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Fastener Spacing and Tightening Torque of Gasket Joints of Oil Filled Transformers

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Abstract

Objectives: Design of leak-proof gasket joint of the transformer is very important to ensure the safe long-term service of a transformer. This paper gives the properties of gaskets, fastener spacing calculation and recommended tightening torque values. **Methods/Statistical Analysis**: This study commences with a review of the equations applicable for the calculation of leak rate of gas and oil through a gasket joint. **Findings:** A comparison of properties of various types of gaskets used is carried out and NITRILE Rubber and NITRILE Cork gaskets are selected as the most suitable ones for transformer application. The procedure to calculate the fastener spacing and the recommended tightening torque values are given. **Application/Improvements:** This paper is useful for the transformer designer because the gasket types and parameters fastener spacing calculation and torque requirements are not consolidated in any published paper. Further studies to determine the relationship of surface finish, gasket characteristics, fastener spacing and tightening torque on the long-term performance of the transformer.

Keywords: Distribution Transformers, Gasket, Tightening Torque, Fastener Spacing, Oil-Filled Transformers

1. Introduction

Leakage of oil/insulation liquid through the joints in a transformer is a serious issue for the end user, the manufacturer & the environment. Several Studies and continued development regarding the selection of gasket, spacing of fasteners are done by manufacturers in the past to ensure leak-proof joints. This paper gives the principles employed in the selection of gaskets, the spacing of fasteners and tightening torque to be applied.

2. Leakage Rate Through Gasket Joint

The leakage rate through a gasket joint is a function of the contact pressure, property of the gasket including load-deflection characteristics, surface properties of the gasket seat, fastener spacing etc. The relationship is approximate by the formula

$$Q_p = f\left(\frac{P_c}{E}\right) \tag{1}$$

Where

$Q_p = LeakageRate$ (m^3 / sec)
$P_c = ContactPressure$ (kg / m^2)
$E = Elasticmodulesofthegasketmaterial$ (kg / m^2)
$f = FunctionalRelationshipConstant$

For molecular flow, the leak rate is given by Knudsen equation

$$Q_m = \left(\frac{2\pi RT}{m}\right)^{0.5} . \left(\frac{D^3}{6L}\right) . (P_1 - P_2) \tag{2}$$

Where
Q_m= *Volumetric leak rate of gas.[This equation is applicable for gas leak through gasket for sealed transformer with gas cushion]*

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R = universal gas Constant

T = Absolute Temperature

M = Molecular Weight of gas

L = Leak Path Length

D = Leak Path Diameter

P_1 = *Higher Pressure*

P_2 = *Lower Pressure*

If the gas pressure inside the transformer becomes negative, the leak rate becomes negative showing flow of air from the atmosphere into the transformer. For the leakage of oil/liquid through gasket joint the applicable equation is

$$Q_L = \pi \frac{\left(\frac{D}{4}\right)^4 (P_1 - P_2)}{8\mu L} \quad (3)$$

Where

Q_L = *Leakrate of oil / liquid*

μ = *Viscosity of oil /liquid*

The design of a leak-proof gasket joint will have to consider the following factors

- Properties of the gasket including load deflection curve
- Correct fastener size and fastener spacing
- Correct pre-stress on the gasket which is a function of the tightening torque
- Surface finish of the metallic surface

To prevent leakage over a period of time, the pre-stress on the gasket will have to be maintained. This is achieved by the storage of elastic strain energy in the joint system. The elastic strain energy is received from the compression of the gasket, the flange deflection and the bolt strength in a joint.

3. Properties of Gasket Required for a Good Joint

- The internal structure of the gasket shall be elastic.
- The stress relaxation shall be low.
- The physical properties of the material shall not be affected by the fluid/oil/gas in the transformer. Also the fluid/oil/gas shall not be affected by the gasket material.
- Property shall not be affected by temperature cycling
- At the lowest operating pressure the gasket material shall not be porous
- The material shall conform to environmental regulations such as asbestos free, heavy metal free (i.e. free from Lead, Cadmium, Mercury and Chromium) etc.
- The material shall be capable of overcoming flange & surface imperfections such as distortion, waviness, roughness etc.

4. Types of Gaskets used and Comparison of Properties

The common types of gaskets used for transformers including the applications are shown in Table 1. One of the most commonly used gaskets especially for power transformers is NITRILE Rubber conforming to Grade BO-70 as per BS 6996[1]. The parameters of the material suitable for application of transformer are given in Table 2. NITRILE Rubber (NBR) and NITRILE Cork gaskets are most commonly used for oil filled transformers. For distribution transformers, flat sealing gasket without grooves or stoppers is most commonly used where the bolt passes through the gasket. In this case, NITRILE Cork gasket is most suitable.

5. Fastener Spacing

$$L = \left(\frac{480\, Y E t^3 d}{13\, F_1 + 2F_2}\right)^{0.25} \times K \quad (4)$$

$$Fo = \frac{(2F_1 + F_2)L}{3} \quad (5)$$

L = Distance between fasteners(m)
[For Nitrile (NBR) and Nitrile Cork gaskets for transformer the maximum spacing L is less than 110mm]
Y = Width of Curb (m)
E = Modules of Elasticity of Curb/Cover plate(kg / m^2)
t = Thickness of cover plate (m)
d = Deflection of gasket (m)
D = Thickness of gasket (m)
F_1 = Minimum force on gasket(kg / m)
F_2 = Maximum (kg / m)

Table 1. Comparison of gaskets used for Oil Field Transformers

Sl.No.	Gasket Material	Temperature Range (°C)	Compression (%)	Typical Applications
1.	Neoprene	40 to 90	30	Used where UV proof application is required. To be used with stoppers.
2.	NITRILE (NBR)	40 to 140	25-50	Used with compression limiter or grooves. O-Rings flat and extruded / type available.
3.	Neoprene Cork	10 to 90	40	Can be used as flat to flat surface with no groove
4.	NITRILE Rubber	30 to 130	40	Can be used as flat to flat surface with no groove
5.	VITON	25 to 200	30	For high temperature O-Rings, flat & extruded gaskets. Use with grooves or recess or stoppers.

Table 2. Properties of NITRILE Rubber gasket material

Sl. No.	Property	Parameter	Test Method
1.	Type of Polymer	ACRYLO NITRILE Butadine	BS 4181
2.	Polymer Content	45% (min) by weight	ASTM E 1131
3.	Ash Content	7% Max	ASTM E 1131
4.	Density	1.2 (+ 0.05) gm/cc	BS 903 part A1 method A
5.	Hardness	70 (0 to 4) shore A	BS 903 part A26 method N
6.	Tensile Strength	12.5 N/mm[2] (min)	BS 903 part A2
7.	Elongation at Break	250% (min)	BS 903 part A2
8.	Compression set	20% (max)	BS 903 part A6
9.	Aging in Transformer Oil Max change in volume Change in Hardness Change in Tensile Strength Change in Elongation	 +5 to 0 % + 5 Shore A + 20% + 15%	 BS 903 part A16 72 + 2 Hours at 100 + 1ºC in Transformer Oil

F_o = Pre stress to compress the gasket to 30~40% of initial thickness (kg/m)

K = Safety factor ~ 0.8

It is assumed that the cover is parabolic ally loaded with 2 fasteners.

F_1 is the minimum force that will have to be maintained on the gasket to get a leak-proof joint.

F_2 is the force required on the gasket to obtain a deflection "d" over and above the deflection obtained by applying force F_1. A leak-proof joint is realized when the gasket material flows into the imperfections of the contact surface. The amount of force to be applied to the contact surface for a good gasket flow is defined as the "Y" factor in ASME VIII. This is the yield force and this is the minimum stress to be applied even for low-pressure application. When the internal pressure increases, the force on the gasket reduces. The ability of the gasket to maintain the seal at this reduced stress is defined as gasket factor "m" in ASME VIII.

6. Bolt Torque

The gaskets are usually purchased in rolls by the transformer manufacturer. The gasket manufacturers make butt joints in the roll and supply the material to the manufacturers considering this in practice the bolt hole shall be avoided at the gasket joint if any. The correct pre-stress of the gasket is applied by Torque. However, the relationship of Torque and Force depends on several factors and the theoretical formula is not convenient for practical application. The relationship between force and Torque can be represented as[2].

$$T = \frac{F}{4}\left[\mu_H + (A + D) + \mu + (2d_e \sec\theta) + \frac{2\rho}{\pi}\right] \quad (6)$$

Where

T = Torque(Nm)

F = Axial Load(kg)

A = across flat dimensions of the nut(m) {Outside diameter of nut and washer in contact}

D = Washer inside diameter(m)

μ_H = Friction coefficient under the head of the nut(m)

μ_t = Friction coefficient of the thread (m)

d_e = Effective diameter of the bolt(m)

P = Thread pitch

θ = Half thread form angle

$\mu_H and \mu_t$ Change with various factors including lubrication. The above formula is simplified for practical application as

$$Torque = 0.2\ X\ Load\ X\ Diameter \tag{7}$$

When installing the gasket, initial tightening torque is necessary to give pre-stress to ensure leak-proof joint at the lowest pressure of operation and also to ensure that the gasket is not overstressed at the maximum operating pressure. The pre-stress for the NITRILE rubber and NITRILE cork gaskets used in the transformer is to limit the gasket compression to about 40%. The typical torque values are shown in Table 3 based on the simplified formula.

Table 3. Torque values for different bolts

Size of the bolt/stud mm	Torque required Nm
M10	20
M12	30
M16	70
M20	150
M24	200

7. Joining/Splicing of the Gasket

The distribution transformer manufacturers generally buy gasket in standard rolls. When this gasket is used for the top cover, joints at the four corners will be necessary and the common practice is to use cold splicing for the joint. Cold splicing uses quick setting glue and the process doesn't require any special tools. However the joint is a weak link in the system. The preferred practice is to use "Hot splicing" where rubber based glue is used which has to be cured (Vulcanized) in place. This creates a joint that retains the properties of the gasket at the joint and the joint is not visible.

8. Thickness of Gaskets for Distribution Transformers

The thickness of gasket for tank cover, cable box fixing, monoblock bushing fixing, cable box cover plate fixing on distribution transformers are dependent on the type of gasket used, the thickness of flange, fastener size, and fastener spacing. The thickness given in Table 4 can be used as a general guidance.

Table 4. Gasket thicknesses

Gasket location	Flange thickness mm	Typical gasket thickness mm
Tank cover	6 to 8	6
Tank cover	16	12
Cable box fixing	8	6
Cable box cover	3 to 4	3
Monoblock bushing fixing	6 to 8	6

9. Conclusions

The theoretical formula of a gas leak and oil leak applicable to transformers is presented and the properties of gasket required for a good joint in a transformer is discussed. The paper further compares the properties of various gaskets materials and gives recommendations for gasket suitable for the oil-filled transformer. The theoretical formula for spacing of fastener and the practical values of torques required for various bolt sizes are presented.

10. References

1. BS 6996-2003. Mineral oil resistant Acrylonytrile - Butadiene Rubber compounds. Specification. Available from: https://shop.bsigroup.com/ProductDetail/?pid=000000000030101114. Date assessed: 18/06/2003.
2. Marks LS. Standard Handbook for Mechanical Engineers. Macgraw-Hill Book. Co. 2006 Dec; p. 1936.