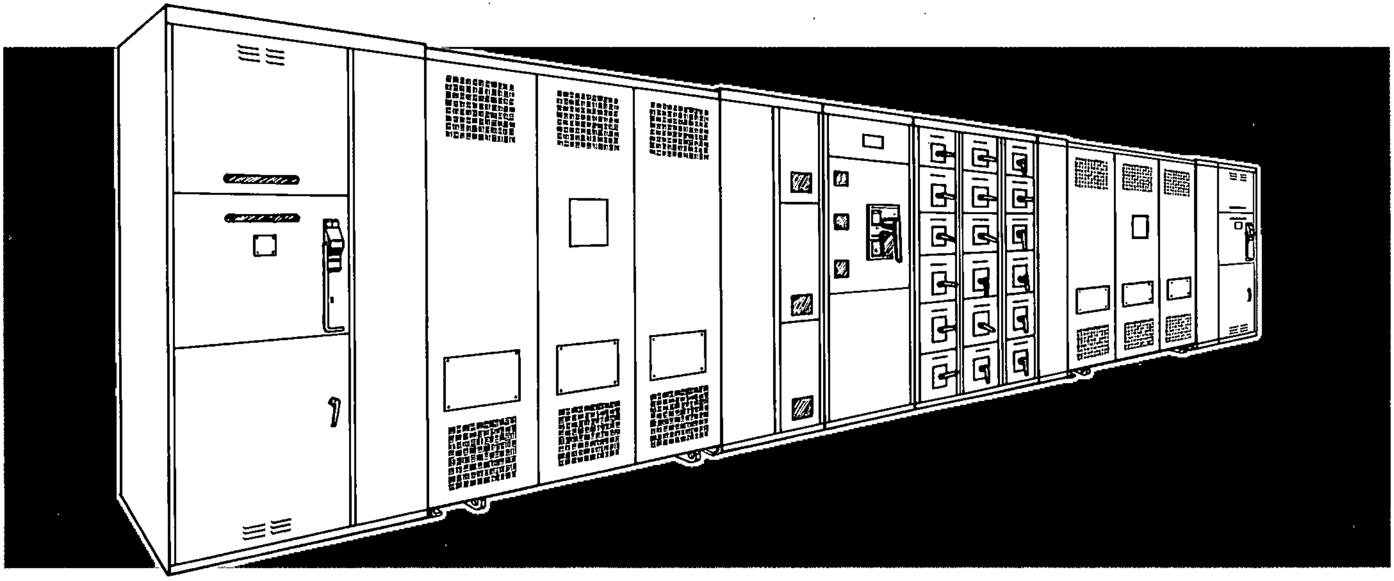
GEA-11737A

CAST-COIL TRANSFORMER



In developing the General Electric cast-coil transformer the objective was to produce a dry-type transformer with electrical, mechanical and thermal characteristics truly comparable to those of liquid-immersed transformers and also capable of satisfying present and future environmental regulations.

THE CONCEPT

- **Four simple subassemblies**
  Core, high-voltage windings, low-voltage windings, connection system.
- **Strip and sheet windings**
  These windings produce the lowest electrical stress on the insulation and their electro-magnetic properties also reduce the axial forces produced by short circuits.
- **Aluminum conductors**
  The advantages of aluminum outweigh those of any other material.
- **Cast-resin insulation of the windings**
  Protection against hostile environments. No toxic or physiological dangers to the environment.
  Mechanical strength to resist radial electro-magnetic forces.
  Outstanding dielectric strength.

This concept gave rise to the cast-coil transformer which employs a system with the following characteristic features:

- Low-loss grain-oriented silicon core steel.
- High-voltage winding comprising several individual aluminum-strip coils, vacuum cast in epoxy resin with quartz powder filler.
- Low-voltage winding of aluminum sheet (width of sheet = height of coil) insulated with a specially developed epoxy impregnated insulation.

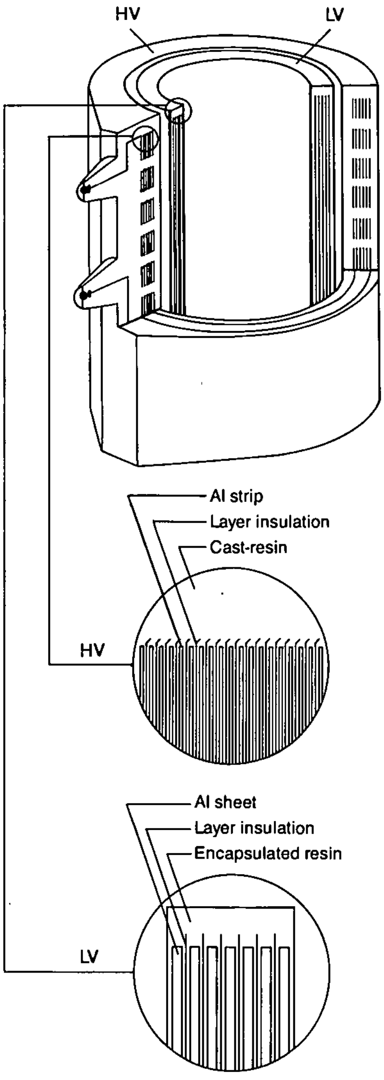


Fig. 1. HV and LV windings

- Clamping of the windings in the transformer frame through elastomeric blocks to prevent transmission of structure-borne noise.

WHY STRIP WINDINGS?

A. Because of their high power-frequency and impulse voltage strength.

Strip and sheet windings share the advantage of the voltage difference between adjacent conductors being no more than the turn-to-turn voltage of the transformer (only 5 - 50 volts, depending on the kVA of the transformer) whereas with wire windings the insulation of adjacent conductors can be subjected to several times the turn-to-turn voltage up into the kV range, depending on the type of winding.

The distribution of lightning-impulse voltages in strip and sheet windings is basically the same as in other types of windings according to the coil capacitance and capacitance to ground over the whole transformer winding. However, due to the high turn capacitances being in series in the strip winding, the distribution of the impulse voltage is almost linear within each individual coil. This ensures exceptionally high strength for the windings against lightning-impulse and switching-impulse voltages.

B. Because of the virtual absence of partial discharges.

The cast-coil transformer's high level of freedom from partial discharges at up to twice rated voltage is due to the low electrical stresses on the insulation of strip windings and to the encapsulation under vacuum.

- Partial discharges can gradually destroy the insulating material, thereby reducing the life of the transformer.
- Although a transformer may be free from partial discharges at rated voltage, they can be initiated by overvoltages and only cease at 20- to 30-percent below the inception value. Therefore, if the ratio of partial-discharge inception voltage to rated voltage is too low, there is a danger of continuous discharge under rated operating conditions.
- In the case of the GE cast-coil transformer the extremely high ratio of inception voltage to rated voltage precludes any possibility of reduction in life due to partial discharges.

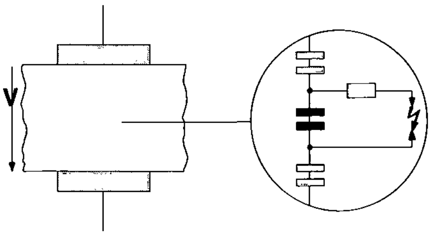
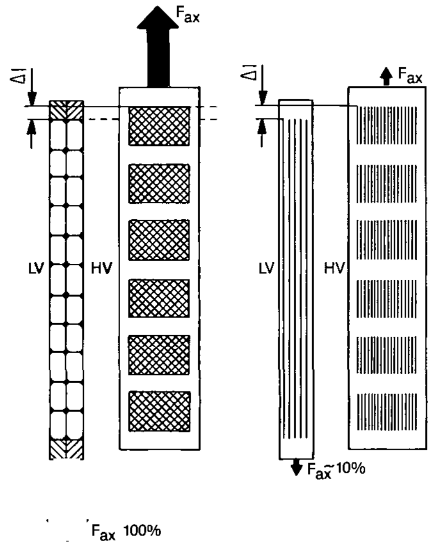


Fig. 2. Simplified representation of a defect, e.g., a bubble or void in the casting, with its equivalent circuit diagram.

WHY SHEET WINDINGS?

A. Because of their high short-circuit strength.

Unlike a wire winding, the current in the low-voltage sheet winding (where the width of the sheet is the height of the coil) can redistribute itself quite freely. It can adapt to any balanced or unbalanced electro-magnetic flux in the high-voltage winding, thereby minimizing any radial components of the leakage field. The axial short-circuit forces are reduced to approximately 10 percent of those of transformers with wire windings.



Conventional design	Cast-resin transformer

Fig. 3. Axial short-circuit forces.

The compactness of the high-voltage winding encapsulated in cast-resin and the inherently strong low-voltage sheet winding with the turns bonded solidly by the epoxy-impregnated layer insulation enable all other mechanical stresses arising from short-circuits to be accommodated easily.

High short-circuit strength is one of the principal features of cast-coil transformers.

B. Because of their low noise level.

To prevent the transmission of structure-borne noise between the core and the windings, elastic spacer blocks are clamped between the windings and the transformer frame to isolate any vibration. This particularly effective method of noise isolation is made possible by the substantial reduction in axial short-circuit forces produced by the low-voltage sheet winding.

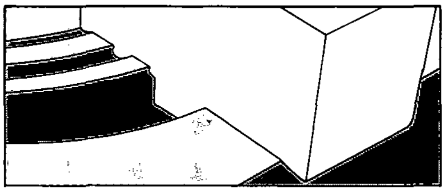


Fig. 4. Anti-vibration elastic spacer block between core and windings.

The blocks provide a break in the path of structure noise to the high-voltage and low-voltage coils and the windings themselves become sound-absorbing walls for airborne noise transmitted from the core legs.

C. Because of its low hotspot to average winding rise differential.

The full sheet winding permits rapid transmission of heat from the center of the sheet to the edges, thereby keeping the temperature differential to a minimum.

WHY ALUMINUM CONDUCTORS?

A. Because of their favorable expansion coefficients.

Aluminum strip conductors were chosen because of the great precision with which strip can be produced and a coefficient of linear expansion very close to that of the cast-resin. The methods of joining aluminum and the complexities of its mechanical strength are fully understood and present no problems in the design or operation of the transformers.

The encapsulation of metal conductors in cast-resin needs careful attention to the mechanical stresses produced in the resin by the difference between the coefficients of linear expansion. The problems involved are shown clearly in TABLE 1.

TABLE 1.

Material	Expansion Coefficient (Relative)
Cast-epoxy with Quartz Filler.	1.000
Aluminum	0.828
Copper	0.586

The greater similarity in expansion coefficients between cast-epoxy and aluminum results in less stress due to temperature variation than if copper were used.

B. Because of the low ultimate short-circuit temperature.

Normal values of load loss for cast-coil transformers with aluminum conductors result in relatively low current densities. The extra winding temperature rise resulting from short circuits of duration in accordance with ANSI Standards is therefore well within the permissable limits. (See TABLE 2)

TABLE 2

	HV	LV
Ambient Temperature	40	40
Temperature Rise	80	100
Winding Rise + Ambient	120	140
Safety margin to ultimate short-circuit temperatures of 200° C	80	60

C. Because of thermal capacity.

The higher the thermal capacity of a winding, the greater the overload

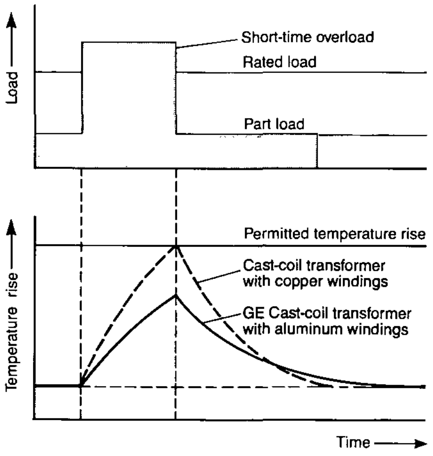


Fig. 5. Temperature variation under short-time overload.

capability of the transformer without the maximum permitted winding temperature being exceeded.

The thermal time constant of the winding is used as a basis for comparison.

In windings with equal losses, the properties of the material—specific heat, electrical conductivity, relative density—result in a greater thermal time constant when aluminum is the material than when it is copper. And the effect is enhanced further by the close thermal bonding of the cast-resin encapsulation.

OTHER IMPORTANT FACTORS

A. Insulation life.

Generally speaking, the temperature capability of the insulation is no indicator of transformer quality. It only shows that the insulation has been selected for the permitted winding temperatures. It is important that allowances be made for thermal aging of the insulation so that throughout its life it will be able to withstand normal overvoltages.

B. Vacuum casting of the high-voltage winding.

The high-voltage strip windings of cast-coil transformers are encapsulated under vacuum in casting resin with a quartz powder filler. The high proportion of inorganic quartz powder insures flame-inhibiting and self-extinguishing properties. Hence, the fire risk of cast-coil transformers is extremely low and there is no toxic pollution.

The excellent electrical properties of the cast-coil transformer—high impulse voltage capability and freedom from partial discharges at up to twice the rated voltage—are direct consequences of the strip-winding and vacuum-casting technique.

C. Epoxy-impregnated insulation for the low-voltage winding.

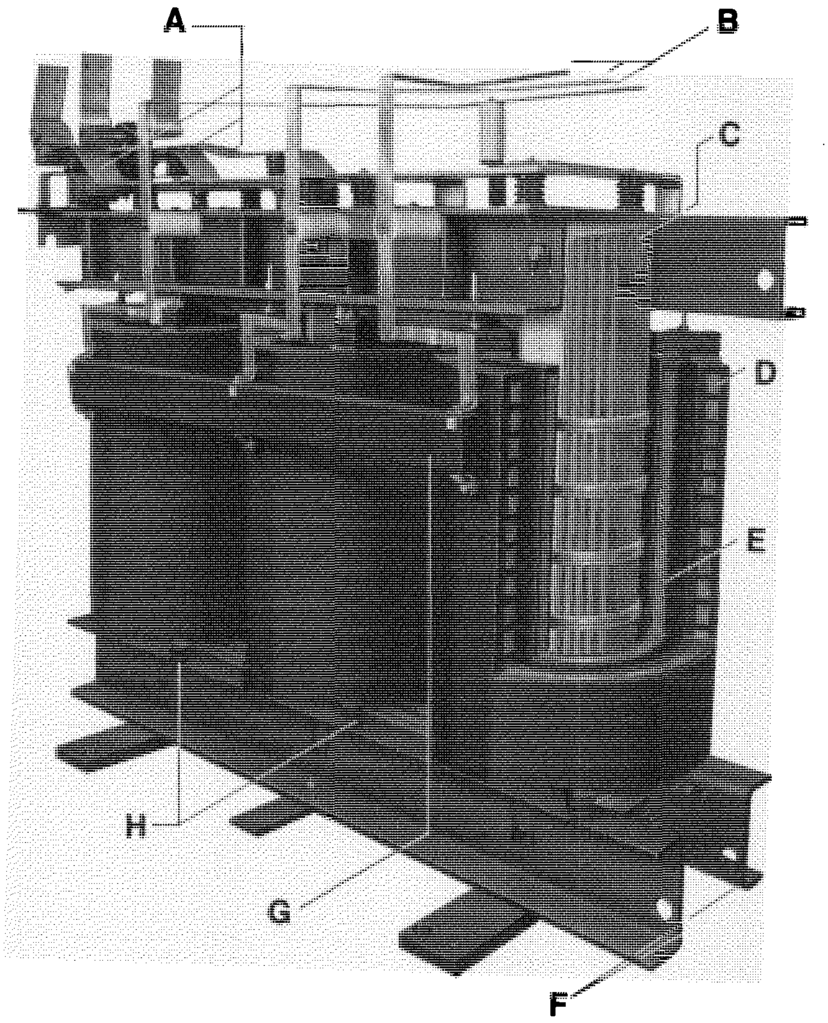
The axial short-circuit forces in cast-coil transformers are reduced considerably by the low-voltage sheet winding as described earlier, and the radial short-circuit forces are contained by the epoxy-impregnated insulation and the bonding of the winding turns.

Vacuum encapsulation is not required for low-voltage sheet windings because of the lower electrical stresses. The encapsulation of the end faces of the windings and the covering of the outer surface with layers of epoxy-impregnated insulation produce the same ability to resist moisture as the high-voltage winding.

The choice of epoxy-impregnated insulation for the low-voltage winding results in a service life expectancy equal to that of the high-voltage winding.

RESULT

The General Electric cast-coil transformer symbolizes a significant engineering achievement which has produced a modern transformer with exceptional features.



A	***Low-voltage buswork***	**E**	***Low-voltage aluminum sheet winding with epoxy-impregnated insulation***
B	***High-voltage buswork***	**F**	***Core clamps***
C	***Grain-oriented silicon steel core laminations***	**G**	***High-voltage interphase connection board***
D	***High-voltage aluminum strip winding vacuum-cast in epoxy resin***	**H**	***Winding support blocks***

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GEA-11737A 9/87/10M

Printed in U.S.A.