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Designing of Amorphous Core Distribution Transformer and Comparison with CRGO Core Distribution Transformer

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ABSTRACT*: In this paper possibilities of improvement in properties of electric distribution transformers through the use of new soft magnetic materials, mainly amorphous alloys, as transformer cores. The properties of amorphous were compared to conventional electrical cold-rolled grain oriented (CRGO). Amorphous metal is a unique alloy that exhibits a molecular arrangement that is random in structure, rather than the organized crystalline structure. By utilizing amorphous metal as a transformer core material, it is possible to achieve higher transformer efficiency. Because of the improved magnetic properties and the physical dimensions of the material, the hysteresis and eddy current losses are greatly reduced. With the application of amorphous metal cores, transformer core loss can be reduced by more than 60 %. The initial costs of amorphous core transformer are higher than that of a standard CRGO transformer but it has several advantages. In this paper the design of CRGO, amorphous core distribution transformer with square section of core (AMDTS) is compared with CRGO core distribution transformer in terms of losses, efficiency and cost.*

Keywords: *CRGO steel, transformer design, core losses, amorphous core.*

I. INTRODUCTION

Distribution transformers are used to distribute the electrical power in residential, commercial and industrial areas. Distribution transformers are energized for twenty four hours with wide variation in load; therefore they are designed to have low no-load losses. It is generally designed for maximum efficiency at about half full load. In order that the all-day efficiency is high, iron loss is made less by selecting a lesser value of flux density. In other words distribution transformers are generally designed for a lesser value of flux density. Two types of losses are inherent in the running of distribution transformers: no-load losses that occur in the transformer cores due to hysteresis and eddy current losses which are constant and present as soon as the transformer is energized and load losses that occur in the transformer's electrical circuit due to resistive losses that are a function of loading conditions. The main no-load loss is core loss, which is associated with the time varying nature of the magnetizing force and results from hysteresis and eddy currents in the core materials. Core losses are dependent upon the excitation voltage and can increase sharply if the rated voltage of the transformer is exceeded. Hysteresis losses can be reduced by selecting low core losses material (such as amorphous metal), while eddy currents can be lowered by reducing lamination thickness. The problem has been overcome to some extent with the development of amorphous metal strips. This is achieved by compacting number of thin ribbons. This strip is commonly known as `Power Core'. Amorphous strips are four times harder than CRGO steel [1] [3]. The brittleness property of amorphous metal has also made it un-friendly to the transformer manufacturers. The manufacturers of amorphous core distribution transformers are very limited in the world because of two reasons, one is its high material cost and another is its brittleness property. Because of limitation of its brittleness property, in amorphous core transformers manufacturers are using square or rectangular cross section of the core

This paper primarily focuses on design of amorphous core distribution transformer. Amorphous metal core has some merits; the non-crystalline structure and random arrangement of atoms gives low field magnetization and high electrical resistivity. Due to low field magnetization, hysteresis loss is low and due to high electrical resistivity eddy current loss is suppressed. As such core losses of amorphous metal alloys get reduced by 42 per cent and magnetizing current by 53 percent.

II. DESIGN CONSIDERATIONS

Amorphous cores are usually produced as wounded, one-side cutting ones, due to mechanical properties of amorphous ribbons. This solution ensures the correct location of air gaps inside a core and simplifies electric windings assembling as well. Amorphous transformers are produced as 1-phase or 3-phase units, with 3-limbs or 5-limbs core construction. The capacity of currently produced amorphous transformers is limited up to 10 MVA.

The cross-section of amorphous cores is larger in comparison to silicon steel ones, due to lower saturation induction of amorphous ribbons. It results in the increase of transformer dimensions and weight. An essential part of the design of a transformer consists of the determination of the ferromagnetic material cross section core and the conductor's cross-section area. These areas are determined from estimates of suitable values for the peak flux density B_m the winding space factor K_w , the stacking factor K_s, and the full-load RMS current density in the windings. This current density depends on the mode the transformers will be operated, if intermittent or in a continuous form. The space factor is the ratio between the total conductor cross-section area and the core window area. The stacking factor is defined by the ratio between the ferromagnetic material cross-section area and the total core cross-section area.

Usually, the thickness of a sheet of grain oriented silicon is 0.9 mm or higher. With the amorphous alloy this value is smaller than conventional silicon iron. This thinness, combined with its uneven surface, gives the amorphous material a space factor of only 80% compared to 95% achieved with silicon iron. The Designing of various types of core is discussed.

2.1 Design of Cold-Rolled Grain Oriented (CRGO Design)

Sectional view of core and winding is shown in Figure 1.

2.1.1 Core Design:

The various governing equations for the CRGO core design consideration are given below.

Voltage per turn, $E_t = K\sqrt{Q}$ volts

Q = KVA rating of transformer

K = Output constant (according to problem)

The output voltage of the transformer is given by,

$E_t = 4.44\, f\, \emptyset_m$ Volts

$\emptyset_m = E_t/(4.44\, f)$

Here, f = supply frequency

$\emptyset_m =$ Flux in the core

Flux in core is calculated by using flux density and area of core

So, $\emptyset_m = B_m A_i$

$A_i =$ Net Iron Area of core = $\emptyset_m / B_m$

Flux density (B_m) = 1.55 Wb/m^2 (according to problem)

Area of Circle = $\pi D^2/4$

Here D is the diameter of circle.

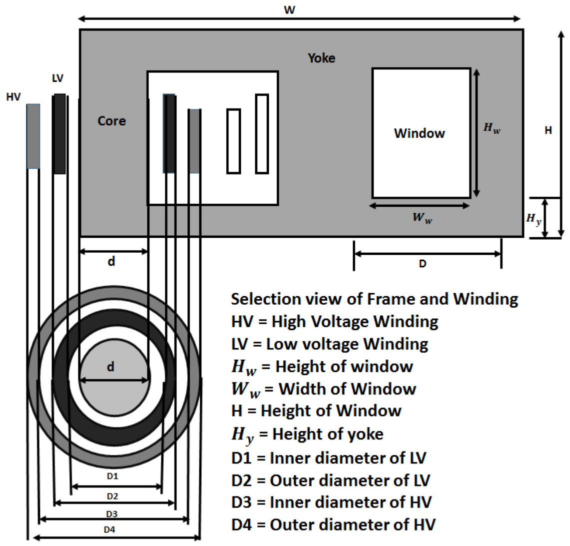

Fig 1: Circular Core

2.1.2 Window dimensions:

The area of window depends upon total conducted area and the window space factor.

Window space factor $K_w = X/(30 + KV)$

Here X is 8, 10, and 12 for 20 KVA, 50-200 KVA and 100 KVA respectively
Rating $Q = 3.33\ fB_mA_i(K_wA_w\delta)\ 10^{-3}$ KVA
A_i = Net Iron Area of core;
δ =current density
Normally, $H_w/W_w = 2\ to\ 4$
Window area, $A_w = Total\ Conductor\ Area$ /Window space factor
$A_w = H_w$ x W_w
Distance between adjacent core centers, $D = W_w + d$

2.1.3 Yoke design:

Following calculations are being done for designing the yoke for the CRGO design.
$A_y = Depth\ of\ yoke \times Height\ of\ yoke$
$A_y = D_y \times H_y$
The area of yoke is taken as 1.2 times that of core or limb to reduce the iron losses on yoke
$A_y = 1.2 \times A_i$
Flux density in yoke $B_y = \emptyset_m/A_y$
$B_y = (B_m \times A_i)/A_y$
Net area of yoke = $stacking\ factor \times gross\ area\ of\ yoke$
Net area of yoke = 0.9 × $gross\ area\ of\ yoke$

2.1.4 Overall dimension of frame:

The overall dimension of the frame is found by considering the height, length as well as the depth of frame.
Height of frame $H = H_w + 2H_y$
Length of frame $W = 2D + a$
Depth of frame = $D_y = a$

2.2 Design of Amorphous Design with Square section of core (AMDTS)

Sectional view of core and winding is shown in Figure-2

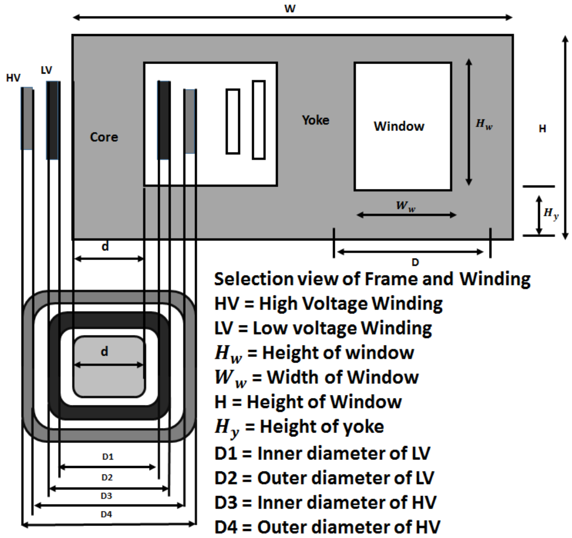

Fig 2: Amorphous Core with Square section

2.2.1 Core design:

The various governing equations for the amorphous core design consideration are given below.
Voltage per turn, $E_t = K\sqrt{Q}$ volts
K = Output constant
The output voltage equation for the transformer is given by,
$E_t = 4.44\ f\ \emptyset_m$ Volts
$\emptyset_m = E_t/(4.44\ f)$
We know that $\emptyset_m = B_m \times A_i$
A_i $Net\ Iron\ Area\ of\ Core = \emptyset_m/B_m$

(B_m) = 1.5 Wb/m^2
Cross sectional area of core $A_i = \emptyset_m/B_m$
Square core $A_i = i^2 \times Staking\ Factor$
Here i is the side of square section,
Taking stacking factor = 0.9

2.2.2 Window dimensions:

The window dimensions can be calculated from the following steps.
Window space factor $K_w = 12/(30 + KV)$
$Q = 3.33\ fB_m A_i (K_w A_w \delta)\ 10^{-3}$ KVA
$A_i =$ Net Iron Area
δ = current density in conductor
Normally, $H_w/W_w = 2\ to\ 4$
Window area, $A_w = H_w$x W_w
Distance between adjacent core centers
$D = W_w + d$

2.2.3 Yoke design:

The area of yoke is taken same as limb
$A_y = A_i$
Flux density in yoke $B_y = B_m$
Taking section of yoke as square of yoke,
Depth of yoke, $D_y = d$
Height of yoke, $H_y = A_y/D_y$

2.2.4 Overall dimension of frame:

Height of frame $H = H_w + 2H_y$
Length of frame $W = 2D + d$
Depth of frame = d

Estimation of Losses:

Core losses in CRGO = (specific core loss in watt per Kg.) CRGO x mass of CRGO in the frame
Core losses in amorphous = (specific core loss in watt per Kg.) Amorphous x mass of amorphous in the frame
Copper losses in windings = $i^2 \times R$
No-load loss of amorphous core transformers is very low comparing to conventional transformers with silicon steel core. It results from very low energy loss of amorphous ribbons and also its small thickness, what significant reduces eddy currents flow. The reduction of no-load loss in amorphous transformers is estimated at 70% - 80%.

Estimation of Cost:

Mass of CRGO in the frame = [mass of core + mass of yoke] $_{\text{CRGO}}$
Mass of amorphous material in the frame = [mass of core + mass of yoke$]_{\text{amorphous}}$
Mass of copper in winding = [(mean length of turn) x (number of turns) x (area cross section of conductor) x (mass density of copper)]
Cost of CRGO = Price per Kg. x mass of CRGO in the frame
Cost of Amorphous = Price per Kg. x mass of amorphous material in frame
Cost of copper windings = Price per Kg. x mass of copper in windings.

III. Conclusion

By using the above designing parameters the design of CRGO and AMDT are done. As well as by using these design aspects the losses and efficiency for both types are estimated and compared in tabulated form.

Table 1 dimensions of the transformer

Description	CRGO core distribution transformer (CCDT)	Amorphous core distribution transformer (AMDT)
Window dimensions		
Width W_w	179 mm	178 mm
Height H_w	358.3 mm	357.9 mm
Core or Limb		
Net iron area A_i	0.0206 m2	0.02133 m2
Laminations	d=191.8 mm, (a=163 mm, b=101.6 mm)	l=154 mm depth = 154 mm
Mass of one limb	55.63 Kg	58.02Kg
Yoke		
Depth D_y	163 mm	154 mm
Height H_y	168.1 mm	154 mm
Net Yoke area A_y	0.0247 m2	0.02133 m2
Length W	847 mm	794 mm
Mass of one yoke	160 Kg	128.71Kg
Total mass of frame	486.88 Kg	431.48Kg
Winding details		
Turns per phase	34	1639
Mean length of turn LV ,HV	644 mm,853mm	647 mm, 894 mm
Conductor size LV,HV	139 mm2, 3 mm2	139 mm2, 3 mm2
Total mass of windings	194.43 Kg	199.41 Kg

Table 2 Losses, Efficiency and Cost

Description	CRGO core distribution transformer (CCDT)	Amorphous core distribution transformer (AMDT)
Core losses in watts	1058	43.1
Copper losses in watts	2862	2913
Full load η at P.F. 0.8 lag	98 %	98.5 %
Cost of core in rupees	38,952	86,296
Cost of winding in rupees	1,12,769	1,15,658
Cost of core and winding in Rupees	151,721	201,954

From these it shows how the amorphous core transformer is better. In amorphous design no-load losses and excitation power, is reduced which yield considerable energy saving with increased cost.

Among CRGO, AMDT, the CRGO has minimum efficiency with minimum cost. As well the AMDTS has maximum cost with increased efficiency. For AMDTH the cost has been reduced with further increase in efficiency as compared to AMDTS. The cost of AMDT is more than conventional CRGO. In future to obtain more efficiency by using combination of Amorphous-CRGO is preferred. The cost of the transformer can be reduced by replacing the amorphous core with Amorphous-CRGO core, but losses are quite more than amorphous core transformer.

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