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Prominence of Magnetic Properties in Grain Oriented and Non-Grain Oriented Steels for Transformer Industry

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Cold rolled grain oriented (CRGO) electrical steel is a critical raw material for manufacturing of transformers, which is fully imported as it is not manufactured in India. Currently India consumes about 2.5 lakh metric tonne per annum of CRGO electrical steel and with the growth in demand of transformation capacity the consumption is estimated to be 11.5 lakh metric tonne and 13.5 lakh metric tonne respectively during the 12th and 13th five-year plan period. Magnetic cores for the wide range of modern electrical and electronic devices require magnetic materials with many combinations of properties and characteristics. The evaluation of magnetic core materials is very crucial before using for transformers, motors and Inductors.

Keywords: *Grain oriented steel (GOs), Non-grain oriented steel (NGOs), Iron loss, Elastic & plastic stress and Ductility.*

1.0 INTRODUCTION

Magnetic materials form the back bone of the modern electrical, electronics and communication industries. Based on the magnetic characteristics, magnetic materials are grouped into two classes, soft magnetic materials and hard magnetic materials. To use the transformer in electrical power applications, efficiency, stability and reliability of the transformers are necessary. The information provided in this paper attempts to give the basic foundation about magnetic materials and characteristics. Soft magnetic materials are normally used as the magnetic core materials for inductors, transformers and actuators in which the magnetic fields vary frequently. It is also clear that the hysteresis loop is as "flat" as possible, and as steeply inclined as possible. Moreover, quite generally we would like the material to have a high resistivity [1]. The soft magnetic materials are further classified in to two more categories namely, soft magnetic metal alloys and soft magnetic ferrites.

Hysteresis loss is encountered each time as the polarity of the alternating current reverses. The loss is proportional to the area enclosed by the hysteresis loop under B-H curve. "Soft" iron alloys have lower losses than "hard" high carbon steel alloys. Silicon grain oriented steel with 4% silicon, rolled to preferentially orient the grain or crystalline structure, has still lower losses. This group consists of rapidly quenched amorphous magnetic alloys containing 75–80% transition metal together with 20–25% metalloid elements like boron, phosphorus and carbon. Use of isotropic materials, in particular amorphous metals also called metallic glasses, produced by extremely fast cooling from the melt. Stuff like $Fe_{78}B_{13}Si_{19}$ is made in to very thin long ribbons and used [6]. Hard materials are sometime called as permanent magnets are used to generate static magnetic fields in electric motors. An important criterion for permanent magnets is the energy product, which is proportional to the product of B and H. Rare earth – cobalt magnets have high energy products. Hard magnetic materials

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have wider hysteresis loops as compared to that of soft magnetic materials [2]. The B-H curves with respect to hysteresis loss are shown in the Figure 1 for the comparison.

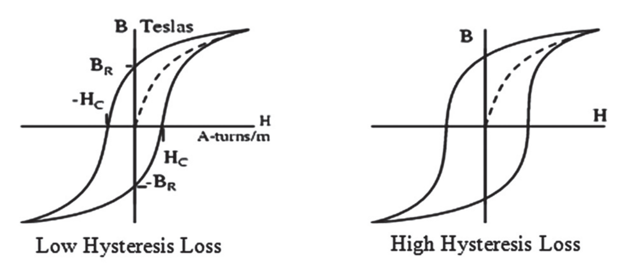

FIG. 1 HYSTERESIS LOSS WITH RESPECT B-H CURVES

Hard magnetic materials are hard ferrites, Alnicos and rare earth transition metal intermetallics.

2.0 ELECTRICAL STEEL FOR TRANSFORMER

The magnetic field distribution depends on loading conditions. Weak insulation, old and used laminations are related with the quality of raw material used. Therefore if the laminations are made from inferior quality of CRGO material then definitely there is a possibility that these reasons would be applicable [3]. Total losses of present day transformer core materials including eddy current losses are around 0.6 W/kg at 50 Hz which, on the one hand translates into an efficiency of 99.25% for the transformer, and a financial loss of roughly Rs. 52/kg and year - which is not to be neglected, considering that big transformer weigh many tons.

2.1 Oriented Electrical Steel

Oriented electrical steels are iron-silicon alloys that were developed to provide the low core loss and high permeability required for more efficient and economical electrical transformers. They are available in grades M-2, M-3, M-4 and M-6, with superior magnetic properties in the rolling direction, oriented steels are used in transformer cores. They are used in large generators and other apparatus when the design permits the directional magnetic characteristics to be used efficiently. Grain –oriented silicon iron was developed by altering the silicon content in the steel, cold rolling the strip to the desired thickness, followed by high-temperature annealing at 1200° C to evolve secondary recrystallization. Large grains were produced, by orienting in the rolling direction results in greatly improved magnetic properties along the strip [5]. However the loss arose across the strip led to considerable research on mitered joints, butt joints, and methods of utilizing. Obviously toroids here had a big advantage and subsequently C cores and E cores were introduced particularly for small transformers. Meanwhile Japan came to the fore and patented their Hi-B Steel which is extensively used today. Here larger grains are evolved and a small tensile stress is imparted to the steel by using a glass surface coating applied at high temperature and resulting in reduced electrical loss.

2.2 Non-oriented Electrical Steel

Non oriented electrical steels are iron-silicon alloys in which magnetic properties are practically the same in any direction in the plane of the material. Standard grades from M-15 to M-47 are available with the advantages of special DI-MAX processing that enhances the magnetic properties. Materials are available with fully processed as well as semi-processed, depending on grade. DI-MAX grades have superior permeability at high inductions, low average core loss and good gage uniformity [5]. In addition, cold finishing plus strip annealing produce a smooth surface and reduce buckles and waves, resulting an excellent flatness and a high stacking factor. Applications include large and small motors, large and small transformers, generators, lighting ballasts and ignition coils.

2.3 Metallic Glass or Amorphous Magnetic Alloys

One final development in magnetic materials is the production of metallic glass or amorphous soft magnetic alloys. Amorphous core is low loss, high permeability material and ideal for single and 3-phase utility in industrial distribution transformers [4]. These are like glass and have no crystalline structure. They are produced by continuous casting and rapid continuous quenching, which results in a quick transition from the fluid to the solid phase. The virtue of these materials is that thin strips, such as 0.05 mm thick and up to 0.01 mm wide in one instance, can be made directly from the casting line, thus avoiding the usual hot rolling, cold rolling, and intermediate annealing processes [6]. Unfortunately, like glass, they are hard and very brittle which makes handling and cutting uneconomic. The composition of metallic glasses may consist of some of the elements like Iron (Fe), Boron (B), Phosphorus (P), Nickel (Ni), Carbon (C), Copper (Cu), and Molybdenum (Mo), a few of these elements constituting a particular brand. Amorphous metal is unlikely to be used in large power transformers owing to its low saturation induction.

3.0 PROCESSING OF CRGO STEEL INTO LAMINATIONS

CRGO steel is a "delicate" steel to be handled with care. The magnetic property of the steel with better tensile strength is the most important quality to be required, so it is commanding that we should 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. The processing route of CGO electrical steel is shown in Figure 2.

Similarly Burrs in cutting, turnings or steel residue between laminations and gaps between yoke and core plates should be done precisely. This is the reason why the activity of manufacturing laminations should be outsourced and not done in-house. The residual steel on the edge of steel sheet where shearing or punching during fabrication has taken place, thereby increasing the thickness on the edge and reducing the stacking factor. Burrs can be reduced by accurate and precise fabrication and having cutting blades and tools well sharpened at all times. They can also be reduced by deburring and stress relief annealing [8]. This is because, manufacturing of laminations though a seemingly simple job of shearing, cutting and notching, is in reality a high precision, high accuracy job. The thickness of the sheet being handled and cut is only 0.23–0.35 mm or 230–350 microns.

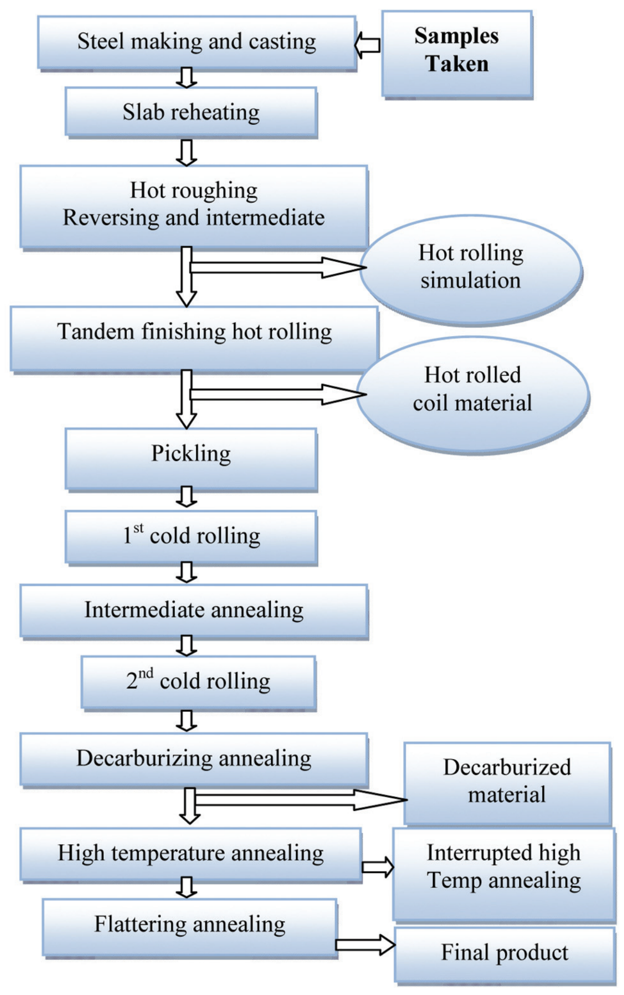

FIG. 2 PROCESS ROUTE FOR CONVENTIONAL GO ELECTRICAL STEEL.

a) **Pickling:** The starting material is ultra-pure hot rolled coils supplied to precisely determined specifications by carefully selected suppliers. The hot rolled coils are cleaned and descaled in Pickling line.

b) **Cold Rolling:** After pickling the coils are cold rolled to desired thickness with very close thickness tolerances by using modern gauge control methods.

c) **Tandem Annealing, Decarburizing and Coating:** The cold rolled coils are treated in state of the art continuous annealing, decarburizing and coating line. During decarburizing, the carbon content of the strip is reduced to a level which avoids magnetic ageing. Precisely controlled furnace parameters like strip speed, temperatures and composition of inert gas atmosphere are determined as per customer's requirement of properties. The strip is coated on both sides with one of wide choice of insulations customized to final application requirements.

d) **Slitting/Trimming:** The finished coils, after extensive quality tests, are slitted/trimmed to the dimensions required by the customers with close width tolerances.

e) **Cut to Length:** Coils are sheared to customer's specified lengths. Coils can also be sheared in shapes like parallelogram etc.

The sheet should not be bent, dented or damaged during handling as this directly affects the core loss and the magnetic property of the resultant core [5]. The dimensional accuracies in terms of length, breadth and the angles 45° or 90° as the case maybe have to be within the tolerance. The V-Notch in the yoke has to be precisely done so as to accommodate the yokes without air gaps. Holes have to be accurately punched so that the clearances of the bolts are adequate, slitting has to be perfect to avoid camber and the burrs have to be within the specified tolerance. Processing operations like slitting, shearing, notching, holing etc. all damage the grain structure of the GO material around the area of fabrication and working. To determine the effect of annealing, two stacks of Epstein samples measuring 30 mm × 305 mm 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 820º C and stack 2 was left unannealed. Both the stacks were evaluated and the specific core loss results are as per the Table.1

The method of holding the laminations in a core assembly and the mechanical pressure applied to the core assembly 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.

TABLE 1

CORE LOSS INDEX FOR ANNEALED AND UNANNEALED

Sample	Core loss at 1.5 T/50 Hz (W/kg)	Core loss at 1.7 T/50 Hz (W/kg)
Stack 1 (annealed)	0.82	1.36
Stack 2 (unannealed)	1.00	1.61
Values as per Mill T.C	0.81	–

4.0 SELECTION OF SPECIFIC GRADE OF CRGO

As the technology advances over time, super fine grades of CRGO steel, commonly known as Hi-B and laser grades are available and use of these grades helps in reducing losses. The Magnetic circuit consists of laminated iron core and carries flux linked to windings. Energy is transferred from one electrical circuit to another through the magnetic field carried by core. The core losses consist of eddy current losses and hysteresis losses. Innovated superior CRGO grades offer very low core losses even at higher flux densities which enables designers to design transformers at high flux densities. Design of very low losses transformers is achievable with developed core grades [10]. The reduction of around 2.4% in core weight and around 2% in copper weight is possible with the use of such grades in power transformers.

As per the development scheme in Figure 3 it can be seen that by using better grades of steel, the losses can be reduced by 74% from that of the conventional core transformers designed with 0.27 M4 grade CRGO steel. During the energy transfer losses incurred are called core losses. The methods like use of multi-step lap construction, elimination of punching holes and less handling of laminations while core assembly also helps in achieving reduced no load losses. The core loss characteristics are enhanced in domain refined products where laser scribing is employed. These grades have far lower core loss the possible than with Hi-B or conventional CRGO grades with same thickness.

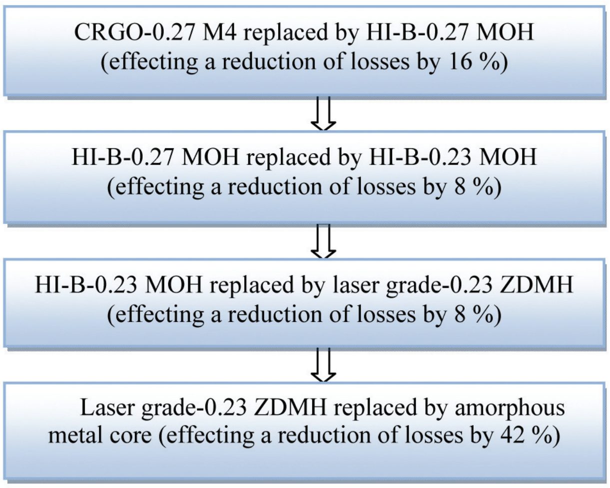

FIG. 3 DEVELOPMENT OF CRGO STEELS IN INDUSTRY.

Steel sheets with low silicon content and with low carbon content having low hysteresis losses and high permeability. As stated earlier, various grades of CRGO steel laminations with different thicknesses are available in the market and some of the widely available grades are given in Table 2. CRGO steel is basically an imported material, we need to ascertain the availability of the particular grade of material in the market before selecting it for use. For acceptable performance figures of no-load loss, no-load current, working flux density the designer should select a suitable grade of CRGO lamination from the grades readily available in the market.

TABLE 2

GRADES OF CRGO STEEL LAMINATIONS

Conventional grade (mm)	Hi-B grade (mm)	Laser grade (mm)
M6 - 0.35	MOH - 0.27	ZDMH 0.95–0.27
M5 - 0.30	MOH - 0.23	ZDMH 0.90–0.27
M4 - 0.27	–	ZDMH 0.90–0.23
M3 - 0.23	–	ZDMH 0.85–0.23

5.0 TESTING OF STEEL SHEETS FOR MAGNETIC CIRCUITS

It is highly essential to determine the magnetic, electrical and physical properties and insulation coating of magnetic steel sheets and strips. Electrical Grain Oriented steel is the one with flat rolled silicon-iron alloy usually containing approximately 3% silicon, having enhanced magnetic properties in the direction of rolling is normally used in transformer cores [9]. The Indian standard IS 649 prescribes the methods of test for determining the requirements of magnetic steel sheets and strips used for the construction of magnetic circuits of power electrical apparatus. Grain oriented electrical steels of low carbon, silicon-iron alloys have silicon contents of approximately 3% in which low core loss and high permeability in the direction of rolling are achieved by appropriate metallurgical processing [8]. IS 3024 covers the requirements of flat rolled, fully processed grain–oriented electrical steel sheets or strips intended for the construction of transformer cores operating at moderate to high inductions at commercial power frequencies.

5.1 Magnetic Characteristics

Magnetic circuit consists of laminated iron core and carries flux linked to windings. Energy is transferred from one electrical circuit to another through the magnetic field carried by core. Eddy current losses increases in the proportion to the square of the thickness of the lamination. For reducing the Eddy current losses thinner laminations are Preferable [7]. Steel sheets with low Silicon content with low carbon content will be having low hysteresis losses and high permeability. Inorganic coating, generally glass film and phosphate layer having thickness of 2–3 micron is provided on both surfaces of laminations to with stand Eddy voltages. CRGO (Cold rolled grain oriented) Steel has the minimum Epstein losses to the flow of magnetic flux along the directions of grain Orientation. If the magnetization is applied across the grain direction the core losses increases substantially. Core Design is the one of the key factor for noise level. Operating flux density, Leg centers, Core weight, Frequency of operation are closely related with noise level [8].

5.2 Contributions for Building Factor

Core which is surrounded by windings is called a limb or leg, generally vertical portion. Core which is not surrounded by windings but is essential for completing the flux path is called yoke, generally Horizontal portion. Joints near the corners are called metered joints. The angle of the metered joints is generally 45°. Building factor is defined as the ration between assembled transformer core loss Watt/kg to Material Epstein core loss (Watts/kg). The gap at core joint has significant impact on No Load Losses and No Load Current. As Compared to 0 mm gap, the increase in loss is 1–2% for 1.5 mm gap, 3–4% for 2.0 mm gap and 8–12% for 3 mm gap. Joints of limbs and yokes contribute significantly to the core loss due to cross fluxing and crowding of flux lines in them. Higher ratio of window height i.e. Leg Length to window width, Lower is the contribution of corners to the loss and hence the building factor is lower.

5.2.1 Core loss

The core loss of a magnetic material depends not only on its relative magnetic quality, but also upon the induction and frequency at which the material is used. The test methods covers the tests for the magnetic properties of basic flat-rolled magnetic properties at power frequencies 25–400 Hz using a 25 cm Epstein test frame and the 25 cm double lap jointed core with corner setting. It covers the determination of core loss, volt-amperes, rms and peak exciting current and AC permeability and related properties of flat rolled magnetic materials under AC magnetization. This test method provides a test for core loss and exciting current at moderate and high inductions up to 15 kg that is 1.5 T on non-oriented electrical steels and up to 18 kg that is 1.8 T on grain oriented electrical steels. The frequency range of this method is normally that of the commercial power frequencies 50–60 Hz [11]. Core loss limits for fully processed as-sheared material apply only to specimens of standard Epstein (30 mm) width. Because the effects of shearing strains tend to increase the core loss as the sheared width is reduced, the core loss in laminations may be slightly higher or lower than that of test specimens. Annealing eliminates possible variations in core loss due to strain effects, but variations can occur due to differences in annealing practice. Even though limits apply to magnetic quality obtained on Epstein samples, they approximate commercially attainable core loss limits The Epstein test sample shall be the standard specimen for determinations of the magnetic properties of flat rolled electrical steels, except when otherwise established by mutual agreement between the manufacturer and the purchaser. The comparison between 6.5% Si steel and gradient Si steel in terms of Iron loss is presented in the Figure 4.

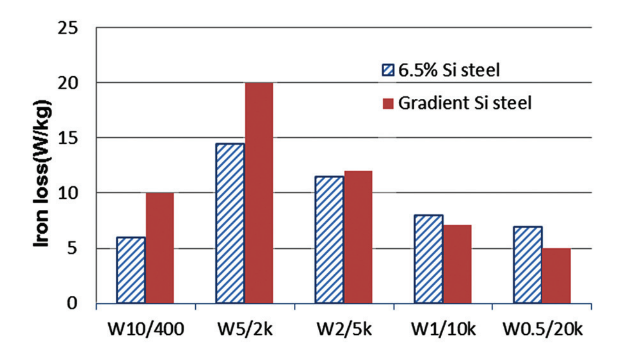

FIG. 4 HIGH-FREQUENCY IRON LOSS OF GRADIENT Si STEEL 0.10 MM THICK.

The Epstein test specimen shall consist of strips sheared or punched in a width of 30 mm and not less than 280 mm long. For ease of assembling the specimen in the test frame, it is desired to use strips slightly longer than 280 mm and a length of 305 mm is recommended. The accepted tolerances for the specified dimensions are within ± 0.8 mm.

5.2.2 Magnetic polarization

Magnetic polarization is the vector field that expresses the density of permanent or induced magnetic dipole moments in a magnetic material [11]. The origin of the magnetic moments responsible for magnetization can be either microscopic electric currents resulting from the motion of electrons in atoms, or the spin of the electrons or the nuclei. Net magnetization results from the response of a material to an external magnetic field, together with any unbalanced magnetic dipole moments that may be inherent in the material itself. Magnetization is not always homogeneous within a body, but rather varies between different points. Magnetization also describes how a material responds to an applied magnetic field as well as the way the material changes the magnetic field, and can be used to calculate the forces that result from those interactions. The specified minimum values of magnetic polarization for magnetic field strength of 800 A/m peak values are specified in IS 3024. The magnetic polarization shall be determined in an alternating magnetic field expressed as a peak value at 50 Hz.

5.2.3 Stacking Factor

The proportion of steel that would be found when Lamination sheets are stacked on top of each other as compared to a solid steel section for the same volume. It varies between 95–97% for CRGO steel coils, however it reduces with fabrication if there are "burrs" developed. This is turn would increase the overall core loss of the electrical equipment. The balance percentage of stacking factor 3–5% is air. In the measurement of stacking factor or lamination factor the test specimen is subject to pressure in compression device and the resulting volume is then determined from the measured specimen height, width and length [13]. An equivalent solid volume is calculated from the specimen mass and the true density of the specimen material. The ratio of the calculated volume to the measured volume is the stacking factor. The compression testing machine is used to predict stacking factor. Two flat smooth rigid metal plates with square edges and ends are required. They shall be of sufficient stiffness to ensure practically uniform pressure in the sample. Each plate shall be 215 mm long and have a minimum width of 50 mm so that the area of strips under pressure when testing 30 mm wide specimens will be 6450 s/m. The test strip shall be selected as representative of surface condition. The test specimens not less than 16 pieces are normally used for this purpose.

Each strip shall have a minimum length of 305 mm and width of 30 ± 0.08 mm. Stack the strips evenly and place them symmetrically between the two flat plates in the compression testing machine. Apply the pressure such that it is distributed uniformly across the test specimen. The recommended standard minimum test pressure shall be 3.5 kgf/sq. cm and is gradually applied. Similarly, the mean path length variation with respect to maximum flux density for different frequencies is shown in the Figure 5.

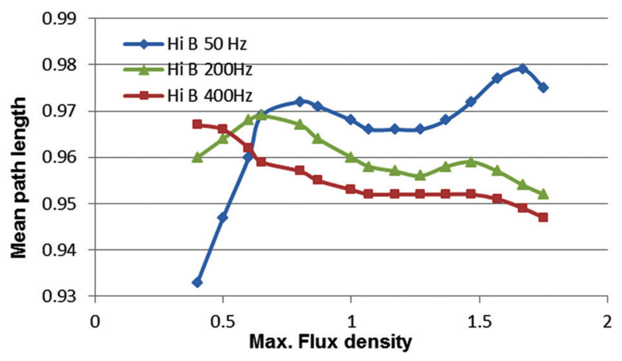

FIG. 5 MEAN PATH LENGTH VS MAXIMUM FLUX DENSITY.

5.2.4 Ductility

Ductility is a measure of how much strain a material can take before rupturing. A material with high ductility will be able to be drawn into long, thin wires without breaking. A material with low ductility is instead brittle, and though it may be strong, once it deforms enough, it will simply rupture. Another example of ductility is the property of malleability, which is the ability of a metal to be pounded into thin, flat sheets. It should be understood that these AC permeabilities in reality are based on different specified assumptions [8]. Therefore their individual values may differ considerably from each other and from the normal DC permeability μ. The evaluation of magnetic material through testing as per national and international standards gives the innovative ideas to improve the quality of magnetic materials further in the transformer industry.

5.2.5 Surface Insulation Resistance

Eddy currents will flow not only within core laminations, but also within the core as a unit, across the lamination surfaces. Laminating a magnetic core is ineffective in keeping excessive currents from circulating within the entire core unless the surfaces of the laminations are adequately insulated and burrs are small. 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. The resistance of lamination surface insulation can be considered quite adequate when the inter laminar power loss is limited to a small fraction, usually about 1–2%, of the total core loss. What magnitude of insulation is adequate and which of the much available surface insulation should be used are somewhat complex questions [10]. The readings by the Franklin Test can be used directly to indicate satisfactory levels of surface insulation resistance. In any event, the indicated resistance values obtained by this test are not directly convertible to resistance values that would be obtained by the stack method. Because the Franklin Test eliminates the effect of burrs and other variables on insulation values, requires little time, and provides more reproducible measurement, it has become the most widely used method for the control of the application of insulative coatings. The stack method probably gives resistance values more closely related to electrical design factors involved in interlaminar core loss but is less useful for control of coating application.

6.0 EFFECT OF STRESSES ON MAGNETIC PROPERTIES

The magnetic properties of electrical steels are especially sensitive to stress. Substantial reductions in magnetic properties can be caused by a stress of only a few hundred pounds per square inch which would, of course produce an elastic strain. Likewise, stresses that produce plastic deformation of electrical steel create even greater changes in the magnetic properties. These changes occur because the metal crystals in the strained metal are distorted [14]. This distortion of the crystal or atomic structure affects the relationship between magnetizing force and induction, and consequently affects all the magnetization characteristics of the material. Normally, stresses create a harmful effect by causing a degradation of magnetic properties.

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 can only be rectified by a stress relief annealing at around 820º C. Storage of CRGO coils has to be done properly as improper storage may result in excessive stresses unintentionally. Improper handling of strip, sheets or long laminations can introduce stresses that can distort magnetic properties. 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. Tests conducted at the plants showed a deterioration of 7% in core loss for material that was bent [14].

However after stress relief annealing at 820º C, the deterioration was only 2% and most of the original magnetic properties with respect to core loss of the material are improved. If the stress is so low that it creates only an elastic strain in the metal, removal of the load or restraining force will permit the metal to return to essentially a stress-free condition. But if material has been plastically deformed, it will retain a permanent set and likewise retain stresses even after the load is removed. During fabrication of electrical steels into cores, it is obvious then that preventing elastic strains prevents the stress. Stresses introduced into electrical steel as it are being wound into cores or as laminations are assembled can be eliminated only by annealing [13]. When electrical steels are fully processed by the steel producer, they are annealed under carefully controlled conditions of temperatures, time and atmosphere to obtain the desired magnetic properties. This mill anneal, at comparatively high temperatures, develops final magnetic quality through several accomplishments. These include developing the proper metallurgical structure, insuring that desired chemical refinement will take place, and developing some degree of surface insulation for certain grades. After such an anneal, electrical steel is substantially free of stress. But stresses will be introduced by subsequent operations such as shearing and coiling that elastically strain or plastically work the steel. Such stresses can materially influence the selection of material or the design for a given application unless the stress is removed.

7.0 CONCLUSION

The discussion above provides a general guideline to the CRGO processors and transformer manufacturers to produce a better product. Empirical methods can model all components of no-load loss while numerical methods are able to analyze different parameters accurately. In case the materials beyond tolerance limits are used, the performance of the transformer will be adversely affected. Though the processing of CRGO steels appears to be a simple engineering activity, the fabrication of steel into desired shapes as per the design is one of the most demanding and precision job in the engineering industry. The steel industry in India should be in a position to manufacture the electrical grade CRGO to avoid the importing from other countries. There are several areas in magnetic materials where concerted research and development efforts are desirable that is domain refined high permeability grain oriented silicon steels, amorphous magnetic alloys with ultimate objective to use in distribution transformers. Moreover, studies on composite alloys like iron-nickel-neodymium alloy and Mn-Zn ferrites are on high demand to ensure better performance from the transformer core.

APPENDIX A

Max flux density (T)	Mean path length (m)		
	Hi-B 50 Hz	Hi-B 200 Hz	Hi-B 400 Hz
0.4	0.933	0.96	0.967
0.5	0.947	0.964	0.966
0.6	0.96	0.968	0.962
0.65	0.969	0.969	0.959
0.8	0.972	0.967	0.957
0.87	0.971	0.964	0.955
1	0.968	0.96	0.953
1.07	0.966	0.958	0.952
1.17	0.966	0.957	0.952
1.27	0.966	0.956	0.952
1.37	0.968	0.958	0.952
1.47	0.972	0.959	0.952
1.57	0.977	0.957	0.951
1.67	0.979	0.954	0.949
1.75	0.975	0.952	0.947

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