Experimental Validation of a New Methodology to Reduce Hot Spots on the Screws of Power Transformer Tanks

J. C. Olivares-Galván, S. Magdaleno-Adame, R. Escarela-Perez, R. Ocon-Valdéz, P. S. Georgilakis, G. Loizos

Abstract -- **In power transformers, the presence of stray currents in the structural elements near to the high current bushings can be considerable and this usually leads to hot spots. This work presents the analysis of the overheating of the screws that join the tank and the cover; these screws are near to the low voltage bushings of the transformer. Overheating results are analyzed and discussed for the case of a 420 MVA, 20/230 kV, OA/FOA transformer. The hot spots in the screws are discovered by thermal maps (thermography) that are obtained during the power transformer operation as part of the preventive maintenance program. This paper proposes the use of copper sill to ensure the connection of both the cover and the tank body because this solution significantly reduces the overheating of the screws. The proposed solution, which has been validated by measurements, significantly reduces the hot spots on the screws of power transformer tank.**

Index Terms--**Eddy currents, hot spots, low voltage bushings, transformer cover, overheating, power transformer, screws, thermography, transformer failures.**

I. INTRODUCTION

TRANSFORMERS are expensive and vital components in electric power transmission and distribution systems [1]. Globally, the statistics of failures in power transformers are as follows: 41% of faults are related to the tap changer, 19% with the windings, 3% with the core, 12% with terminals, 13% with tank and fluids, and 12% with accessories [2]. In Mexico, the statistics showed that 53% of failures are related to problems in the winding insulation, 19% to bushings, 11% to the tap changer, 2% to the core, 13% to other causes and 2% to fire explosion. The hot spot failures in the tank are included in the 13% referred to other causes. Consequently, it is important to analyze the causes and consequences of tank hot spots as well as to present solutions to the problem of bolts heating.

According to the authors' experience, overheating of distribution transformer screws is not important. However, in the case of large power transformers (Table I), the overheating of screws can lead to transformer failure.

Hot spots generated in the cover screws of transformer tank and its surroundings are produced by the stray flux of transformer. The eddy currents are forced to circulate through the screws. The induced currents can also move around the tank and cover, which are connected by a flange using screws. This cause large concentration of magnetic field in some screws and eddy currents are generated resulting in heating. When the induced currents are high, these currents cause overheating, which can degrade the dielectric properties of transformer oil, damage the sealing system, the painting of the tank and damage the insulation of the conductors nearby. All this can be a cause of major fault in the transformer.

After reviewing the existing literature, the authors note that there are many papers that deal with the problem of losses in the tank due to high currents flowing through the low voltage conductors [4]–[20], but the research related with hot spots on the screws placed on the tank cover of the transformer are very scarce [21]–[25]. References [23] and [24] analyze the problem of hot spots on the screws but the solution they propose is presented without any experimentation.

The solution implemented in this work consists of installing bridges of copper sill, in all the 49 screws distributed at the junction of the cover and the tank. The configuration adopted is shown in Fig. 1. The use of copper as a material of the sill was selected because of its high conductivity. The nuts and bolts were made of stainless steel to reduce corrosion, ensuring good contact with the walls of the tank, thus avoiding the overheating due to bad contact; also the relative permeability of steel is equal to 1, while carbon steel is in the range of 100 to 500. The sill as a bridge provides a low impedance path for induction currents, and keeps both parts at the same electrical potential. Reference [23] mentioned that when stainless steel screws are used in practice to avoid the concentration of magnetic flux, hot spots are generated in the flange of power transformer.

Reference [21] shows that when the screws have a good contact, the reluctance of the screw-flange set is more than twice that of a solid wall (one piece). Furthermore, the magnetic field strength H on the surface of the screw is 1.4 times higher than H in the solid parts of the flange. The saturation of the screw-flange set and the reluctance by the separation of the flange can significantly increase the field in the junction region. Reference [21] also shows the effect of having inappropriate contact between flange and bolts, caused by the painting, the magnetic field saturation, the separation of the flange, and so on. Reference [26] shows that higher values of H=40 A/cm produce heating. So, the proposal to put the copper sills connected to the cover screws to reduce overheating (see Figure 1), is the most viable option in cases that the cover is not welded to the tank.

In order to avoid the relaxation process that occurs over time in the force that holds tightly the screw, the connection scheme presented in [27] was used. More specifically,

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978-1-4673-0142-8/12/$26.00 ©2012 IEEE

Belleville washers were used, since they have the property that by relaxing the screw, washer expands to maintain a strong connection. The reluctance of the flange–screw set is reduced with increasing the clamping force of the screw. The recommended torque by Industrias IEM S.A. de C.V. for ensuring good contact of the flange–screw set is 190 Nm. The reduction of the friction coefficient between the screw and the flange increases the screw tension for a given torque. For this reason, anti-seize paste was used as a means of lubricant on the surface of the flange that contacts the washer.

The CFE and PEMEX specifications of 2006 [28]-[29] mention that covers and tanks of transformers must be designed to be able to be welded; this is applicable (a) for transformer ratings from 6250 to 40000 kVA in case of CFE, and (b) for transformer ratings of 500 kVA and above in case of PEMEX specification. Power transformers can have a useful life of 40 years, which means that there exist transformers that use screws to secure the tank and cover. This work will serve as a reference to the problem of hot spots in the flange, when the connection is with screws.

TABLE I
CLASSIFICATION OF POWER TRANSFORMERS ACCORDING TO TRANSFORMER RATING [3]

TRANSFORMER CLASSIFICATION	RATING (MVA)
Small power transformer	0.5 – 7.5
Medium power transformer	7.5 – 100
Large power transformer	100 and above

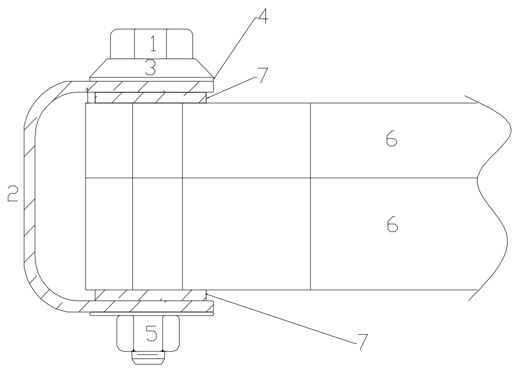


Fig. 1. A solution that reduces the hot spots on the screws of the transformer tank. (1. Stainless steel screw A-316; 2. Copper sill; 3. Belleville washers, anti-magnetic material; 4. Flat washers, anti-magnetic material; 5. Stainless steel nut, anti-magnetic material; 6. Flange for connection of tank and crest; 7. Toothed washer, anti-magnetic material.)

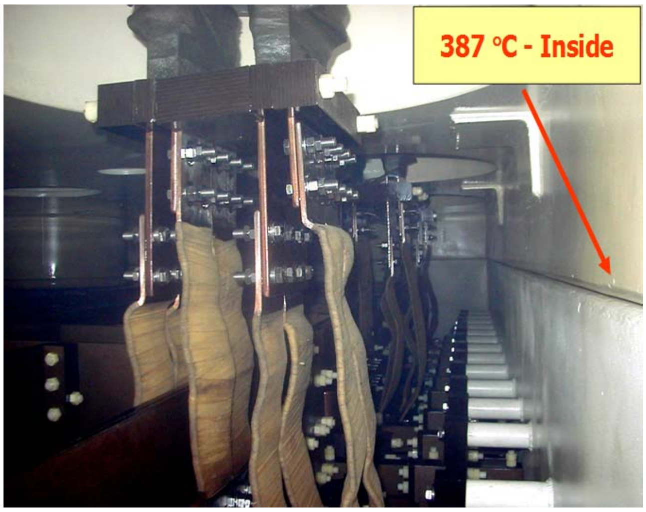


Fig. 2. The arrow shows the connection of flange-screws inside the transformer.

II. DESCRIPTION OF FAILED TRANSFORMER

The transformer under study is located at the power plant of Petacalco, located 12 km from the industrial port of Lazaro Cardenas, Michoacan, Mexico. The geographic location is 102° 06' 22" west longitude and 17° 59' 04" north latitude. The particular characteristics of the transformer are shown in Table II. The connections of flange-screws inside the transformer are shown in Fig. 2.

TABLE II
TRANSFORMER CHARACTERISTICS

Transformer rating	135/375/420 MVA
Connections	High voltage: Star, Low voltage: Delta
Core	Shell type
Impedance	12 %
Manufactured in	Mexico
Phases	3
Low voltage (LV) current	12124 A
High voltage (HV) current	1054 A
HV bushing	oil-gas SF6
Cooling	OA/FOA
Serial number	24-7194
Year of manufacturing	1997
Primary and secondary voltage	20/230 kV

Fig. 3. Paint loss due to overheating in the connection of flange-screws (front view).

Fig. 4. Paint loss due to overheating in the connection of flange-screws (top view).

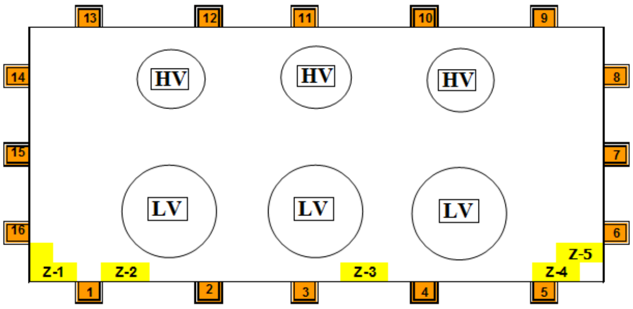


Fig. 5. View of transformer cover. Zones Z-1 to Z-5 presented hot spots.

III. Measurements, Results and Discussion

We found evidence of areas with high temperatures, which are shown in Figs. 3 and 4. Additionally, Fig. 5 shows the cover of the failed transformer showing that in the areas Z-1 to Z-5 there was overheating.

Table III shows the most relevant measurements of temperature that were collected from September 3, 2005 until February 21, 2008. In May 2007, we placed a total of 14 copper stranded conductors, as well as copper sills, while all screws were installed according to the proposed solution shown in Fig. 1. As a result, the last three measurements shown in the last three rows of Table III correspond to transformer operation after the application of the proposed solution for the reduction of hot spots on the screws of power transformer tank. It can be seen from Table III that the proposed solution of Fig. 1 managed to reduce the temperature to 84 ^{o}C.

TABLE III
TEMPERATURE MEASUREMENTS FROM 2005 TO 2008. THE USE OF COPPER STRANDED CONDUCTORS REDUCED THE TEMPERATURE TO 84 ^{0} C

DATE (D/M/Y)	LOAD (MW)	TEMPERATURE (°C)		
		AMBIENT	ZONE	ZONE 2
03/09/05	350	35	Zone 1: 140.8	386.9
01/05/07	350		Zone 4: 59	83.5
01/05/07	350		Zone 4: 53.3	84.5
21/02/08	175		Zone 1:45	46.8

Temperature measurements were carried out using infrared thermography, a hybrid temperature recorder and J-type thermocouples. Fig. 6 shows the thermal behavior of zone 2 at the junction of the cover with the transformer tank, where we can see that there are various dates with temperatures above the limit of 135 °C. According to [30], it is not advisable to let the temperature of the transformer metal parts (where there is poor contact with the transformer oil) to reach values greater than 147°C, because above this temperature gas formation can take place within the transformer oil.

Fig. 7 shows ten copper bridges between the cover and the tank. The staff of Industrias IEM S.A. de C.V. carried out the following changes in the failed transformer:

a) changed the existing screws and nuts by new screws and nuts made of non-magnetic material (Stainless steel A316),
b) installed Belleville washers of non-magnetic material (Stainless Steel A316),
c) installed toothed washers of non-magnetic material (Stainless Steel A316),
d) installed bridges using copper sill in 49 screws.

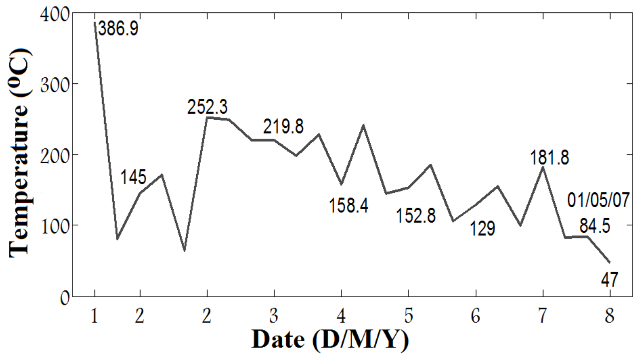
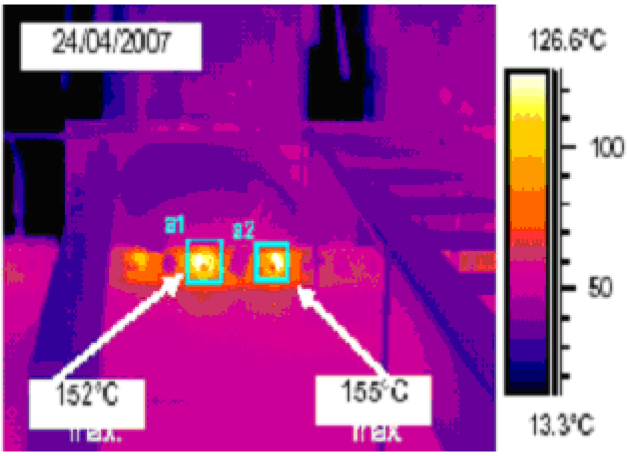
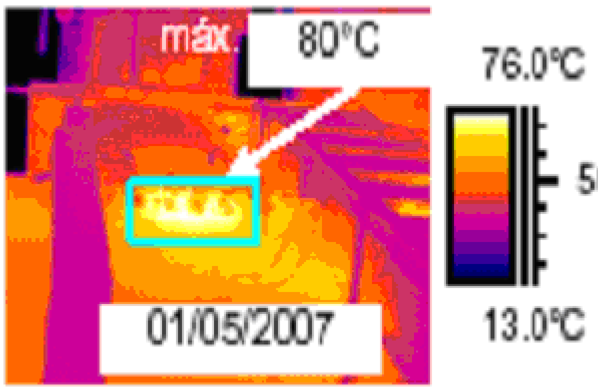


Fig. 6. Thermal behavior of zone 2. Date 1: 3/09/05, Date 2: 5/09/05, Date 3: 12/09/05, Date 4: 14/09/05, Date 5: 16/09/05, Date 6: 20/04/06, Date 7: 30/04/07, Date 8: 21/02/08.

Fig. 7. A copper sill used as a conductor bridge between the tank and the cover.



(a)



(b)

Fig. 8. Measurement of zone 2 by infrared thermography. (a) Before placing the copper sill, (b) After placing the copper sill.

Fig. 8 shows the infrared thermography in zone 2, before and after placing the copper sill; before placing the copper sill (April 2007) the maximum temperature reached 155 ^{o}C; after placing the copper sill in all cover screws (May 2007) the temperature was reduced to 80 ^{o}C. Similarly, in zone 4, the maximum temperature was 86 ^{o}C before placing the copper sills, while the maximum temperature was reduced to 59 °C when copper sills were placed.

IV. Conclusion

This paper has shown the effect on preventing physical contact between the cover and walls of the transformer tank. The results indicate that not tight screws (torque less than 190 Nm) increase the thickness of the sealing system. This causes an increase in the reluctance of the screw zone, which causes eddy currents using the screws as "path" to be distributed throughout the tank, while the magnetic field strength increases in the screws. These effects cause overheating of the flange, which could result in extreme fire explosion. To avoid the occurrence of such hot spots, it is important that the screws are kept tight all the time, so as to present a high reluctance by an arrangement like the one implemented in the solution of this work (Belleville washers, anti-seize paste and proper torque provided by the transformer manufacturer). Furthermore, when copper sills are installed between the screws that connect the cover and the transformer tank; in this way they avoid concentrations of stray currents and increases *H* in the flange, while the copper sill provides greater surface for heat dissipation. This experimental work shows the effect of installing a copper sill as a bridge to the eddy currents, and proves that the copper sill, placed as a bridge between the cover and the tank, works very successfully.

As future work, we plan to have a complete 3D analysis of the stray losses in the screws of the transformer cover under study (420 MVA). This research would use ANSYS Maxwell software for finite element calculations [31].

V. Acknowledgment

The authors would like to thank Mr. Alvaro Cancino-Quiroz of Industrias IEM S.A. de C.V. for experimental validation and providing practical data.

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