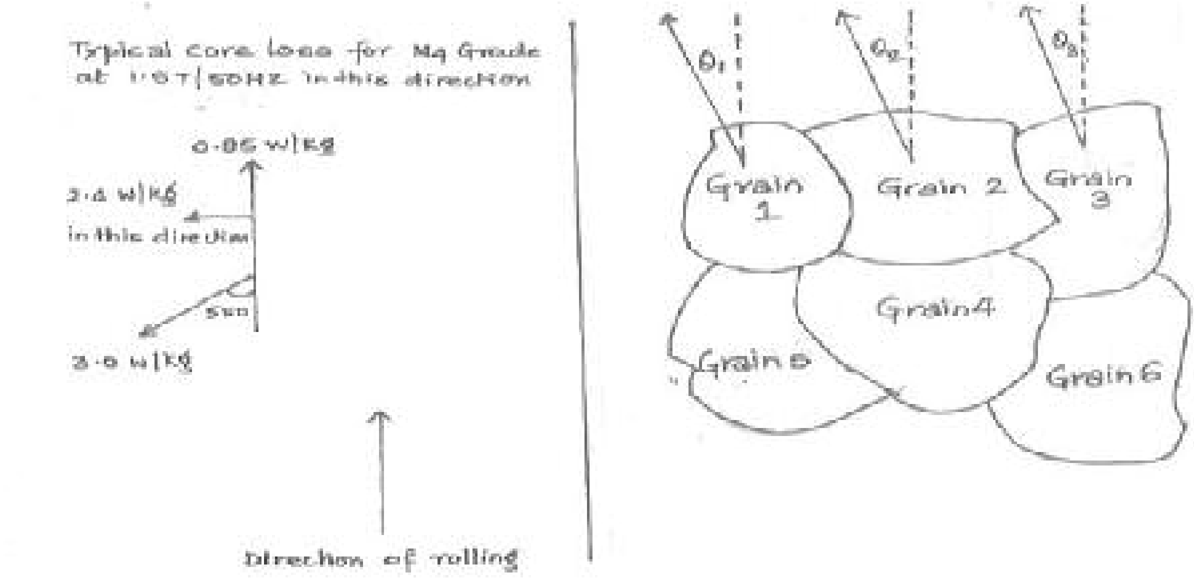
(C) PROPERTIES OF GRAINS, DOMAINS AND UNDERSTANDING OF HYSTERESES LOSSES

Every type of steel has "grains" which consist of "domains". These "domains" are nothing but electrical charges oriented in any random direction. Therefore if a Transformer were to be made of Mild Steel used as core material, the core loss would be approx. 16 to 17 w/kg at 1.5T/50Hz and the size of the Transformer would be approx. 18 to 20 times the size of a Transformer manufactured with GO steels.

The main difference between regular "carbon" steels and GO steels are:

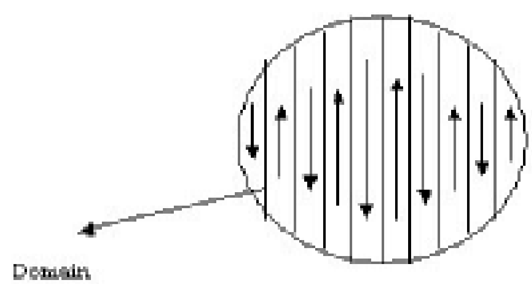
1. The size of the "grains" in GO steels are purposely "grown" and made bigger and are about 10 times the size of the grains in regular steel, thereby reducing the hystereses losses. The size of grains in CGOS is 2 mm to 5mm and HGOS is 5mm to 20mm. In regular steels the size of a grain is less than 0.5mm.
2. The grains in GO steels are all aligned almost parallel to the direction of rolling of the steel (i.e. the length of the steel). The angle of mis-orientation (i.e. deviation from the rolling direction) is maximum 7% for conventional GO and less than 3% for Hi-B GO steels. This reduces the hystereses losses as "switching" (explained later) becomes easier within the domains.
3. The chemical composition of the GO steels has about 3.2% of Silicon as an alloy, thereby increasing the specified volume resistivity of the steel, thereby reducing the eddy currents. GO Steels are also decarbonised and have no more than 0.06% of carbon in their chemical composition, which prevents aeging of the steel.
4. There is a special carlite insulation coating on the steel, which reduces the inter-laminar eddy current losses within the core.

Let us understand how exactly hystereses losses are developed with respect to GO electrical steels: The microstructure of the steel, as mentioned before, consists of numerous "grains" each of which have domains. The magnified diagram would look like this:

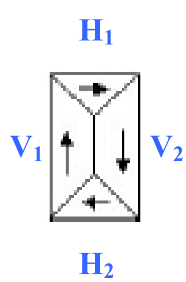


O = Angle of misorientation from Rolling direction Grains which is less than 7% for CGOS and less Than 3% for HGOS

The typical picture inside any "grain" would consist of domains like this:

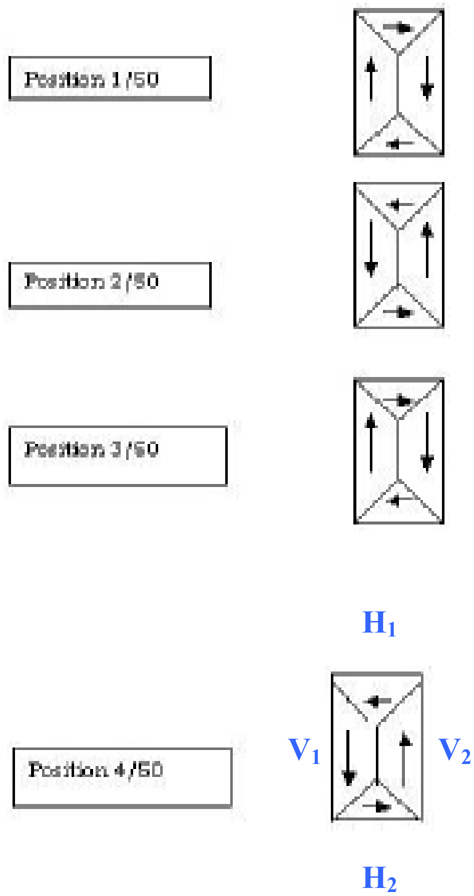


A domain when expanded would look like this:



Thus, every domain is nothing but a closed magnetic circuit as shown in the figure above.

Now consider what happens when an alternating current of 50 cycles is applied. The domains "switch" to and fro 50 times in a second. Therefore the domain looks like this as the current alternates 50 times and the diagrams below represent the direction of the domain as the current alternates.



And so on ….. 50 times every second

It is relatively very easy for the vertical switches (V1 and V2) to occur but very hard for the horizontal (H1 and H2) switches to occur.

The horizontal switches require more energy to be completed and also "lag" behind the vertical switches, and this results in heat, which results in the hystereses loss within the steel. The sum total of the energy required for the horizontal switches to occur are the total hystereses losses of the steel. Thus the larger the grains, the lower the losses as there are less total number of grains in the steel and therefore less number of "switches" and low hystereses losses.

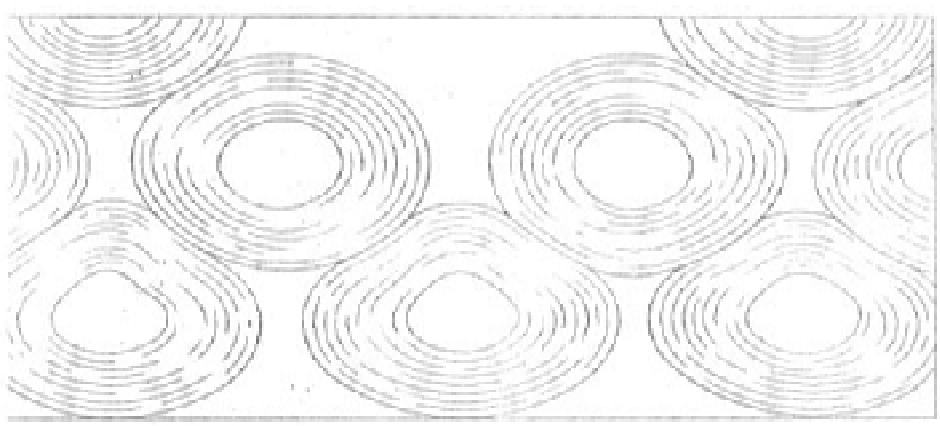
(D) PROCESSING OF CRGO STEEL INTO LaminationS

CRGO steel is a "delicate" steel to be handled with care. As the magnetic property of the steel and not the tensile strength (as is the case with most other steels) is the important quality required, it is imperative that we understand the nuances in handling, storing and processing of this steel. If these are not done properly, it ultimately leads to higher losses and the results are not as per design.

Stresses are of two types, elastic stress and plastic stress. An elastic stress is a temporary stress which any GO steel may be subjected to like some load on top of the coil or a slight force to decoil. The moment the stress is removed, the original magnetic properties of the material are restored and these are no longer damaged.

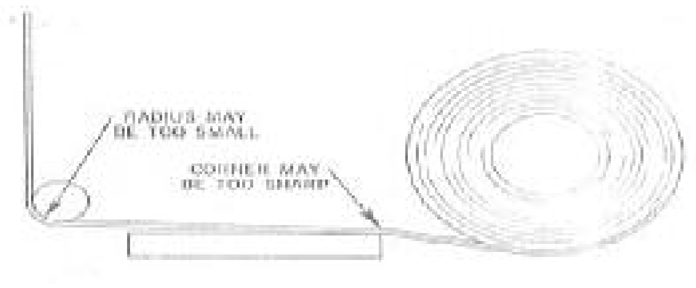
However, a plastic deformation due to winding into cores or pulling or stretching or bending GOS as shown below, can only be rectified by a stress relief annealing at around 820ºC.

1. Storage of CRGO coils has to be done properly as improper storage may result in excessive stresses unintentionally. This type of stress can be elastic or plastic depending on the severity of the wrong storage and the resulting deformation in coil shape (if any).



UNINTENTIONAL INTRODUCTION OF EXCESSIVE STRESS IN STEEL DURING STORAGE OF COILS

2. Improper handling of strip, sheets or long Laminations as shown in the diagram below, can introduce stresses that can distort magnetic properties. These stresses are usually plastic stresses.



COIL SET INTRODUCED IN HANDLING STRIP OR LONG LAMINATIONS

Tests conducted at the plant of M/s. Kryfs Power Component Ltd., Kherdi, on Soken Single Sheet Tester showed a deterioration of 7% in core loss for material that was bent. However after stress relief annealing at 820ºC, the deterioration was only 2% and most of the original magnetic properties (with respect to core loss) of the material were restored.

3. Processing operations like slitting, shearing, notching, holing etc. all damage the grain structure of the GO material around the area of fabrication and working. Most of these induced stresses are plastic stresses that can only be removed by stress relief annealing. To determine the effect of annealing, two stacks of Epstein samples measuring 30mm x 305mm were fabricated from M4 grade CRGO steel coils. Stack 1 was cut and annealed in a fast single sheet roller hearth annealing furnace at a temperature of 820ºC and stack 2 was left unannealed. Both the stacks were sent to ERDA, Vadodra for evaluation of specific core loss and B-H curves. The report is attached in Annexure 1 but the brief results are as under:

	Core loss at 1.5T/50hz(w/kg)	**Core loss at 1.7T/50Hz (w/kg)**
Stack 1 (annealed)	0.82	1.36
Stack 2 (unanealed)	1.00	1.61
Values as per Mill T.C	0.81	-

4. This clearly shows that stress relief annealing significantly restores the original magnetic value of the material and removes both elastic and plastic stresses. This is especially true when the width of the strip being worked with is extremely narrow.
5. Burrs are developed during fabrication which are unavoidable in any steel fabrication operation. Burrs decrease the stacking factor (see the definition of Burrs) In Indian conditions where most of the fabrication processes are performed manually and carbide blades are not used, burrs are easily developed and can dramatically increase the overall losses of the GO steels. Therefore the Laminations need to be deburred (to reduce / remove the burr) and also stress relief annealed thereafter as it creates an oxide film on the burrs, thereby reducing the conductivity of burr contact and minimising losses.
6. The method of holding the Laminations in a core assembly and the mechanical pressure applied to the core assembly also affects the total core loss. Uninsulated bolts or assembly by welding, would provide a low resistance path and increase eddy current losses and should therefore be avoided. High assembly pressures decrease the surface resistance and increase the inter-laminar losses and increase the total core losses. Therefore excessive clamping on the core must be avoided as the resistance of surface insulation is inversely proportional to the pressure applied. A high clamping pressure leads to breakdown of surface insulation resistivity and higher inter-laminar losses.
7. Inaccurately cut angles in mitred cores also result in a distortion of flux and increase in overall core losses. Air gaps at joints can drastically alter the values of t he total core loss.
8. Variation in thickness in the same width step of material not only results in problems in core building, but also increases the overall core loss of the material as it increases the air gaps during the assembly.
9. Residual material on Lamination surfaces like oil, dust etc. also adversely affects the stacking factor and increases the total core loss.
10. The method of assembly of core, i.e. one piece at a time or two pieces or three pieces also marginally increases or reduces the core loss (lower number of sheets in assembly results in lower core loss).

(E) DESIGN LOSSES VERSUS ACTUAL LOSSES

A regular complaint of Transformer designers is that though individual losses on single sheet tester are within the guaranteed parameters, the total no load core loss of the material on assembled core are not matching the theoretically derived no load losses.

In the light of the above discussions, it is clear that there are various other factors affecting the total no load core loss besides the intrinsic value of the core loss of the GOS material alone.

It must also be mentioned that SOKEN (Japanese) single sheet tester which is mentioned in Nippon Steel Catalogues and is known to display consistent readings and results over a number of years, requires regular calibration which is often ignored. Much cheaper locally (Indian make) versions of the single sheet tester, whilst reliable for non-grain oriented and lower grade of electrical steels are not consistent in their results and cannot be relied upon to provide accurate measurements for Grain Oriented Steels. This observation is made from practical experience.

Further, designers would be well advised to develop their own data on the points mentioned above as there is no universal standard on most of these points and the practices differ with different Transformer Manufacturers.

However, a guideline on dimensional and other tolerances extracted from major international standards from finished Transformer Laminations is given below as a quick reference guide:

ATTRIBUTE	**TOLERANCE PERMISSABLE**
Length	Upto 315mm) +0/-0.4 mm (From 315mm to 1000 mm) +0/- 0.6mm (From 1000 mm to 2000 mm) +0/- 1 mm (From 2000 mm to 4000 mm) +0/- 1.6mm
Width	Upto 150 mm) +0/- 0.25 mm (From 150 mm to 500 mm) +0/- 0.3 mm (More than 500 mm))/- 0.5mm
Angle	+ / - 5 minutes
Edge Camber	Max.1.5mm in 2000 mm length (as per BS 60 1)
Burr	25 Microns Max. or 10% of thickness, whichever is less
Stacking Factor	95.5% (for M3) 96% (for M4 & M5)

	96.5% (for M6) (as per major International standards)
Thickness	+/- 0.03 mm (as per major International standards)
Insulation Resistivity	Min.10 Ohm / sq.Cm. as per Franklin method

(F) GRADES, NOMENCLATURES AND MATERIALS

Different mills have different brand names and nomenclatures whilst producing GOS and HGOS. Many a times this creates confusion in the mind of the customer regarding the exact requirement of the material. Designers use outdated nomenclatures from old catalogues of mills which are no longer valid and this causes some confusion in the material being asked for and supplied by the fabricator.

Most mills have now switched over to the following method of grading Grain Oriented Steels: (Thickness) (Brand Name) (Core loss at 1.7T/50Hz)

For eg. Nippon Steel grade 23ZH100 means thickness 0.23mm, ZH is the brand name for Hi-B for Nippon Steel and 100 means 1.00W/kg at 1.7T/50Hz.

Similarly 23 RGH100 IS Kawasaki Steel nomenclature for the same material and 23ORSIH100, the Thyssen Krupp Eklectrical St eel (TKES) nomenclature for the same material.

Therefore TMs would be well advised to use these latest nomenclatures whilst specifying GOS requirements to avoid confusion. Even if a TM is looking for a particular core loss at 1.55T or 1.6T, then the GOS which gives the required core loss (these intermediate losses can only be derived from standard core loss curves of mills as no mill guarantees losses at intermediate flux densities) and specify the core loss of the grade of GOS required at 1.7T in the purchase order. Rather than specifying old nomenclatures like MOH, MIH or MZH which are neither precise nor convey adequate information, new nomenclatures conveying precise thickness and core loss information to the fabricator should be used.

Another important question is how to ensure the quantity of the material being used is prime? Many SEBs have initiated stage inspections of material during fabrication of the

Laminations to ensure that only Prime material is being used. Though this is a step in the right direction, it is a tedious and time consuming process but due to lack of a better solution at the moment, a generally accepted practice.

One more solution could be for Central Electricity Authority to approve fabricators of Laminations who comply with certain specified quality procedures and methods as "Approved Fabricators" who could be entrusted the work of ensuring the required quality, for certain jobs where quality cannot be compromised.

(G) CONCLUSION

Though the processing of CRGO steels appears to be a simple engineering activity of fabrication of steel into desired shapes as per the design provided, in reality it is one of the most demanding and precision jobs in the engineering industry. Therefore, it is imperative that TM have the basic knowledge of this delicately important raw material which forms the core of their Transformer. The information provided in this paper attempts to provide this basic foundation.