Dry-type transformers are often exposed to corrosive environments in both indoor and outdoor applications such as industrial or marine environments

CORROSION PROTECTION OF CORE STEEL IN DRY-TYPE TRANSFORMERS

Anticorrosion coating: some dos and don'ts

ABSTRACT

This article demonstrates how corrosion of core steel starts, presents its negative effect on transformer's efficiency, talks about the types of coating used on core steel material as well as the methods used in applying those layers of coating. It also provides a collection of data and best practices useful to identify the proper method for anticorrosion painting of the stacked iron core in dry type distribution transformers including the difficulties that may be encountered during this operation and the measures to be taken to eliminate the mentioned difficulties. In addition, this paper also presents the quality control checkpoints for final verification of an operation that is so simple, yet so important in preserving a fundamental part of the transformer which helps increasing its life time and decreasing the need for future maintenance.

KEYWORDS

core, dry-type transformers, process, assembly

1. Introduction

Dry-type transformers are often exposed to corrosive environments in both indoor and outdoor applications such as industrial or marine environments. Industrial and environmental factors such as rain, snow, wind, dust, pollution, ultraviolet rays, and sea salt contribute to the degradation of protective coating applied to the transformer. The core steel laminations within the active parts of the transformer are especially susceptible to corrosion due to the aforementioned corrosive agents in combination with the high operating temperatures and vibrations of the core that occur while the transformer is in service. Therefore, there is a need for putting a spotlight on corrosion-resistant coatings for dry-type transformer cores.

ABB is a pioneer in the field of dry-type transformers manufacturing. For over 40 years ABB has provided continuous innovation, research and development for their production and engineering methods which offer the technologies necessary for achieving high reliability performance and lifetime. The processes described in this article, developed along the years of research, are just one example of ABB's leading technology in the transformers industry to deliver high quality products.

2. Properties of core steel

Electrical steel (also called silicon steel, core steel or transformer steel) is special steel tailored to produce certain specific magnetic properties. The magnetic domain can be easily aligned in one or the other direction. The magnetic permeability is high i.e., the material allows easy formation and accumulation of the magnetic field within the core. Also, electrical resistance is high enough to prevent eddy current losses. The processes described in this article, developed along the years of research, are just one example of ABB's leading technology in the transformers industry to deliver high quality products.

3. Corrosion theory and effect

Rust occurs on the outer layer of the steel laminations where oxygen comes into contact with the steel at the lamination edges, Figure 1. Considering that the core is tightly laminated, the rust does not occurs between layers. Since the magnetic flux travels internally parallel to the laminations, the flux does not go perpendicularly through any layer of rust; those laminations are not affected by rust on the outside. On the other hand, the iron in the steel oxidizes and produces rust, which grows to be approximately six times the volume of the original material [1].

Rain, snow, wind, dust, pollution, ultraviolet rays, and sea salt contribute to the degradation of protective coating applied to the transformer

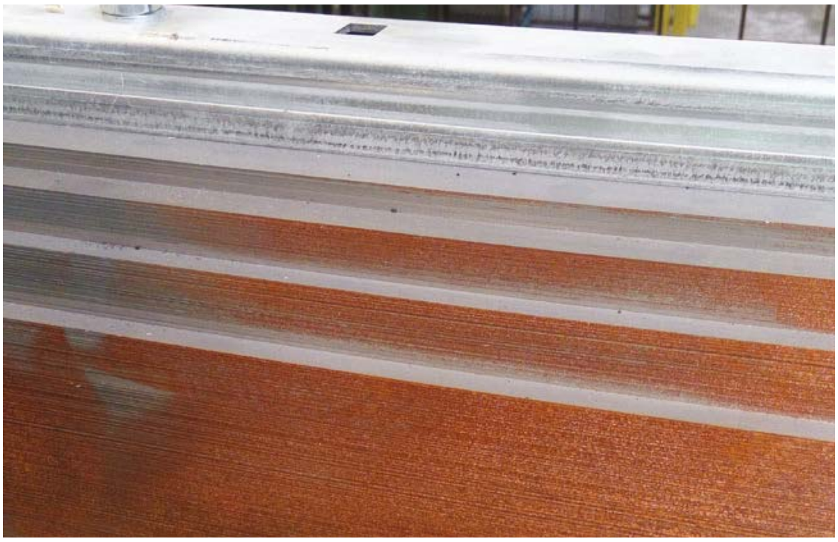

Figure 1. Rust on the core lamination edges

After succumbing to rust, the core section gets bigger and that causes great losses [2] as illustrated in the equation below.

$$W_e = k_2 f^2 t^2 B_{eff}^2 / \rho \qquad (1)$$

where:

W_e is eddy current loss in watts/kg
k_2 is a constant for the material
f is frequency, Hz
t is thickness of the material, mm
ρ is the resistivity of the material
B_{eff} is the flux density corresponding to the r.m.s. value of the applied voltage

With time, the transformer's core can get seriously rusted, and the core's structure becomes unstable which increases the core noise. Therefore, it is necessary to minimize any gaps in the magnetic circuit during manufacturing to minimize core losses and exciting currents.

Electrical steel is usually coated to increase electrical resistance between laminations, reducing eddy currents and providing resistance to corrosion and rust.

Trying to find a solution to the rust dilemma, we resort to lamination coating, the process that takes place in steel mills as a part of the silicon steel manufacturing process or to barrier coating which is done manually after core assembly in the workshop.

4. Lamination coating

Lamination coating takes place during the manufacturing of core steel material. Therefore, we can take a quick look at the production cycle of the aforementioned process.

4.1. Core steel manufacturing process

Transformers cores are mainly made from a type of electrical steel called cold rolled grain oriented (CRGO) silicon steel because it helps in reducing operational costs and increasing the efficiency. When cold rolling is done, the grains are elongated in one direction and narrowed in the perpendicular direction. Hence, due to their shape, it becomes easier for

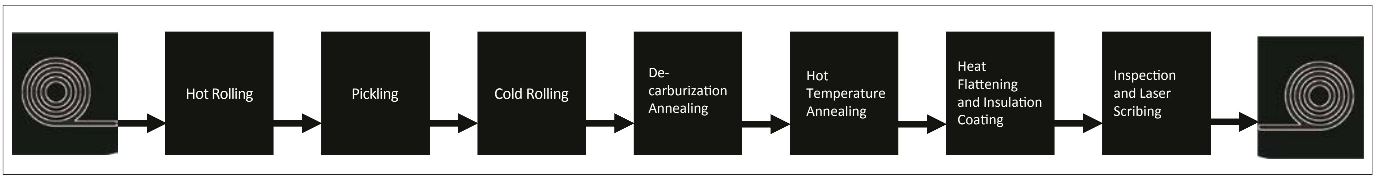

Figure 2. CRGO Manufacturing process steps: Hot Rolling, Pickling, Cold Rolling, Decarburization Annealing, Hot Temperature Annealing, Heat Flattening and Insulation Coating, Inspection and Laser Scribing

Table 1. ASTM A976-03 classifies different types of coating for electrical steel [4]

Classification	Description	For rotors and stators	Anti-stick treatment
C0	Natural oxide formed during mill processing	No	No
C2	Glass like film	No	No
C3	Organic enamel or varnish coating	No	No
C3A	Like C3 but thinner	Yes	No
C4	Coating generated by chemical and thermal processing	No	No
C4A	Like C4 but thinner and more weldable	Yes	No
C4AS	Anti-stick variant of C4	Yes	Yes
C5	High-resistance similar to C4 plus inorganic filler	No	No
C5A	Like C5, but more weldable	Yes	No
C5AS	Anti-stick variant of C5	Yes	Yes
C6	Inorganic filled organic coating for insulation properties	Yes	Yes

The core steel laminations are especially susceptible to corrosion due to the aforementioned corrosive agents in combination with the high operating temperatures and vibrations

Figure 3. Equal lengths of intersected areas can be a clear indication of straight perpendicular limbs

the domains to change polarity back and forth along the length of the grain.

CRGO manufacturing process, depicted in Figure 2, includes the following steps: hot rolling, pickling, cold rolling, decarburization annealing, hot temperature annealing, heat flattening and insulation coating, inspection and laser scribing. The second to last process includes insulation coating. During this process, the insulation coating is applied by using a continuous coater.

4.2. Properties of lamination coatings

There are various coatings, organic and inorganic, and the coating used depends on the application of the steel. The type of coating selected depends on the heat treatment of the laminations, whether the finished lamination will be immersed in oil, and the working temperature of the finished apparatus. Very early practice was to insulate each lamination with a layer of paper or a varnish coating, but this reduced the stacking factor of the core and limited the maximum temperature of the core [3].

5. Barrier coating

Barrier protection is perhaps the oldest and most widely used method of corrosion protection. It acts like a barrier by isolating the base metal from the environment. Like paints, the hot-dip galvanized coating provides barrier protection to steel. As long as the barrier is intact, the steel is protected and corrosion will not occur. However, if the barrier is breached, corrosion will begin. Because a barrier must remain intact to provide corrosion resistance, two most important properties of barrier protection are adhesion to the base metal and abrasion resistance. Coatings such as paint that have pin holes are susceptible to penetration by elements causing under film corrosion to spread rapidly [5].
The variables which govern the success of anti-corrosion coating's application and subsequent performance are:
- Conditions during application
- Surface preparation
- Methods of application
- Coating thickness

6. The dos and don'ts of painting the transformer's core

6.1. Before core coating starts

Take into consideration the following check points prior to the coating process. A good preparation will make the job easy and reduce the risk of rework which may cost you time, money or both.
Do the coating process in a closed dry area, preferably in a dust free environment.
Do measure the dimensions of the core and the stacking height of the core steps to make sure they comply with the design values. Disassembly of the stacked core after painting to correct any dimensional deviations could cause damage to the laminations and produce gaps between layers after re-stacking.
Do check the straightening of the core limbs. The core should be placed on a levelled floor or assembly station so that the limbs are positioned vertically. Equal lengths of intersected areas can be a clear indication of a straight perpendicular limbs as shown in Figure 3.

Do not get the core off the stacking rig until you have firmly tighten the bonding fixtures along the height of the limbs and bolts of the lower clamps according to the recommended torque values as shown in Figure 4.

Do remove dust, oil or foreign particles off the surface of the core using dry clean cloth or compressed air at a maximum pressure of 2 bars.

Do not use chemicals or solvents like isopropyl alcohol, acetone or lacquer thinner in the cleaning process unless you necessarily have to. Denatured alcohol is for local use only.

Do remove adhesive tapes or any fixtures used for binding core laminations after stacking process is complete (if possible) in order to make it easier to reach all areas of the core's surface as shown in Figure 5.

Rust occurs on the outer layer of the steel laminations and grows to be approximately six times the volume of the original material

Figure 4. Bonding fixtures along the height of the limbs and bolts should be firmly tightened before the core is taken off the stacking rig

Figure 5. Adhesive tapes or any fixtures used for binding core laminations should be removed after stacking process is completed

Figure 6. Areas that will not be painted, such as clamps or core leg plates should be isolated by using the paint masking tape

Figure 7. All core parts should be completely covered with the paint layer, especially the areas that are hard to reach such as corners or tight spots

Note: In certain instances, it is necessary to keep the core laminations bonded using iron screw clamps to guarantee that laminated limb is intact.
That makes it difficult for the paint brush to reach certain spots. Therefore, it is advised to carefully manoeuvre around those clamps using the brush in orde not to leave any areas on the surface uncoated.
Do Isolate areas that will not be painted, like clamps or core leg plates, by using paint masking tape. This will keep the aesthetic look of the active part, as well as save any time wasted for touch ups or paint residue removal after painting is complete as shown in Figure 6.

6.2. Coating application process

Safety first. Make sure you take the proper safety measures in addition to wearing the correct PPEs to protect yourself, in accordance with the coating material's safety data sheet and the safety risk assessment of the process itself (if any).

Do not use oil-based paint. Instead, use epoxy coating because it will provide the desired degree of protection, it is waterproof and resistant to salts, diluted acids, alkalis and a wide range of different chemicals and solvents.
Do not use synthetic paint brushes because the styrene in the epoxy paint may dissolve the synthetic bristles and cause contamination.

The type of coating selected depends on the heat treatment of the laminations, whether the finished lamination will be immersed in oil, and the working temperature of the finished apparatus

Do make sure that all core parts are completely covered with the paint layer, especially the areas which are hard to reach like corners or tight spots adjacent to the lower clamps as shown in Figure 7.
Do check the surface of the core 60 minutes after the completion for coating defects or dents.
Do repair paint run, sagged or wrinkled paint surface by applying fresh paint in thinner coats over the area, until it is evened out with the surrounding surface as shown in Figure 8.

Do not start assembly of coils until at least 8 hours have passed since the paint process was completed to make sure the coating is completely dry.

6.3. Final check

After the coating process is completed and the paint is completely dry, a final check has to be done. Most of the checkpoints require only visual inspection which means that the assigned inspector has to have the necessary knowledge concerning coating defects' types, classification and causes.
Do examine the core for coating defects such as peeling, running, crackling, dripping, and sagging before you start removing the isolating layer put over the clamps.
Do measure the coating thickness using a digital coating thickness gauge suitable for ferrous substances. Coating thickness should be in the range of 120 to 200 µm or 5 to 8 mils as shown in Figure 9.

7. Salt spray test

The validation of the processes and their accreditation with third party certification are key elements to guarantee the quality of the final results and their con-

The coating process should be performed in a closed dry area, preferably in a dust free environment

sistency over time. With the aid of an accredited lab, the so-called salt spray test is conducted on a painted specimen providing the means for evaluating the basic corrosion performance of our coating system or process after the exposure to corrosive environments.

Salt spray test takes these products / materials and exposes them to controlled conditions to measure these corrosive properties. ASTM D610 is one of the many corrosion specifications used to evaluate samples that have been exposed. Samples are placed inside a chamber and exposed continuously to an atomized / fog salt solution and along with a controlled temperature. Type IV deionized water with 5 % of salt by volume is used in the salt solution that causes the corrosive behaviour. Aside from the corrosive behaviour affecting the visual aspect of the samples that are tested, physical and electrical aspects can also be evaluated to ensure the product or material is still functioning.

Figure 8. Paint run, sagged or wrinkled paint surface should be evened out with the surrounding surface

Figure 9. Measuring the coating thickness using a digital coating thickness gauge

Bibliography

[1] BS EN ISO 9223: 2012, *Corrosion of metals and alloys – Corrosivity of atmospheres – Classification, determination and estimation*, BSI

[2] M. J. Heathcote, *The J & P Transformer Book*, twelfth edition, page 41

[3] H. W. Beatty, D. Fink, *Standard Handbook for Electrical Engineers 11th ed.*, pages 4-111

[4] ASTM A976 – 03 (2008), *Standard Classification of Insulating Coatings by Composition, Relative Insulating Ability and Application*

[5] American Galvanizers Association, Corrosion protection, https://galvanizeit.org/hot-dip-galvanizing/why-specify-galvanizing/corrosion-protection

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