Power transformer magnetic shunt topologies: A brief review

ABSTRACT

The use of magnetic shunts in power equipment is necessary to reduce the stray losses and possible hot spots in magnetic structural and support elements. This article presents a brief review of interesting magnetic shunt configurations utilized in the power transformer industry in the last 30 years and some research about new magnetic shunt topologies is presented. Real magnetic shunt topologies utilized in power transformers are briefly presented and discussed.

KEYWORDS:

magnetic shunt, shell-type transformer, electrical steel, stray field, leakage field, grain-oriented electrical steel

Magnetic shunts are employed in power transformers to avoid the penetration of stray fields in structural and support elements, reducing the power losses and the presence of hot spots

1. Introduction

Magnetic shunts are employed in power transformers to avoid the penetration of stray fields in structural and support elements, reducing the power losses and the presence of hot spots or high temperatures [1], [2]. Magnetic shunts are generally composed of grain-oriented electrical steel (GOES) laminations, which have a high relative permeability, especially in the rolling lamination direction. The rolling direction of the GOES laminations must be aligned with the main stray field paths to secure a good shunt effect and to protect effectively the structural and support elements of power transformers. High power losses and possible hot spots could be produced if the magnetic shunts are wrongly aligned and positioned with the main stray field paths [3]. Figure 1 (a) shows the typical edgewise magnetic shunt lamination configuration used in power transformers [2]. The shunt dimensions, shunt location, and number of magnetic shunts shall be optimized to avoid shunt magnetic saturation and a low shunt effectivity [4], [5]. Figure 1 (b) shows the magnetic shunts mounted on the LV tank wall side and the end wall of a core-type power transformer.

In core-type transformers, vertical shunts are employed to protect the LV and HV tank wall sides and the end tank walls from high stray fields

There is interesting and practical research about new shunt topologies for power transformers. For example, in [6] the authors analyzed the idea of the use of horizontal magnetic shunts to protect the tank walls of a 200 MVA core-type transformer. Generally, in core-type transformers, several vertical shunts are employed to protect the LV and HV tank wall sides and the end tank walls from high stray fields, as shown in Figure 2 (a). The vertical shunts pretend to protect the entire tank wall surfaces, but with the use of horizontal shunts, the authors sought to protect only the top and bottom HV and LV tank walls located in front of the transformer coils where the stray field is high, reducing the amount of electrical steel used for the magnetic shunts, as shown in Figure 2 (b). The authors optimized the horizontal shunt topology, and they concluded that there was a reduction of 9% in the tank stray losses using the horizontal shunts compared with the use of vertical shunts. In addition, the authors reduced the total amount of shunt material by 25% using horizontal shunts. Similar research about the use of horizontal and vertical shunts in a 650 MVA core-type transformer was presented in [7] where the power loss reduction efficiency of the horizontal shunts is presented. In [8], the authors analyzed the use of GOES laminations and non-oriented electrical steel (NOES) lam-

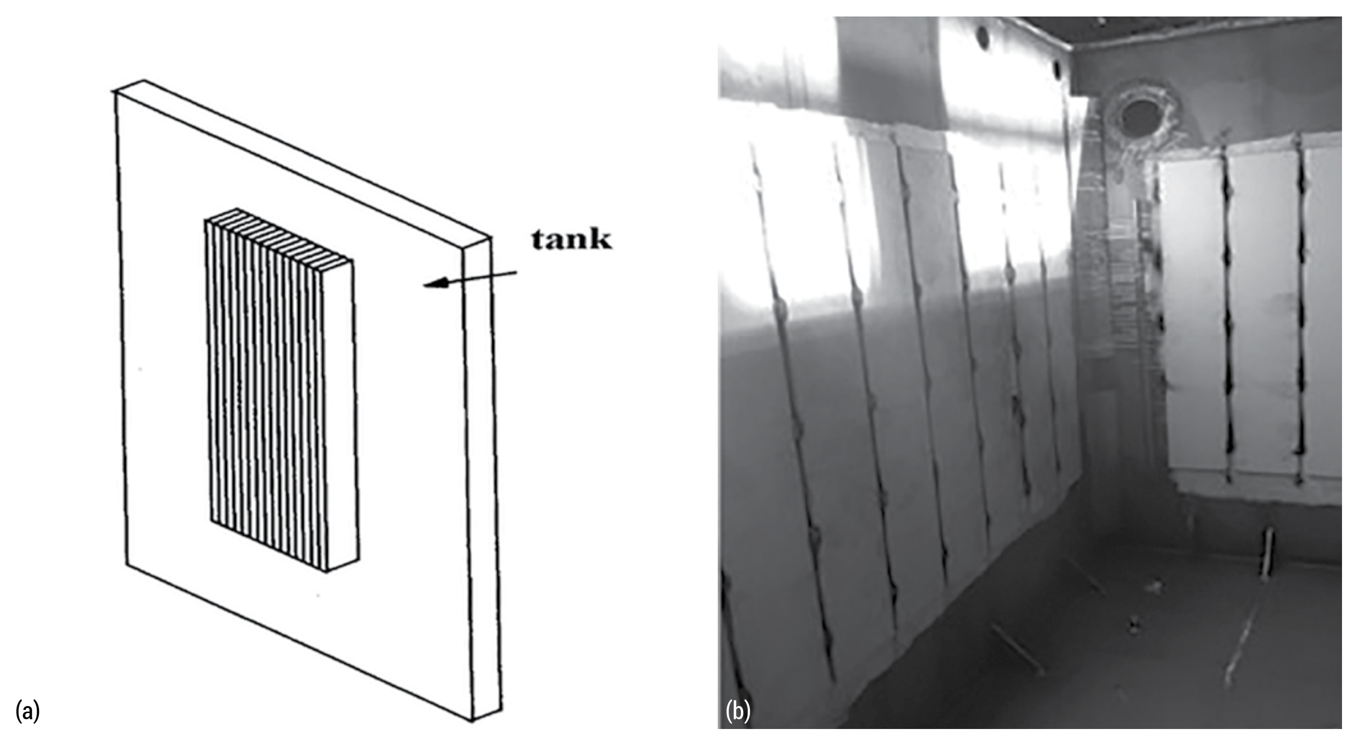

Figure 1. a) Edgewise magnetic shunt configuration [2], b) magnetic shunts of a core-type power transformer.

> **This magnetic shunt topology with tank wall stepped shunts is utilized to reduce the distance between coils and tanks, reducing the overall dimensions**

inations in the vertical magnetic shunts of a 190 MVA core-type transformer. The NOESs have lower relative permeability compared with the GOESs, and the NOESs have similar magnetic properties in the rolling and transverse lamination direction compared with the GOESs. The authors analyzed and compared the use of NOES shunts and GOES shunts, and they concluded that NOES shunts produce 9% more stray losses compared with GOES shunts, and the use of NOES shunts increased 2% the transformer weight. In addition, the authors didn't find overheating issues in the tank walls using NOES shunts. Finally, the authors concluded that there is a shunt material reduction cost of 26% using NOES shunts compared with GOES shunts. In [9], the authors analyzed the use of magnetic shunts in the core frames of distribution transformers to protect them from the stray field produced by closed high current leads. They demonstrated that it's possible to reduce more than 90% of stray losses in the core frames using magnetic shunts.

2. Magnetic shunts in tank walls

Some interesting topologies have been utilized in power transformers during the last 40 years. More interesting topologies have been seen in shell-type transformers compared with core-type transformers. The main reason is that in shell-type transformers, the coils are closest to the tank walls and other support and structural elements, and the designs of shell-type transformers are more compact than those of core-type transformers [1]. Figure 3 shows the magnetic shunts in a single-phase shell-type power transformer, and with a combination of vertical and horizontal shunts covering the tank walls of the transformers. The vertical shunts create a magnetic path for the stray field coming from the top and bottom regions of the coils, and the horizontal shunts create a magnetic path for the stray field coming from the limb and corner regions of the coils [1].

Figure 4 shows an interesting and gradual magnetic shunt topology in a three-phase shell-type transformer. This shunt topology has a design like a "bell curve" covering the tank walls located in front of the top and bottom coil regions. Vertical and horizontal shunts with different lengths are used to cover the main tank walls of the transformer. The vertical shunts create a magnetic path for the stray field coming

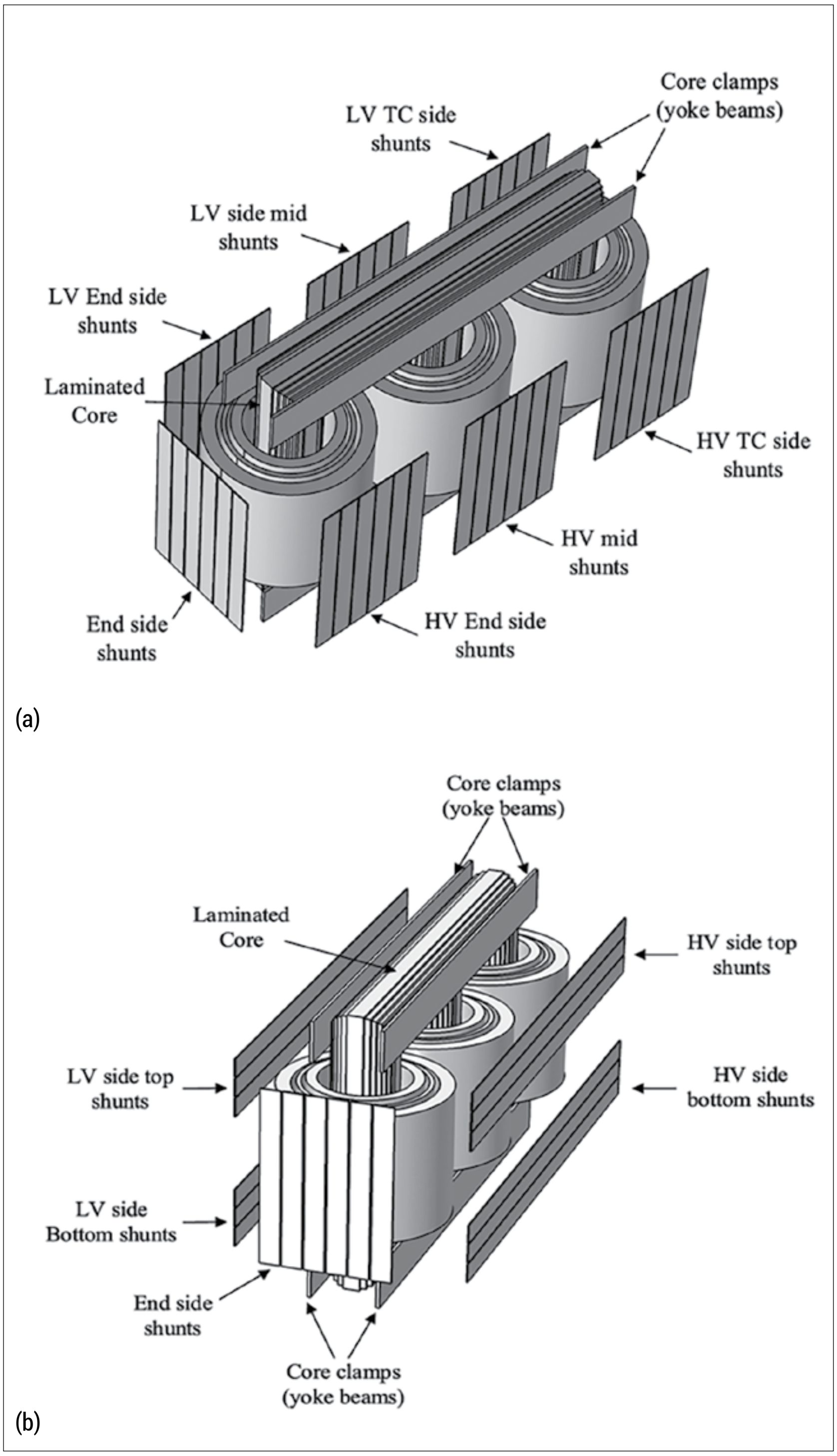

Figure 2. Three-phase core-type transformers: a) vertical shunts, b) vertical and horizontal shunts [6].

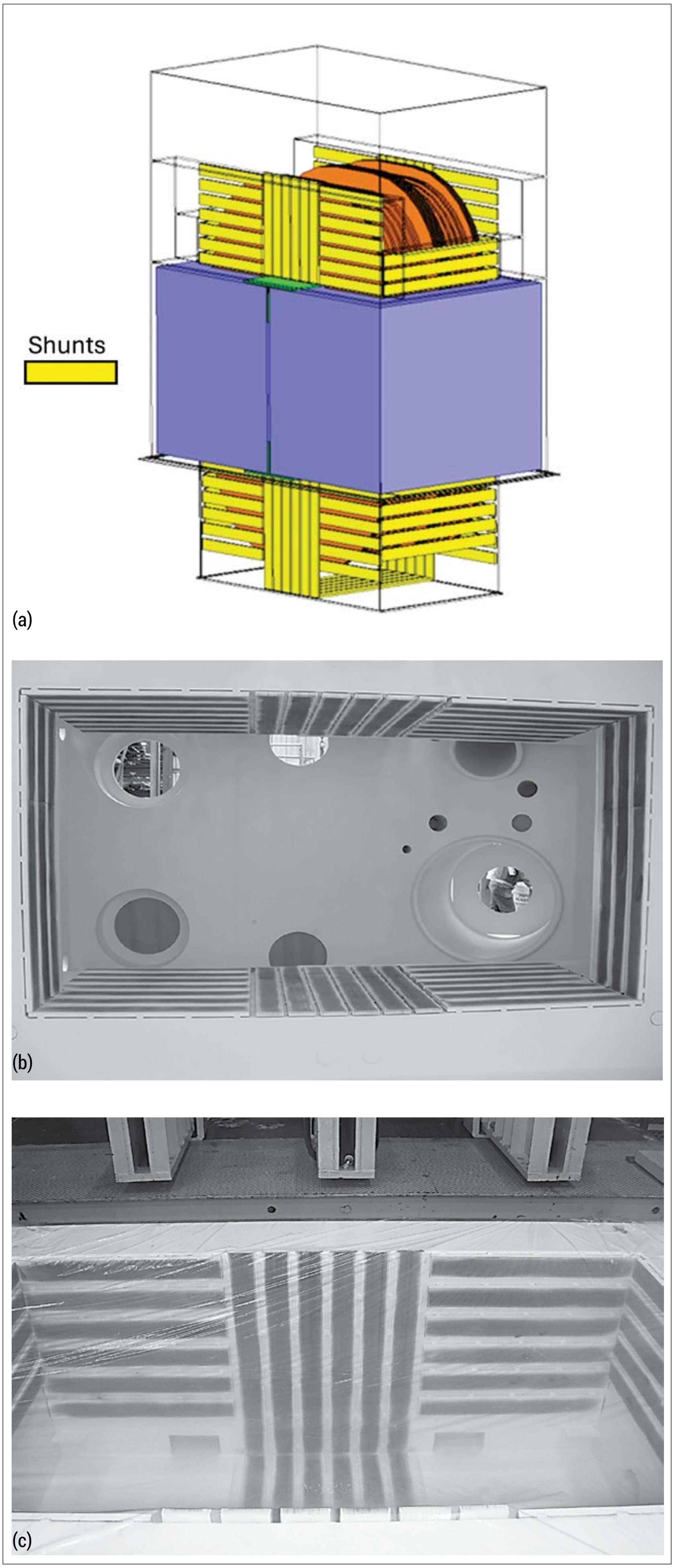

Figure 3. a) Single-phase shell-type transformer, b) top tank shunts, c) bottom tank shunts

from the top and bottom regions of the coils, and the horizontal shunts create a magnetic path for the stray field coming from the limb and corner regions of the coils. The shunt length dimensions should be optimized to protect the tank walls of the transformer effectively. Moreover, the horizontal shunts located in the lateral tank walls of core supports are sometimes stepped to avoid their magnetic saturation because these shunts are closest to the transformer coils, as shown in Figure 4 (c). This magnetic shunt topology with lateral tank wall stepped shunts is utilized to reduce the distance between coils and tanks, reducing the overall dimensions. The tank size of shell-type transformers with this shunt topology presents reduced dimensions compared with the tank dimensions presented by other similar transformers with the shunt topology of Figure 3.

> **In shell-type power transformers, the T-beam supports are subject to leakage fields produced by the transformer coils, which is the reason why they are generally protected by magnetic shunts**

3. Magnetic shunts in support elements

In shell-type power transformers, the T-beam supports are subject to leakage fields produced by the transformer coils. The T-beam supports are generally protected by magnetic shunts, and some interesting shunt topologies have been found in real shell-type power transformers. For example, as shown in Figure 5, stepped shunts are utilized on T-beam supports to gradually distribute the eddy current losses in the end shunt steps to mitigate the risk of high temperatures in the end regions of the shunts [10]. These stepped shunts should be optimized for different transformer sizes and ratings [5], [10]. Figure 6 shows the stepped magnetic shunts on the top T-beam of a

> **Despite using thick shunts to avoid magnetic saturation, high magnetic flux densities and considerable shunt losses are produced in the end shunts during the transformer operation**

shell-type power transformer during the assembly process.

Another interesting and simple magnetic shunt configuration is composed of a set of thick shunts distributed on the T-beam supports, as shown in Figure 7. Despite using thick shunts to avoid magnetic saturation, the author has noted that for this shunt topology, high magnetic flux densities and considerable shunt losses are produced in the end shunts during the transformer operation [10]. Then, the dimensions of these shunts should be optimized to avoid magnetic saturation and to reduce the shunt losses. The design of these thick shunts is simple compared with the stepped shunts presented in Figure 6. These simple shunts don't require cutting laminations with different dimensions for the end shunt steps, reducing the complexity of the manufacturing process. Similar magnetic shunts can be found in arc furnace power transformers where large T-beams are utilized. More research must be conducted on this thick shunt topology for T-beams.

Another interesting shunt topology for T-beams of shell-type transformers consists of mixing the shunt topologies presented in Figures 6 and 7, as shown in Figure 8. Thick shunts with stepped ends are employed to gradually distribute the magnetic field and losses in the shunts. This shunt topology permits the gradual distribution of the shunt losses in the end shunt steps, reducing the risk of high temperatures in these end regions of the shunts.

In core-type power transformers, the core clamps and yokes need to be protected from the high stray field produced by the

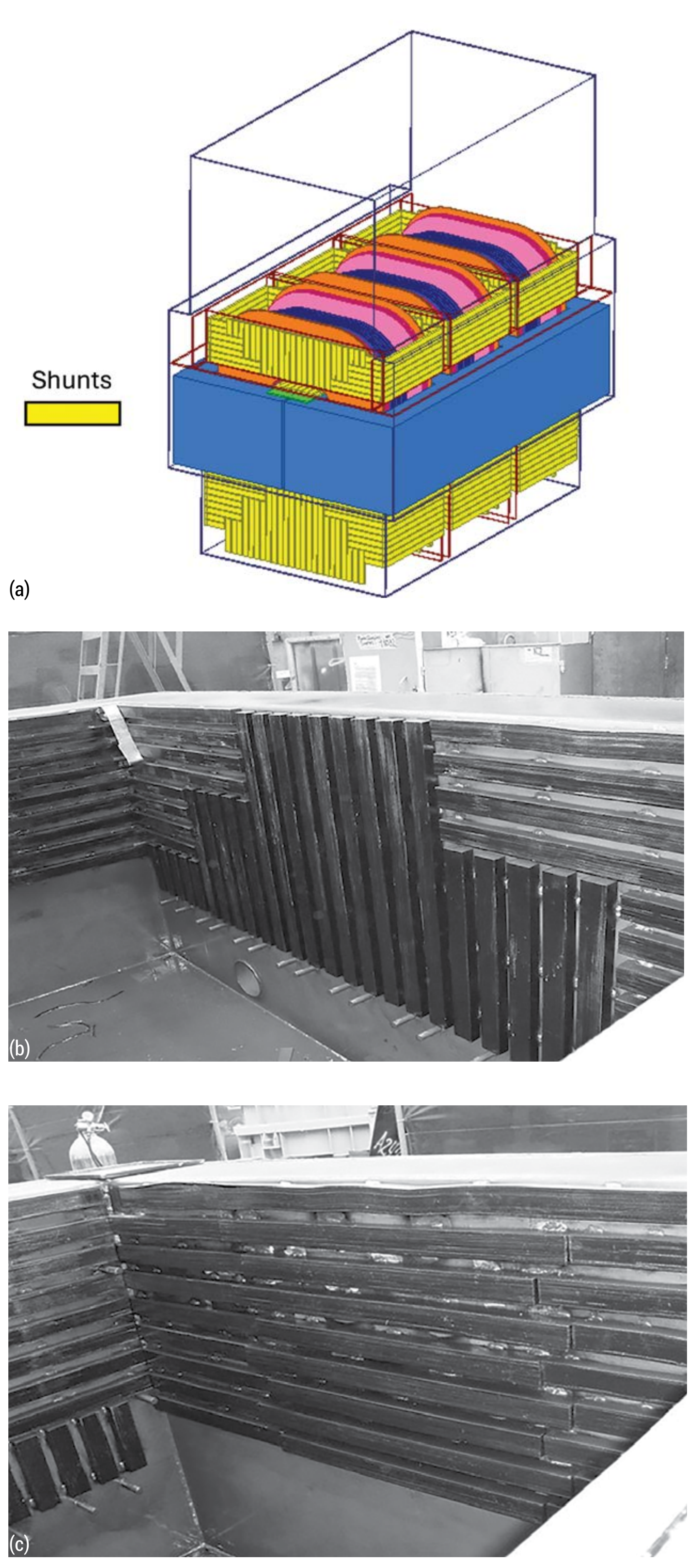

Figure 4. a) Three-phase shell-type transformer, b) bottom frontal tank walls shunts, c) bottom lateral tank walls shunts.

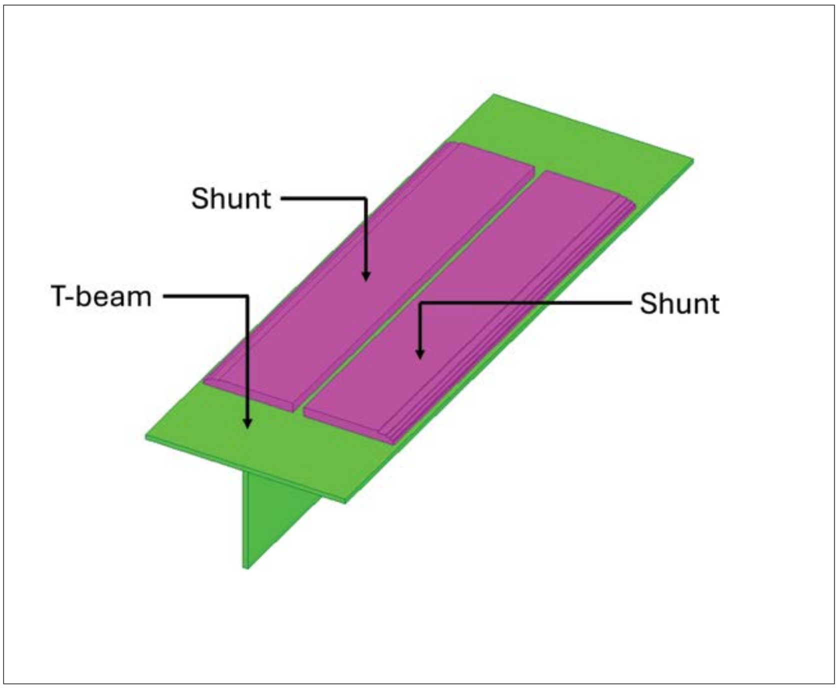

Figure 5. T-beam stepped shunts.

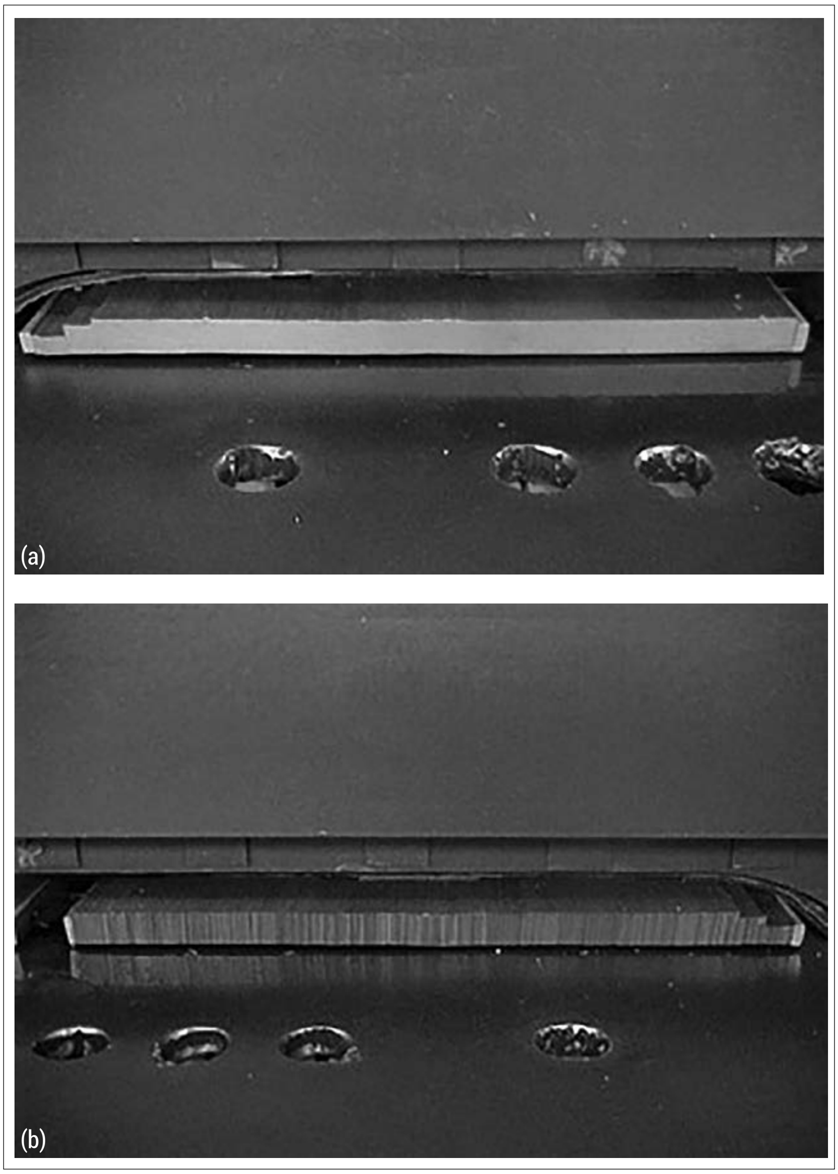

Figure 6. T-beam shunts in shell-type power transformer: a) left shunt, b) right shunt

transformer coils [11]-[13]. The magnetic shunts protect the core clamps and yokes from the stray fields produced by the transformer coils which are closest to the clamps, as shown in Figure 9 (a) [10]. Shunts are located on the top and bottom vertical elements of the core clamps. High power losses and high temperatures have been reported in some transformers without these clamp magnetic shunts. Figures 9 (b) and (c) show the magnetic shunts on the core clamps of a three-phase core-type power transformer.

Conclusion

In this article, diverse magnetic shunt topologies employed in power transformers were presented. Several shunt topologies for core-type and shell-type power transformers were presented, refreshing the perspective and ideas about the use of magnetic shunts in power transformers. The author considers that several transformer shunt topologies could be improved, and new topologies could be proposed using new magnetic materials and geometries.

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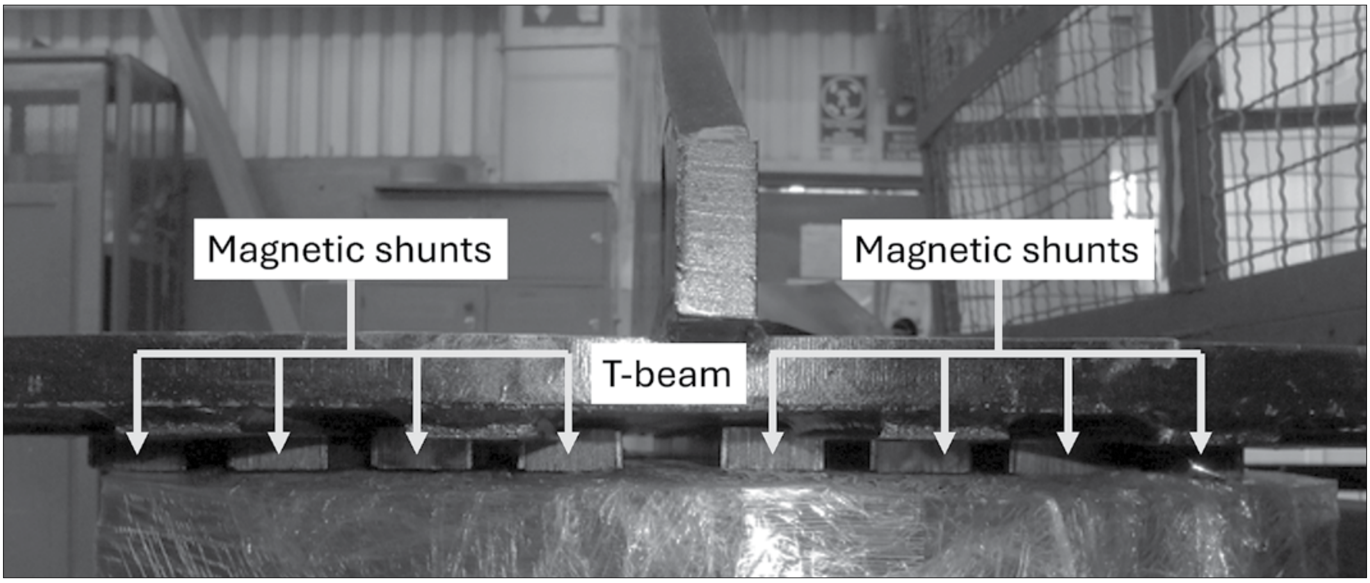

Figure 7. Thick magnetic shunts for T-beams.

> **In core-type power transformers, the core clamps and yokes need to be protected by the magnetic shunts from the high stray fields produced by the transformer coils**

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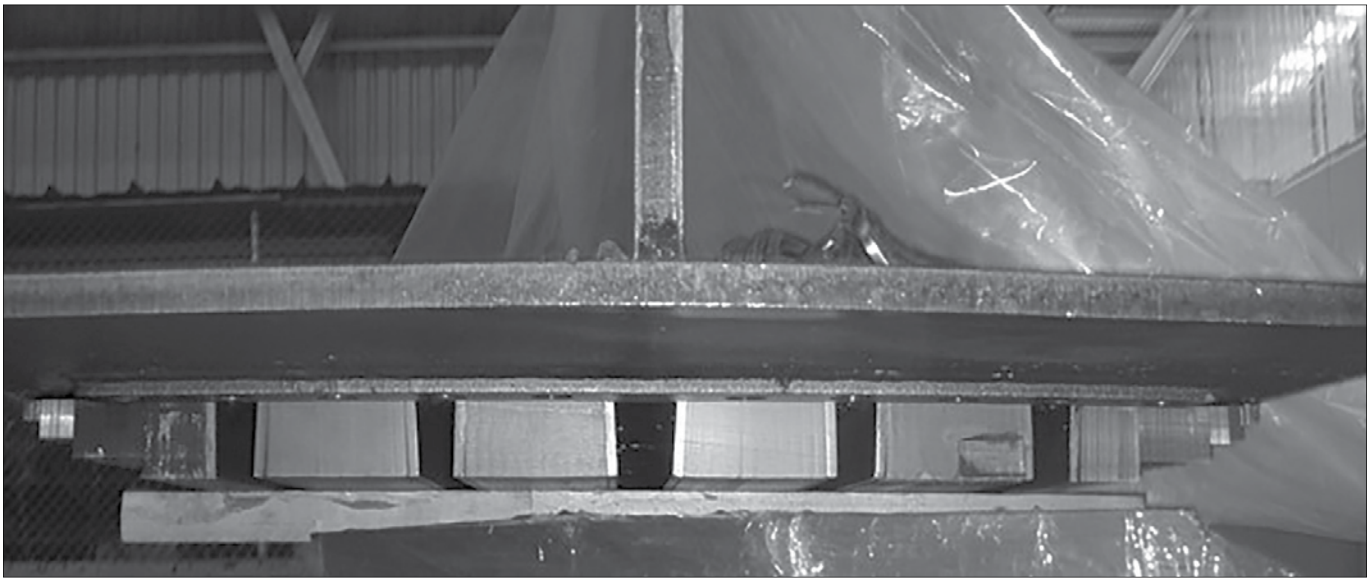

Figure 8. Thick shunts with stepped end shunts for T-beam.

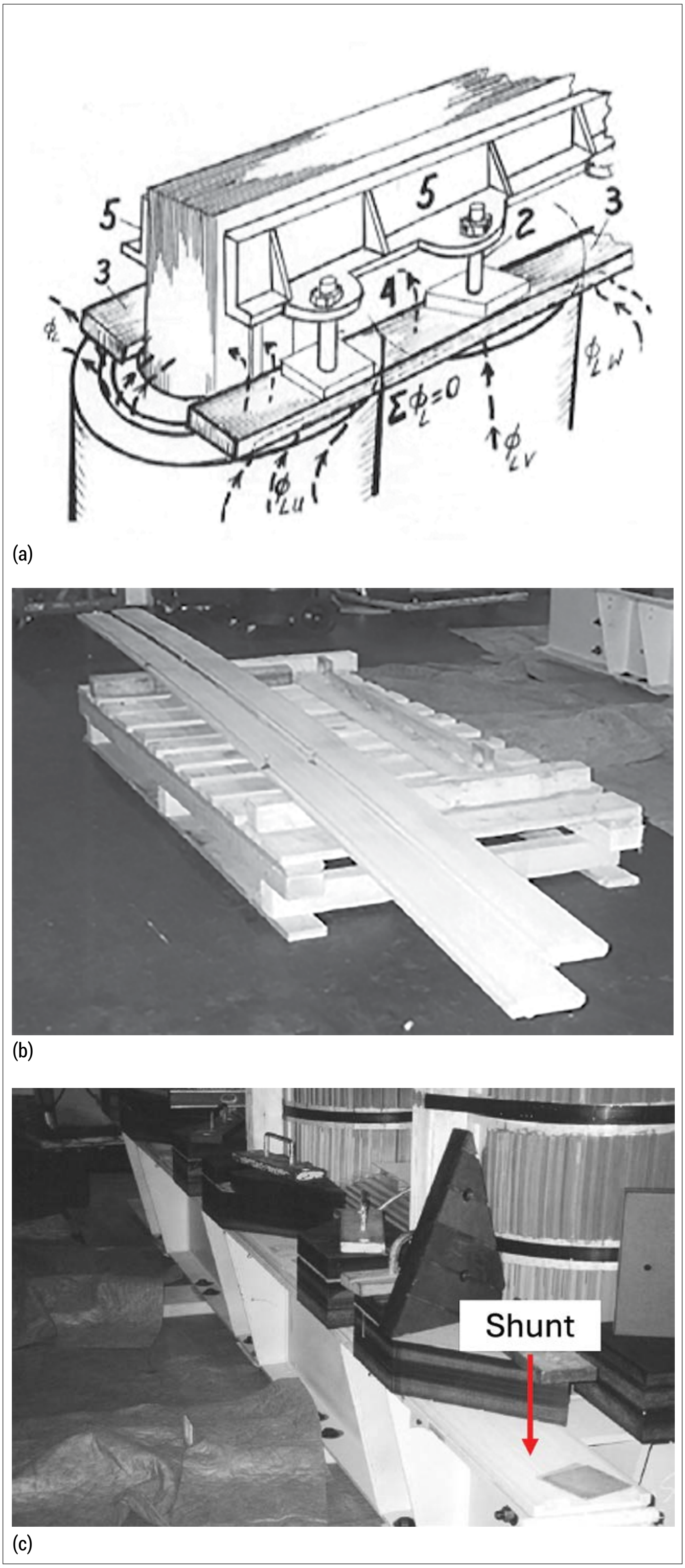

Figure 9. a) Core clamp shunts (#3) [10], b) large core clamp shunts, c) assembly of core clamp shunts.

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