# Flameproof Enclosure for a Dry-type Transformer for use in Hazardous Areas: Design Aspects and Pressure Analysis

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**Abstract** - Every country in the modern era is focusing on industrialization as an instrument for continuous economic progress. The industries like petroleum, coal mines, petrochemical, paint, etc., where flammable gases, vapors, or explosive dust particles are available. Some few micro-joules energy is required to create an explosion in these hazardous areas, so safety is a primary concern for the safe operation of these industries. Electrical power is required to operate the machineries. The power is stepped up, stepped down and distributed by a transformer. It is needed to put all electrical components of electrical equipment within the robust enclosure which helps to prevent explosion and minimize electrical-related accidents in the hazardous area. In this paper, some design aspects and analysis of some parameters like maximum principal stress, total deformation and directional deformation on cover of enclosure/box of flameproof enclosure for dry type transformer through ANSYS software are described. These parameters also were measured at 1MPa applied stress after meshing on all designed compartments of flameproof transformer enclosure.

Keywords: Flameproof enclosure, Hazardous area, Dry type transformer, MIE, and Maximum stress

## 1. INTRODUCTION

The rapid growth in the modern technology segment, where explosion-proof (Ex) equipment is being used to make systems suitable for hazardous areas. Generally, a flammable atmosphere can be present in a hazardous area having different types of explosive gases, vapor and dust particles. Flameproof protection [1] is the most suitable method of protection to design flameproof transformer for hazardous area. Generally, 80-90% of equipment having flameproof (Ex-d) and intrinsic safety (Ex-i) protection are used in the hazardous area for safe operation 2. The basic meaning of providing explosion protection for electrical equipment is to prevent the ingress of explosive atmospheres to the circuitry and or limit the energy of the circuitry so that ignition cannot take place. The explosion should be confined within the enclosure so that it cannot propagate into the surrounding hazardous environment.

Dry-type transformers play a vital role in the modern age, and simply "Dry-type" means normal air ventilation is used to cool the circuit coil. They are superior in terms of safety and environmental protection compared to oil-filled transformers due to their insulating material and becoming increasingly popular for safe use due to their non-flammable properties [3-4]. Generally, there are two types of dry-type transformer, namely Cast Resin Dry-type (CRT) and Vacuum Pressure Impregnated (VPI). The CRT transformer is used in high moisture prone areas such as underground mines, chemical, oil and gas industries and places where fire safety is a significant concern because of its primary and secondary windings are completely encapsulated with epoxy resin [5]. The lifetime of these transformers depends on the insulation material used for winding. Heat, oxygen and moisture are the most important factors for insulation degradation of electrical transformers [6-8].

The VPI transformer is made up of minimum flammable material as the insulation of the winding is void-free impregnated used to make with class H polyester resin. Flameproof dry-type transformers are generally used in potentially explosive atmospheres of petrochemical and fertilizers, mines, oil refineries, supply for gas turbines and drilling systems, fertilizers industries, outdoor

installations, etc. They are simple structure, good heat dissipation, inflammability, moisture protection, stable in operation, easy to use, compact design due to such features, the flameproof dry-type transformers are frequently used in hazardous areas for different applications [9-10].

### 1.1 Brief of the Flameproof Enclosures

In the hazardous areas where explosive gas/combustible dust are present, requiring very little energy to generate the explosion. The mining industries started to ventilate the mines with fresh air to dilute the explosive gas to reach the applicable explosive limits to avoid an accident. Earlier, the general-purpose transformer was available but it could not be installed in hazardous areas. Later on it was decided by many authorities that all electrical equipment must be housed within robust metal enclosures using tight-fitting joints so that electrical equipment cannot become a source of ignition in the hazardous area. The weatherproof enclosure design ensures to prevent the ingress of explosive dust and flammable gases into the electrical equipment. Similarly, the flameproof enclosure design ensures to prevent to egress flames or burnt gases from the flameproof electrical equipment. After that, various protection methods were developed, like flameproof, oil immersion, increased safety, intrinsic safety, encapsulation, etc. to design explosion protected equipment for explosive atmospheres for different purposes. There are many hazardous applications where transformers were used and many inflammable liquids used and developed from the first applications [11] and dry type flameproof transformers are considered safer than liquids/gas type transformers. The pioneering work on explosion-proof concepts was carried out by European and other countries at the beginning of the 20th century.

The two important requirements of flameproof electrical equipment for use in flammable atmospheres are: (a) that the equipment must withstand the pressure of an internal explosion, and (b) that the internal explosion must not be transmitted to the external atmosphere. The enclosure is exploded with a particular stoichiometric explosive gas mixture to determine whether a particular enclosure of an electrical apparatus will withstand the explosion pressure.

Explosion pressures recorded in experiments are never equal to explosion pressures calculated on a simple theoretical basis. Errors can occur through the effects of dissociation, inaccurate knowledge of specific heat and other thermodynamic properties of the burnt gas. Losses occur through quenching of the flame at surfaces and heat losses to surfaces. Errors in measurement can be occurred through heat transfer to the gauge or by fluid flow effects causing the gauge to record the kinetic component of stagnation pressure, or reflected pressure if shocks occur. The last two points are real effects and may be reflected in the stress in the shape of enclosure due to deformation. Losses

due to heat transfer to the apparatus depend on the temperature difference between flame and surface and the area and duration of contact. Therefore, heat loss is close to the minimum and the time taken to achieve maximum pressure is not important for estimating heat loss. For practical flameproof enclosures at low temperature, pressure piling and detonation effects can be severe and have caused increases in explosion pressure very much greater than 40% for the same temperature range. The influence of turbulence, heat losses, pressure piling, shock reflections and detonation are important, but not easy to predict. Pressure is sensitive to small variations in apparatus design, stoichiometry, ignition position and pressure transducer position. These factors should be remembered when designing a test for the determination of explosion pressure in a flameproof enclosure for electrical equipment [12-14].

### 1.2 Hazardous area and its classification

The hazardous area refers to an environment where an explosive mixture exists, and an explosion can take place due to the presence of an explosive atmosphere. Explosion can primarily occur in underground coal mines, chemical plants, petrochemical plants, petrol pumps, oil refineries, liquefied natural gas plants, paint manufacturers, distilling, sewerage treatment plants and other classified hazardous areas due to flammable gases, vapors, mists, dusts and liquids.

Based on the frequency of occurrence and period of an explosive gas existence in the explosive atmosphere, the hazardous areas are classified into the following zones category: Zone 0, Zone 1 and Zone 2. The dust zone system is also divided into three zones based on the persistence of explosive dust atmosphere are as follows: Zone 20, Zone 21 and Zone 22 [15]. The hazardous areas are divided into three groups: Group I, Group II and Group III. The general requirements and selection of electrical equipment are carried out based on the classification of hazardous areas as given in IS/IEC 60079-0 ]16], IEC 60079-10 [17] and IS 5572 [18] respectively. Different countries have approached the standardization of hazardous areas in different ways. The terminology for both hazards and protective measures can vary. The National Electrical Code (NEC) and International Electrotechnical Commission (IEC) have zone system and other countries also accept the IEC 60079 series of standards for hazardous areas. The details of class, group, zone and representative material/gases of hazardous areas as per NEC and IEC system is given in Table 1

### 1.3 Sources of ignition and minimum ignition energy in Hazardous area

To create an explosion, three fundamental components (fuel, ignite energy and oxygen) must be present to cause an explosion in the hazardous area. Generally, many ignition sources are present in hazardous areas for explosions like electrical, mechanical, adiabatic, electromagnetic, sonorous etc. The most common ignition source generates due to electric arc and sparks caused by opening and closing contacts, friction between two bodies, the hot surface of installed electrical equipment, and impact between bodies [19-20]. The minimum ignition energy (MIE) is required to cause a fire or an explosion for a particular explosive gas and dust. The MIE is defined as the minimum amount of energy needed to ignite an inflammable vapor gas or dust cloud. The transformer has an electrical source and the MIE value for a particular representative gas of a gas group for resistive circuit is shown in Table 2 as per published curve in IEC 60079-11 [21] and the combustion does not occur when the MIE value is less than the value specified in Table 2.

Table 2 MIE value based on gas and group

| Group | Gas | MIE ($\mu J$) |
| --- | --- | --- |
| I | Methane | 280 |
| IIA | Propane | 260 |
| IIB | Ethylene | 85 |
| IIC | Hydrogen | 20 |
| IIC | Acetylene | 19 |

### 1.4 Advantage of dry type flameproof transformer

There are many advantages of the dry-type flameproof transformer for hazardous areas, such as non-inflammable and self-extinguishing, maintenance free, instant switching, resistant against temperature fluctuation, non- hygroscopic in nature and less space occupying [22-23]. There is also no issue of pilferage and leakage of oil from the cast resin dry type Ex d transformer.

The flameproof enclosure is required to sustain explosion pressure during the explosion test and overpressure test during the static or dynamic pressure test process in the test house. A suitable design requires to simulate the pressure parameters prior to manufacture and submission for testing a flameproof enclosure for the transformer. If pressure analysis is not analysed properly, a flameproof enclosure can get deformed and or damage/burst during the test in explosive gas atmospheres so to avoid it, a prior design analysis of a flameproof enclosure for transformer must be done. In this context, a flameproof enclosure/box for transformer for gas group I, IIA and IIB was designed and maximum principal stress, total deformation and directional deformation in the cover of main enclosure, high tension (HT) box and low tension (LT) box were measured and analysed with the help of ANSYS software.
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## 2. SECTION DESIGN ASPECTS OF FLAMEPROOF ENCLOSURE FOR TRANSFORMER

The enclosure is used to house electrical components to make safe electrical apparatus suitable for use in hazardous area. The flameproof enclosure must be able to resist all the operating conditions under the specified rating of the electrical transformer without any risk of explosion in flammable gas atmospheres. It must also prevent transmission of flame from the inside of the enclosure to avoid any explosion in the surrounding environment.

The flameproof transformer enclosure shall be made of a structural steel plate to sustain more internal pressure and to avoid corrosion. It shall be of substantial construction to withstand the rough conditions of handling. The transformer may be restrained mainly when being pushed into and out of cages and installed in a hazardous area. Aluminum or alloys of aluminum, magnesium, or paint containing aluminum shall not be employed on the exterior part of the transformer tank or fittings for hazardous areas. Generally, there are three methods to conduct a static over pressure test, namely routine, batch and type test. The safety factor is taken to 1.5 times, 3 times or 4 times of the reference pressure for overpressure in all flameproof enclosures as per IS/IEC 60079-1 [1].

The flameproof enclosure for the transformer must resist the colossal pressure created during an internal ignition of an explosive mixture and prevent the explosions from propagating into the explosive atmosphere. The enclosure must be constructed with a robust mechanical strength to sustain the overpressure caused by the explosion and allow to escape of quenched flue gases. When the short-circuit condition is occurred at operating electric power system, the short-circuit current exerted on a transformer is rushed into the windings. This transient current causes short-circuit force which induces critical mechanical stress on a transformer. The flameproof enclosures are designed to have electrical components which have an ignition source. And accordingly, it must be designed which can reduce the possibility of arc, spark or hot surfaces to avoid explosion, as per IS/IEC 60079-0 and IS/IES 60079-1. The temperature on the external surface of the enclosure must be within the specified limit for a specific gas group, class, division, category and zone.

Flameproof enclosures for transformers were designed using Ex d protection. This is the unique technique of protection based on the explosion containment principle. The components of transformer containing energy source were totally housed inside the enclosure/box so that components cannot become a source of ignition in a potentially hazardous area. The enclosures/boxes were designed to withstand the excess pressure caused by an internal explosion to prevent fire or hot gases propagation into the surrounding potentially explosive atmosphere. The flamepath and gaps in all the joint of enclosure/box were maintained as per standard IS/IEC 60079-1 [1] requirements for gas group I and IIB so that any hot gases could be quenched and released before reaching into potentially explosive atmosphere to make safe hazardous area.

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Table 1 Classification of hazardous areas as per NEC and IEC

| | As per NEC | | |
|---|---|---|---|
| Class | Division | Group | Representative materials/gases |
| I | 1 & 2 | A | Acetylene |
| | | B | Hydrogen |
| | | C | Ethylene |
| | | D | Propane, Methane |
| II | 1 | E | Metal dusts |
| | 1 & 2 | F | Carbonaceous dusts |
| | | G | Non-conductive dusts |
| III | 1 & 2 | None | Ignitible fibres/flyings |
| | As per IEC | | |
| Area | | Group | Representative materials/gases |
| Mine susceptible to firedamp | | I | Methane |
| Zone 0, 1 & 2 | | IIA | Propane |
| | | IIB | Ethylene |
| | II | IIB+H2 | Hydrogen |
| | | IIC | Acetylene & Hydrogen |
| Zone 20, 21 & 22 | | IIIA | Ignitible fibers or flyings |
| | III | IIIB | Non-conductive dusts |
| | | IIIC | Conductive dusts |

## 3. Design and Analysis of Flameproof Enclosure

A flameproof transformer enclosure was designed by using ANSYS 19.2 software for a particular size and used the appropriate value in geometry during design for study the maximum principal stress, total deformation and directional deformation in the cover. The designed and analysed flameproof transformer consisted of main enclosure, high tension (HT) box, low tension (LT) box and the insulated coil inside the main enclosure body as shown in Figure 1. The construction of the material for all enclosure/box was chosen as structural steel. All the joints between the body and cover for all three enclosure/boxes were designed as flange joints. The minimum flame path and a maximum gap between body and cover joint were maintained 50 mm and less than 0.2 mm respectively, which is more sufficient than the specified value 40 mm and 0.2 mm in standard IS/IEC 60079-1 for gas group I, IIA and IIB. All the enclosure/boxes were fastened with its cover with Allen key bolts of size of M20x45L. The windings were connected through the insulated bushing and bushing to be connected HT and LT input and output connections through respective cables respectively. It is assumed that the appropriate cable is passed through the certified and approved Ex d cable glands.
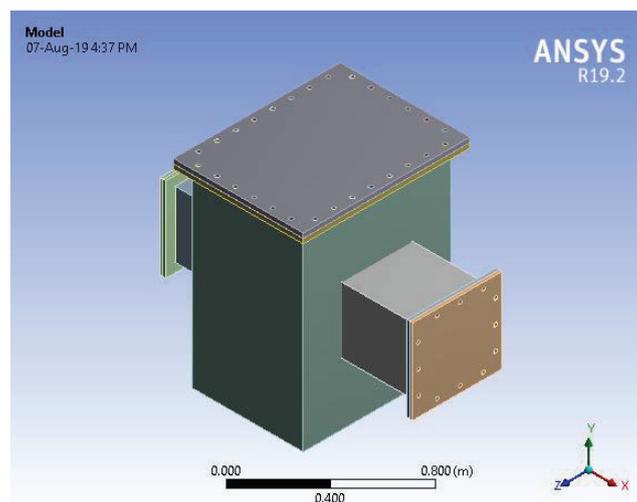


Fig. 1. Layout of designed Ex d transformer

Table 3 Value of k for different dimensions of plates and cover for transformer enclosure

| a/b | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| k | 0.045 | 0.043 | 0.040 | 0.037 | 0.032 | 0.027 | 0.022 | 0.018 |

### 3.1 Main Enclosure

The dimension of main enclosure for a flameproof transformer was taken for study 750 mm (length, *b*) * 550 mm (breadth, *a*) * 1000 mm (height, *h*) as shown in Figure 2(A). The thickness (width, *d*) of steel plate used to design for all sides of the enclosure including its cover were kept at 25 mm. The enclosure was provided three holes on both the cheek sides for fixing the treaded bushing to make connections from the winding to HT and LT cables

through LT and HT boxes. It was seen in the Figure 2(B) that the maximum stress occurred at the front side wall of the main enclosure and had a value of 337.72 MPa which was more than the value as calculated by computational theory formula. The maximum stress on the front side wall of the main enclosure and opposite in magnitude to the stress on the top cover of the main enclosure. The maximum principal stress, total deformation and directional deformation in the cover of the main enclosure body were obtained during analysis as shown in Figure 2(B), Figure 2(C) and Figure 2(D) respectively.
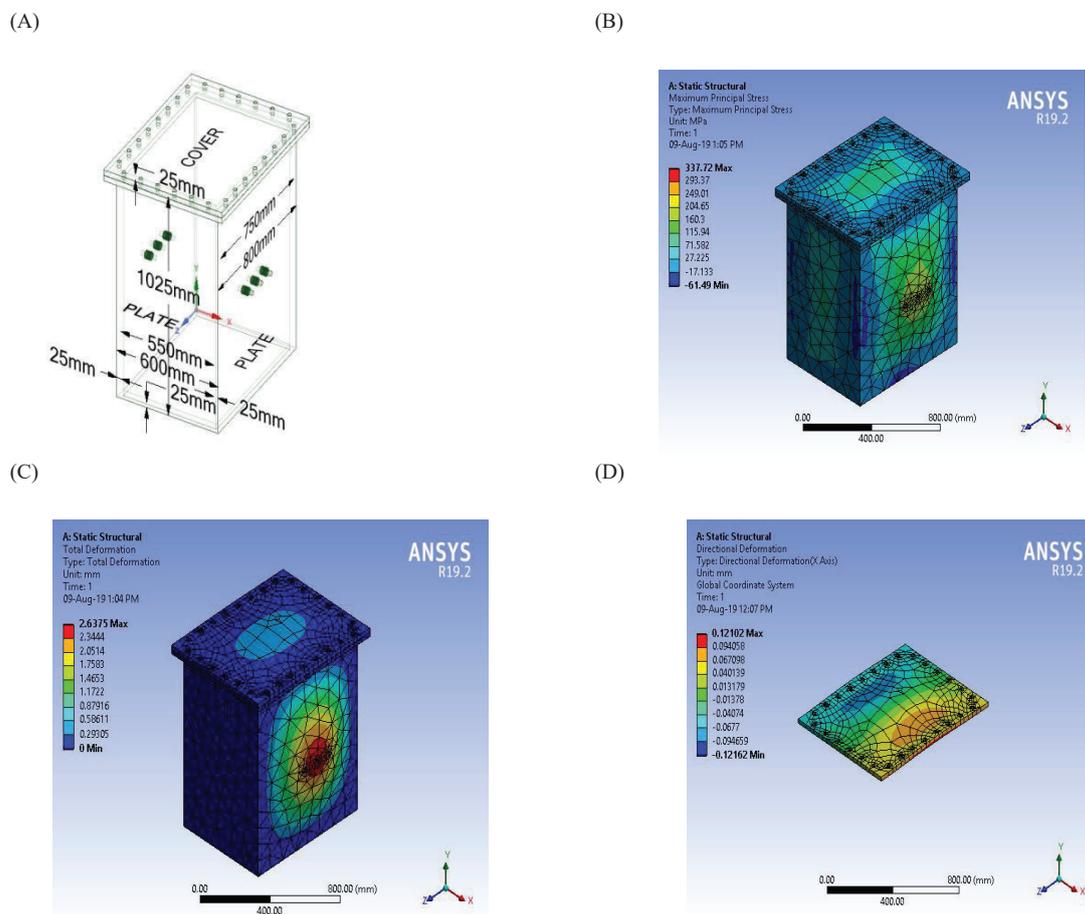
(A)

(B)



(C)

(D)



Fig. 2. (A) Dimensions layout of designed main enclosure (B) Maximum principal stress (C) Total deformation (D) Deformation on designed cover of main enclosure body

### 3.2 HT Box

The dimension of HT box for a flameproof transformer was taken

for study 300 mm (breadth, *a*) * 350 mm (length, *b*) * 325 mm (height, *h*) mm as shown in Figure 3(A). The thickness of all sides of HT box including its cover was kept at 16 mm. The box was provided three holes on the cheek side for fixing the threaded insulating bushing to make connections from the main winding through HT cables into HT box. The maximum stress occurred at the side walls of the HT enclosure and had a value of 134.05 MPa as shown in Figure 3(B) which was more than

the calculated value by computational theory formula. The maximum principal stress, total deformation and deformation in the cover of the HT box body were found during analysis as shown in Figure 3(B), Figure 3(C) and Figure 3(D) respectively. Three numbers threaded insulated bushings were provided by maintaining 16mm threaded length for input connections as shown in Figure 3(A).
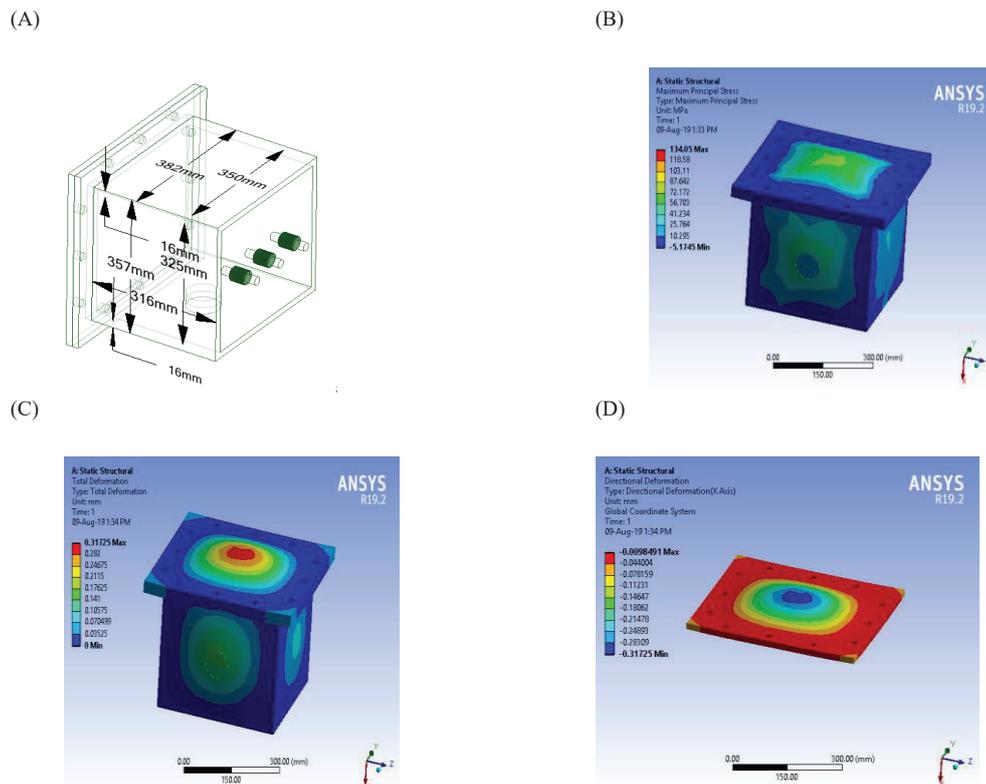
(A)

(B)



(C)

(D)



Fig. 3 (A) Dimensions layout of designed HT body (B) Maximum principal stress (C) Total deformation (D) Deformation on designed cover of HT body.

### 3.3 LT Box

The dimension of LT box for a flameproof transformer was taken for study 350 mm (length, *b*) * 400 mm (breadth, *a*) * 325 mm (height, *h*) as shown in Figure 4(A). The metal thickness of all sides of LT box including its cover was kept at 16mm. The enclosure was provided three holes on the cheek side for fixing the treaded bushing to make connections from the main winding through HT cables into HT box. The maximum stress occurred at the side walls of the LT enclosure and had a value of 130.05 MPa as shown in Figure 4(B) which was more than the calculated value by computational theory formula. The maximum principal stress, total deformation and deformation in the cover of the HT box body were found during analysis as shown in Figure 4(B), Figure 4(C) and Figure 4(D) respectively

## 4. DESIGN ANALYSIS

Earlier studies conducted by many researchers and showed that pressure impulses with short rise times can cause stress enhancement in flameproof enclosures. Further study of the dynamic stresses on flameproof steel enclosures, established that the natural frequencies of the enclosures are important value for the analysis of the material stress[24-25]. So, the maximum principal stress was calculated by using computational formula based on the enclosure/box dimensions used for designing. Further investigations related to thermal stress for flameproof enclosures are necessary to figure out the impact for the material load due to explosion pressure [26-27].

Thus, the computational formula for maximum stress is given as [28]:

$$\sigma_{\max} = \frac{6*k*p*a^2}{d^2} \tag{1}$$

Where $\sigma_{max}$ is the maximum principal stress of the material used for enclosure/box, $p$ is the explosion pressure which was considered to be 1 Mega Pascal for maximum stress analysis, $a$ is the breadth of the plate of enclosure/box, and $d$ is the thickness of the plate of enclosure/box. $k$ is a constant which varies depending on the dimensions of breadth $a$ and length $b$ for the plate and cover of the transformer enclosure. The value of $k$ has been evaluated by Xubo Gong et.al. [29] as tabulated in Table 3. The graph has been generated by using the values of $a$ and $b$ with the help of MATLAB curve fitting technique [30] which is shown in Figure 5 to use for theoretical calculation of maximum principal stress.

Using the values of Table 3, which act as training set, a generalized formula is obtained that will best fit the given values and will project values for any $a/b$ ratio with the help of the curve fitting method.
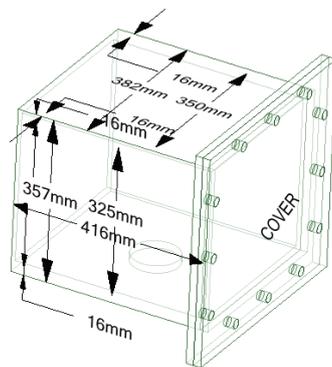
$$k(x) = m.e^n x \qquad (2)$$

Where, $m$= 0.06816, $n$= -1.168.

The formula so obtained uses notation $k$ as a function of $x$ i.e. $a/b$. Theoretical value of maximum principal stress for the front plate of main enclosure, HT box and LT box was calculated using formula number (1) is given in Table 4.
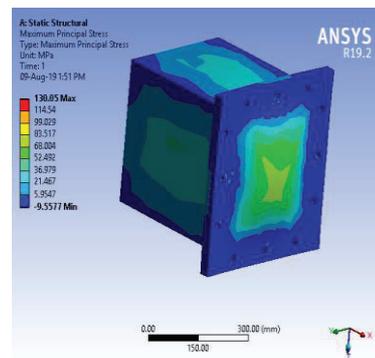
Table 4 Calculated maximum principal stress

| Enclosure/box | $\sigma_{max}$ (MPa) |
|---|---|
| Main enclosure | 90 |
| HT box | 52 |
| LT box | 60 |

The static pressure was applied of 1 MPa for 1 second individually on main enclosure, HT box and LT box to find out the effect of static pressure on the enclosure/boxes. The maximum principal stress, total deformation and directional deformation of the covers for all the three enclosure/boxes were obtained from the ANSYS analysis and tabulated in Table 5. It was found that maximum principal stress of 337.72 MPa, 134.05 MPa and 130.05 MPa withstood successfully by main enclosure, HT box and LT box respectively without any rupture/burst which can be seen from Figure 2 (B), Figure 3 (B) and Figure 4 (B).

The maximum total deformation in the body during stress analysis was obtained 2.6375 mm, 0.3172 mm and 0.3010 mm main enclosure, HT box and LT box respectively. Similarly, maximum directional deformation in the cover was obtained 0.1210 mm, -0.0098 mm and 0.3009 mm for main enclosure, HT box and LT box respectively. The deformation values obtained during simulation are within the total deformation value. It was observed that calculated value for maximum principal stress is less than the obtained value for all three enclosure/box. There is a sufficient safety margin between calculated and ANSYS values. Therefore, the safety factor can be set up as per requirement of statutory authority. It shows that the designed flameproof enclosure and box for flameproof transformer fulfil the requirement of safety for hazardous area

(A)

(B)

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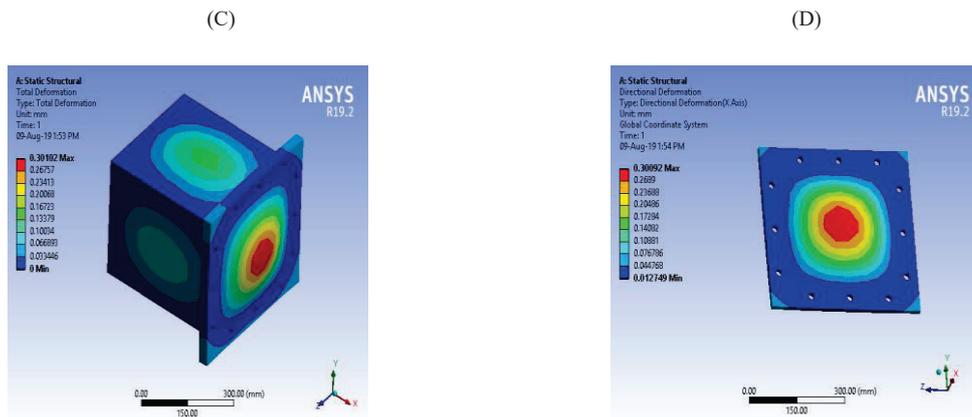**Vol. 15 Issue 02 , February - 2026**

(C)  (D)



Fig. 4 (A) Dimensions layout of designed HT body (B) Maximum principal stress (C) Total deformation (D) Deformation on designed cover of LT body.
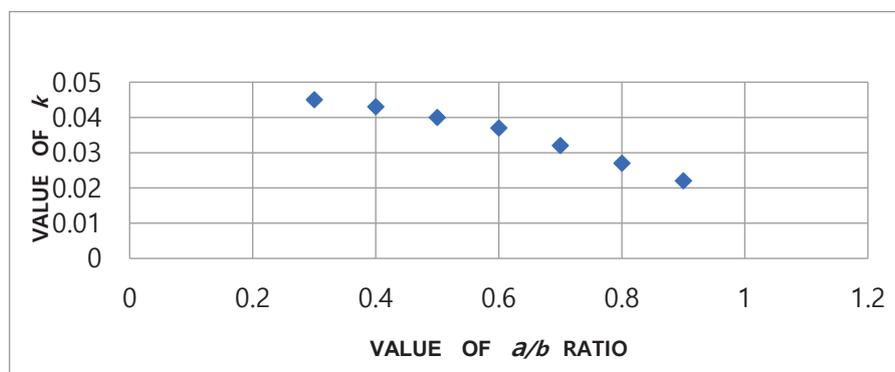


Fig. 5 Graph of k versus a/b obtained from MATLAB curve fitting.

Table 5 Obtained parameters for all three enclosure/box from ANSYS

| Parameters | Value | Main enclosure | HT Box | LT Box |
|---|---|---|---|---|
| Maximum principal stress (MPa) | Minimum | -61.4 | -5.174 | -9.557 |
| | Maximum | 337.72 | 134.05 | 130.05 |
| Total deformation (mm) | Minimum | 0 | 0 | 0 |
| | Maximum | 2.6375 | 0.3172 | 0.3010 |
| Deformation in cover (mm) | Minimum | -0.121 | -0.3172 | 0.0127 |
| | Maximum | 0.1210 | -0.0098 | 0.3009 |

## 5. CONCLUSION

The hazardous area refers to an environment where an explosive mixture exists, and an explosion can take place due to the presence of an explosive atmosphere.

This paper conveys the basic information about the hazardous area with respect to flameproof transformers. The designed flameproof enclosure/boxes for the Dry-type flameproof transformer by using ANSYS software comply with the requirement of overpressure sustainability for hazardous area. The calculated maximum principal stress values are less than the measured value during simulation for all three enclosure/boxes, which is acceptable. The directional deformation in main enclosure, HT box and LT box at maximum stress is also in the range of total deformation value obtained from the simulation. It can be considered that the design of a flameproof enclosure for a dry-type transformer can sustain the maximum pressure without rupturing at one MPa as initial pressure. Hence, the designed flameproof enclosure for transformer can be a suitable model for gas group I, IIA and IIB hazardous areas. The pressure analysis on flameproof enclosure for transformer for different geometric arrangements can be done prior to manufacture so that enclosures can pass all the necessary pressure tests for hazardous area application without any failure. Before the manufacturing of a prototype flameproof transformer enclosure, manufacturers can select the proper size of plates of the enclosure to analyse the sustainability of the maximum stress pressure and deformation by applying these design and analysis recommendations

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