WIND IMPACT PRINCIPAL STRAINS AND DEFORMATION EVALUATIONS OF RECTANGULAR GEOMETRIC BLADES OF WIND TURBINE FOR MAXIMUM POWER DEVELOPMENT IN NIGERIA

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ABSTRACT

In this paper, wind impact principal strains and deformation evaluations of rectangular geometric blades of wind turbine for maximum power development in Nigeria was conducted. Researchers created four geometrical wind turbine rectangular blade models with rotor using Autodesk inventor. Maximum average wind speed of 3.89m/s gotten from NASA website was used to compute the wind site load acting on each blade and was used to run the finite element principal strain simulation. Results showed that the maximum values of 1st and 3rd principal strains were found to be 0.000000694726 and 0.0000000000000990017 respectively. These results indicated that the blades material would fail due to tensile strain rather than compressive strain. Therefore, excessive wind impact on rectangular blades of the wind turbine at XY, YY and ZZ axes must be avoided to achieve a reliable service, since they showed maximum strain values. In addition, strain largest magnitude was found to be much at the tips, bonded or welded points of blades. Furthermore, the equivalent strain was found to be 0.000000981997 and it was within permissible limit. This indicated that the rectangular blade geometry would give lower strain value and long lasting blades when used in the operation of wind turbines. The researchers concluded that the installation of a wind turbine with site orientation of the blades away from the mentioned axes, could contribute to maximum power development by reducing strains and blade sudden failure.

Keywords ---- *Principal strain, Wind impact, Deformation, Rectangular geometry, Wind turbine*

1.0 INTRODUCTION

Wind turbine is a rotating device that is capable of converting kinetic energy of wind in motion into mechanical energy of a rotating rotor shaft as an output. The blades have been a major unit that is actually responsible for the motion extraction and conversion; it is usually welded, bolted or bonded to the rotor periphery or circumference. According to Khurmi and Gupta (2012) as cited by Onyenobi et al., (2022) in Ibezim et al., (2024) opined that vibration and deformation of blades are bound to occur when blade design is not properly done with respect to site wind pressure or wind load. Studies showed that effectiveness of the energy conversion in wind turbine is dependent on blade response to wind attack or impact during operation.

Efosa et al (2024) maintained that the geometrical dimensions of wind turbine blades adopted during design and production determines the maximum wind impact load experienced on blades during operation. They further added that the use of variables like site wind pressure, blade surface area and drag coefficient in the design of wind turbine blades would aid in safety of operations of the overall system as well as maintaining longer service life of entire system. It is on this note that the researchers aimed to study wind impact principal strains and deformation evaluations of rectangular geometric blades of wind turbine for maximum power development in Nigeria.

Nworie et al (2023) stated that finite element analysis is a process of simulating the behavior of the rectangular wind turbine blades on wind impact load, and it is a numerical technique that cut the structure of the blades into several elements, analyze each element and then reconnect the elements at a point called nodes. Principal strain is the maximum and minimum values of strains experienced by a body under stress, along the principal axes where shear strain is zero.

In this paper, researchers created geometrical wind turbine rectangular blade models with rotor using Autodesk inventor. Rectangular blades retained dimensions of 30mm by 6mm with thickness of 5mm. The rotor hub and shaft diameters were 60mm and 35mm with rotor height of 50mm respectively and shaft length of 80mm. A fillet radius of 2mm was adopted to de-concentrate stress acting at the hub and shaft rims (Efosa et al, 2024).

According to Efosa et al (2024) the average monthly wind speed data from 1981 -2021 (40 years) for fourth-seven (47) study locations are sourced from National Aeronautics and Space Administration (NASA) website as cited by Njoku et al (2022) in Nkwor et al (2023). The major cities in Nigeria were covered by the study locations as shown in the table 1.0 below. Maximum average wind speed of 3.89m/s was used to compute wind site pressure and subsequently wind site load acting on each blade. Finite element simulation was run with blade geometry, using wind site load, turning moment of 6 N mm and the impact stresses were evaluated and reported as shown below.

2.0 MODEL ANALYSIS

The wind power acting on wind turbine during operation can be given as follows:

$$P_w = \frac{1}{2}\rho V^3 \text{ Watts } \ldots\ldots.(1.0) \qquad \text{(Spera, 1994)}$$

Where $P_w = wind\ power, V = wind\ \ site\ speed\ and\ \rho = density\ of\ air$

The displacement or deformation field is shown below.

$$a_n = \frac{\partial u_n}{\partial x} \ \ldots(2.0) \text{ (Westmann, 2004)}$$

$$e_n = \frac{\partial v_n}{\partial y} \ \ldots(3.0)$$

$$b_n + d_n = \frac{\partial u_n}{\partial y} + \frac{\partial v_n}{\partial x} \ldots.(4.0)$$

$v\ and\ u\ are\ velocity\ components\ of\ x\ and\ y$

The principal strains are given below

$e_x = \frac{1}{E}\left[\sigma_x - \frac{1}{m}\left(\sigma_y + \sigma_z\right)\right] \ldots..(5.0)$ (Rajput, 2008).

$$e_y = \frac{1}{E}\left[\sigma_y - \frac{1}{m}(\sigma_x + \sigma_z)\right] \ldots..(6.0)$$

$$e_z = \frac{1}{E}\left[\sigma_z - \frac{1}{m}\left(\sigma_x + \sigma_y\right)\right] \ldots\ldots (7.0)$$

$Angular\ velocity\ of\ rotor\ , \omega = \frac{2\pi N}{60}$ rad/s …….(8.0) (Rajput, 2008)

Where N = rpm of rotor;

$Work\ done\ per\ seconds = Torque \times angular\ velocity$ …… (9.0)

3.0 RESULTS

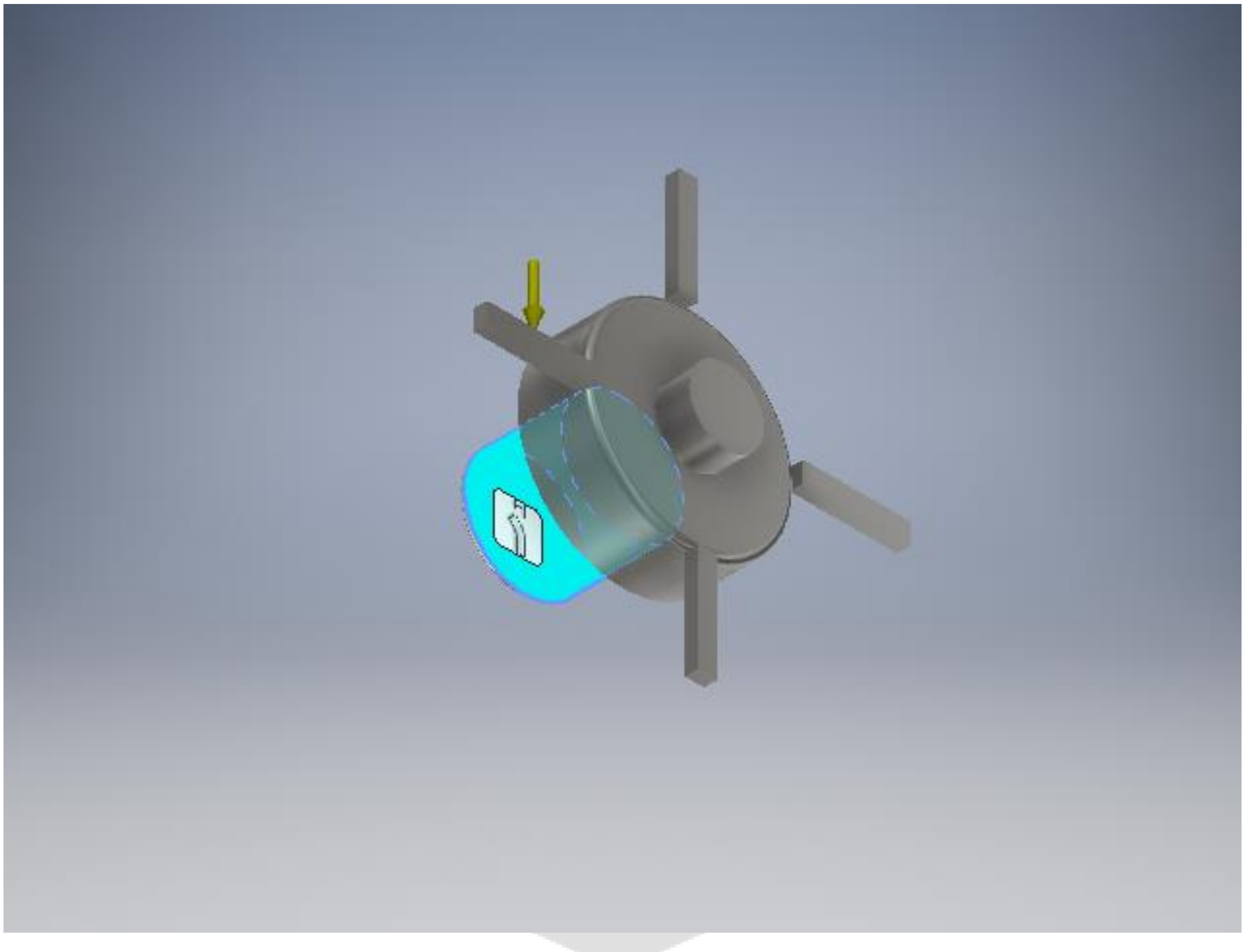

Fig 1.0: Solid View of Wind Turbine Rotor, Blade, Load and Constraint

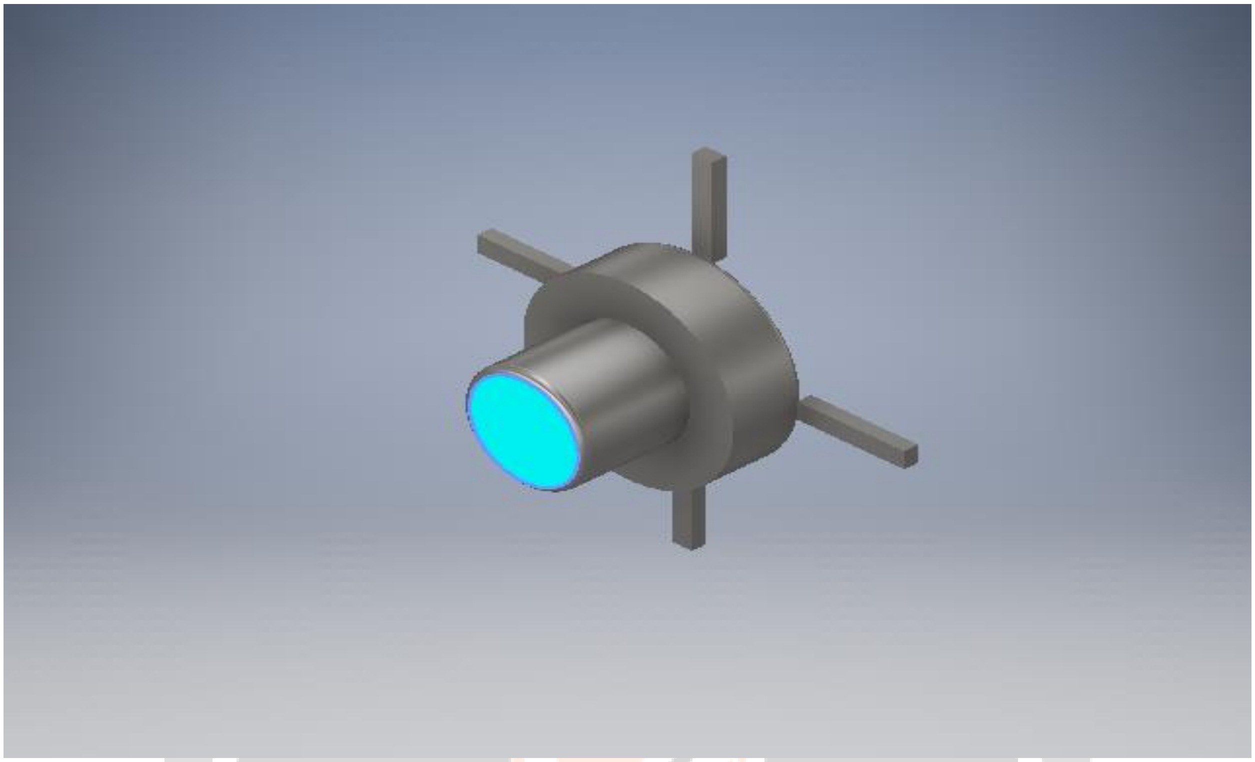

Fig 2.0: Solid View of Wind Turbine Rotor Showing Reaction on Shaft

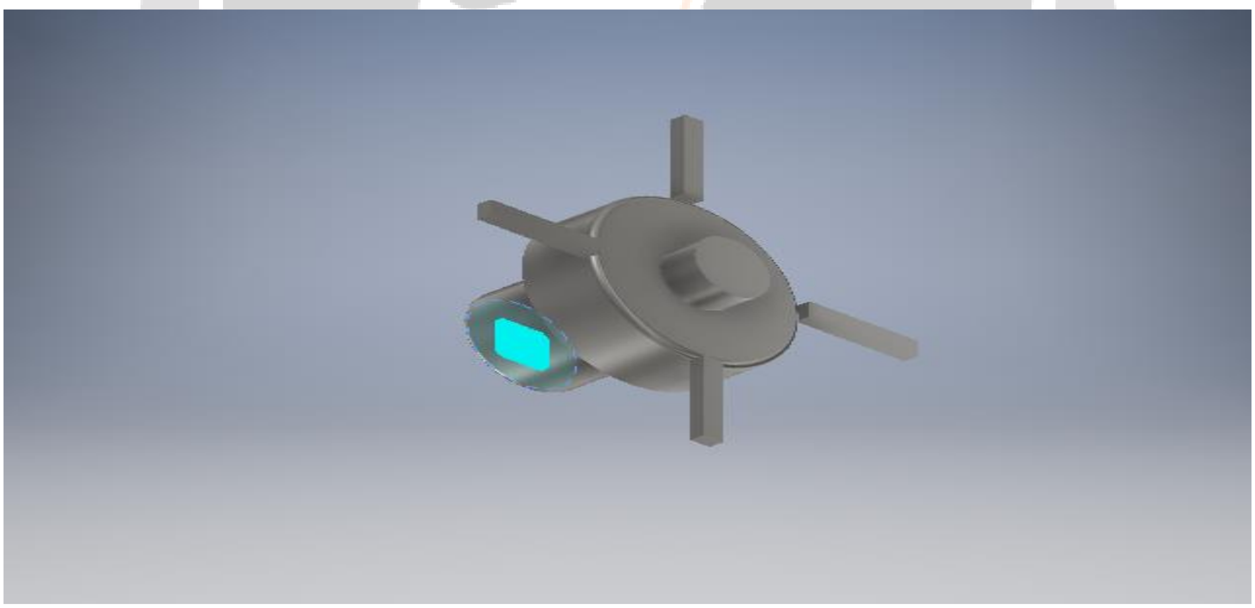

Fig 3.0: Solid View of Wind Turbine Rotor Showing Reaction on Shaft

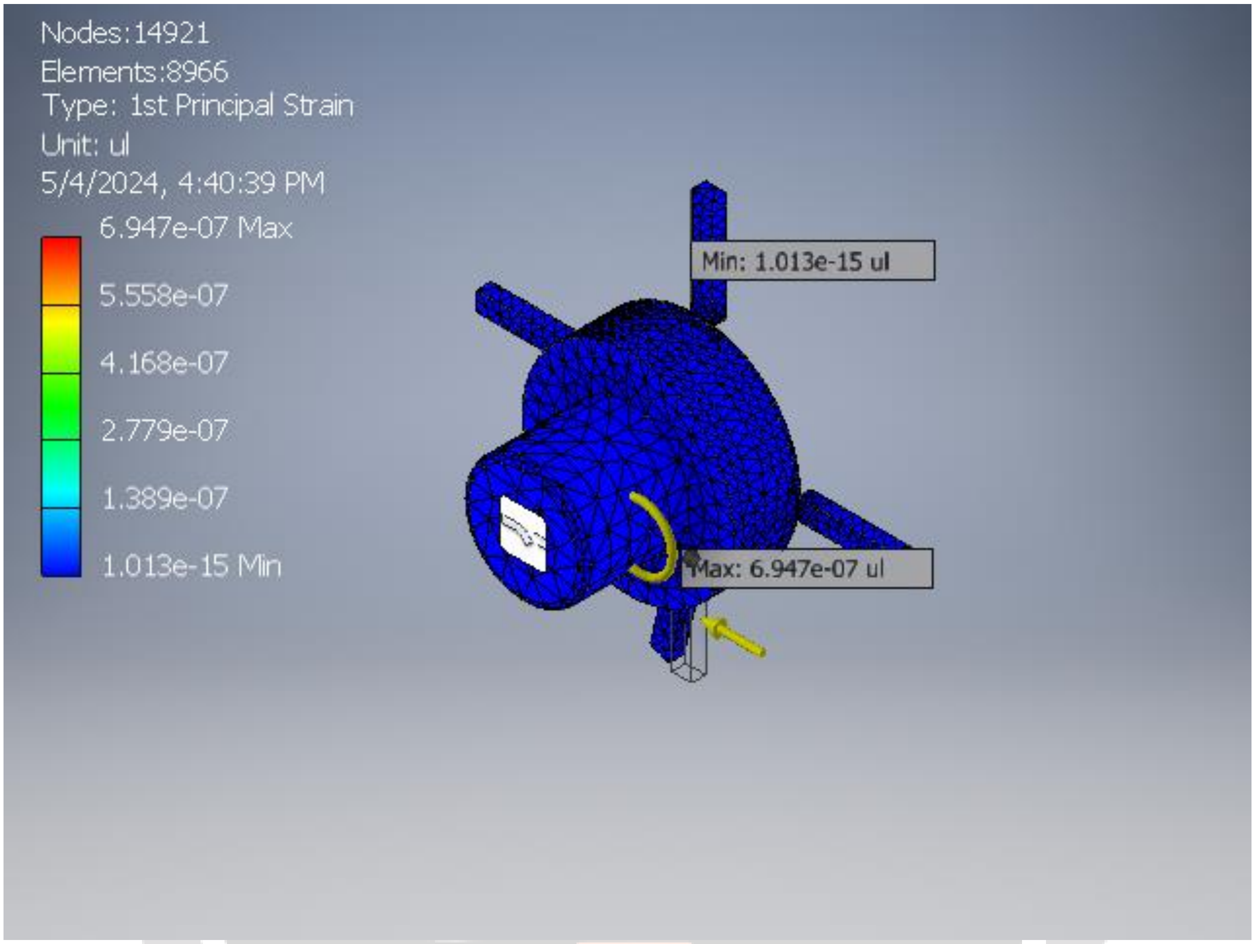

Fig4.0 (a): 1ST Principal Strain

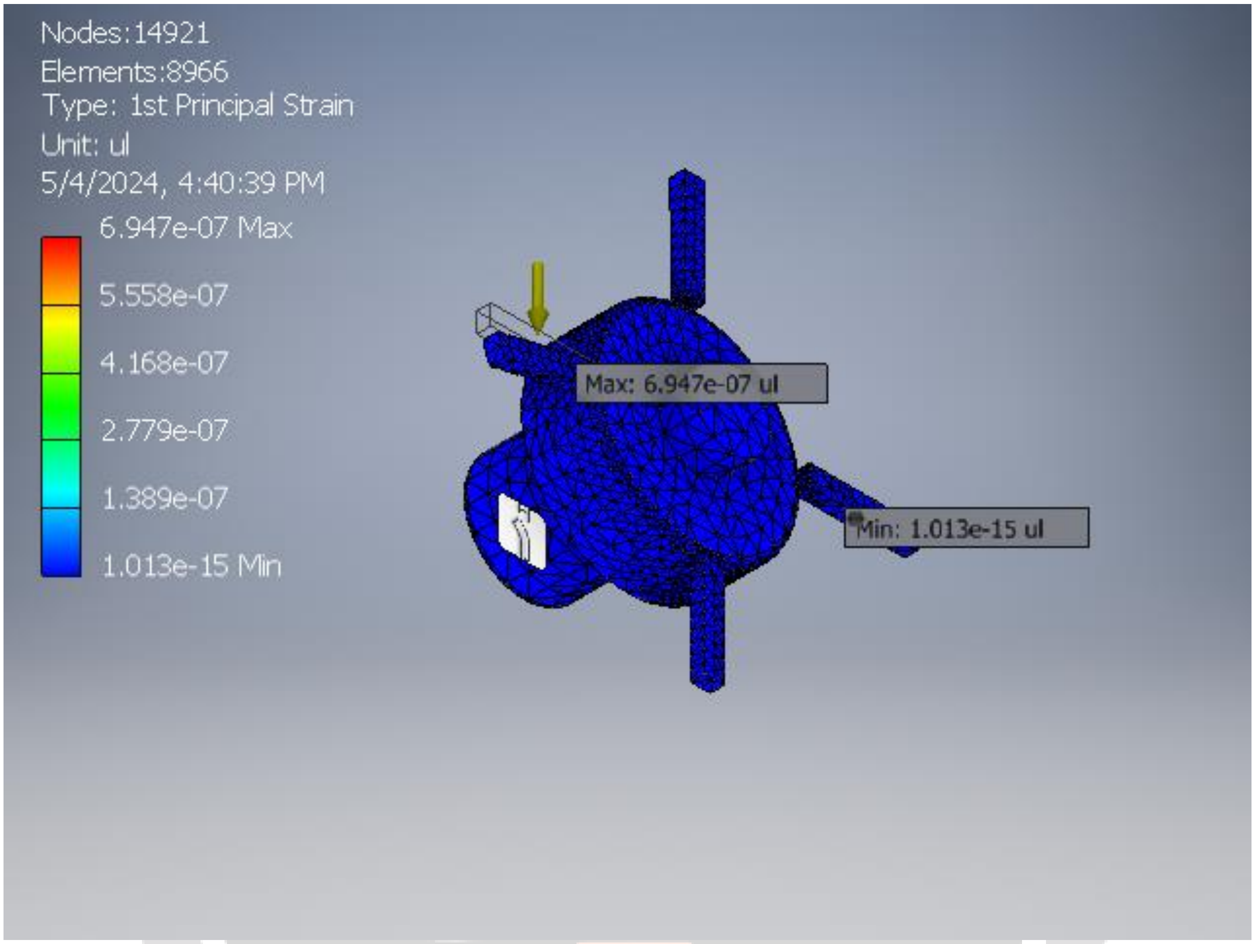

Fig4.0 (b): 1^{ST} Principal Strain

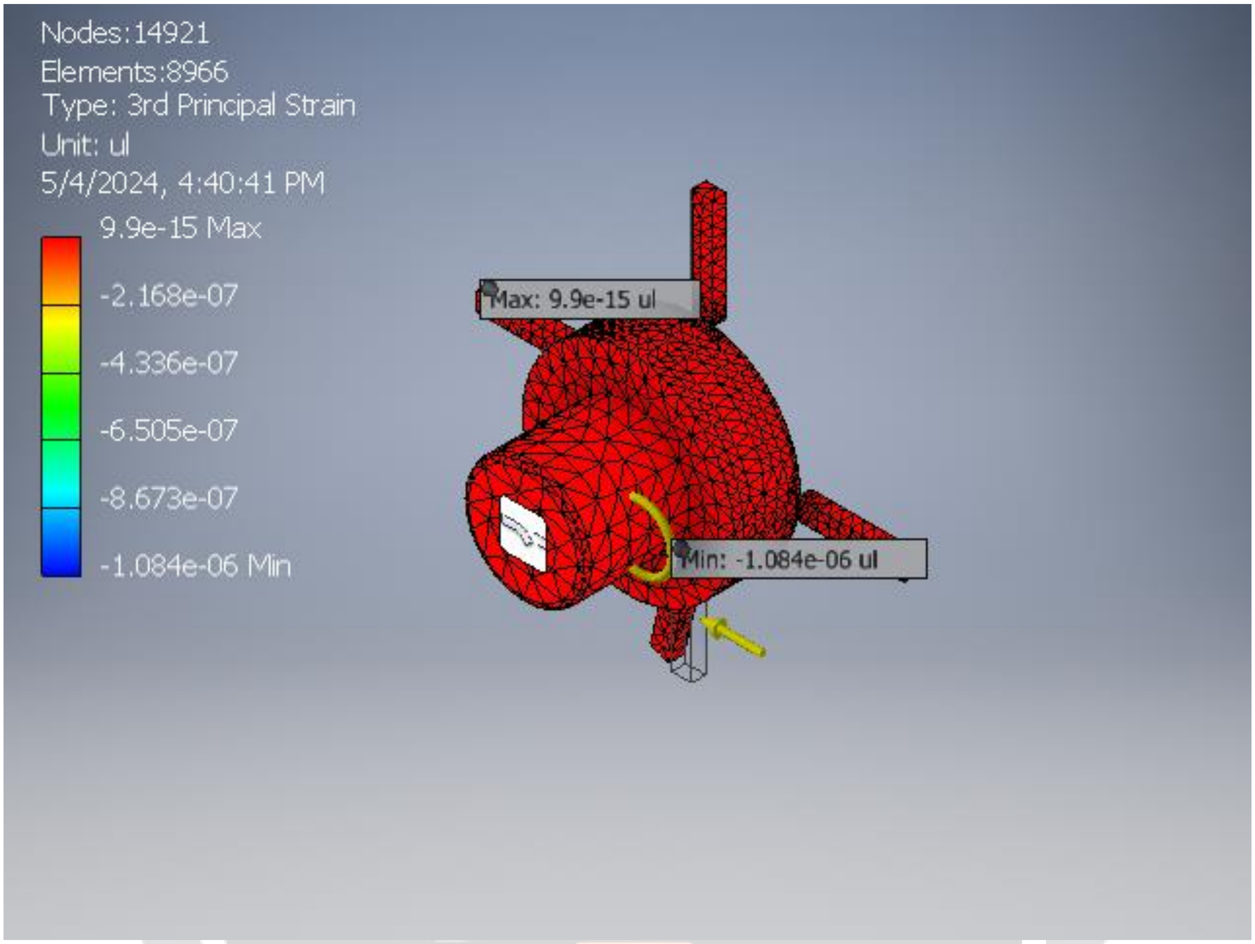

Fig5.0 (a): 3RD Principal Strain

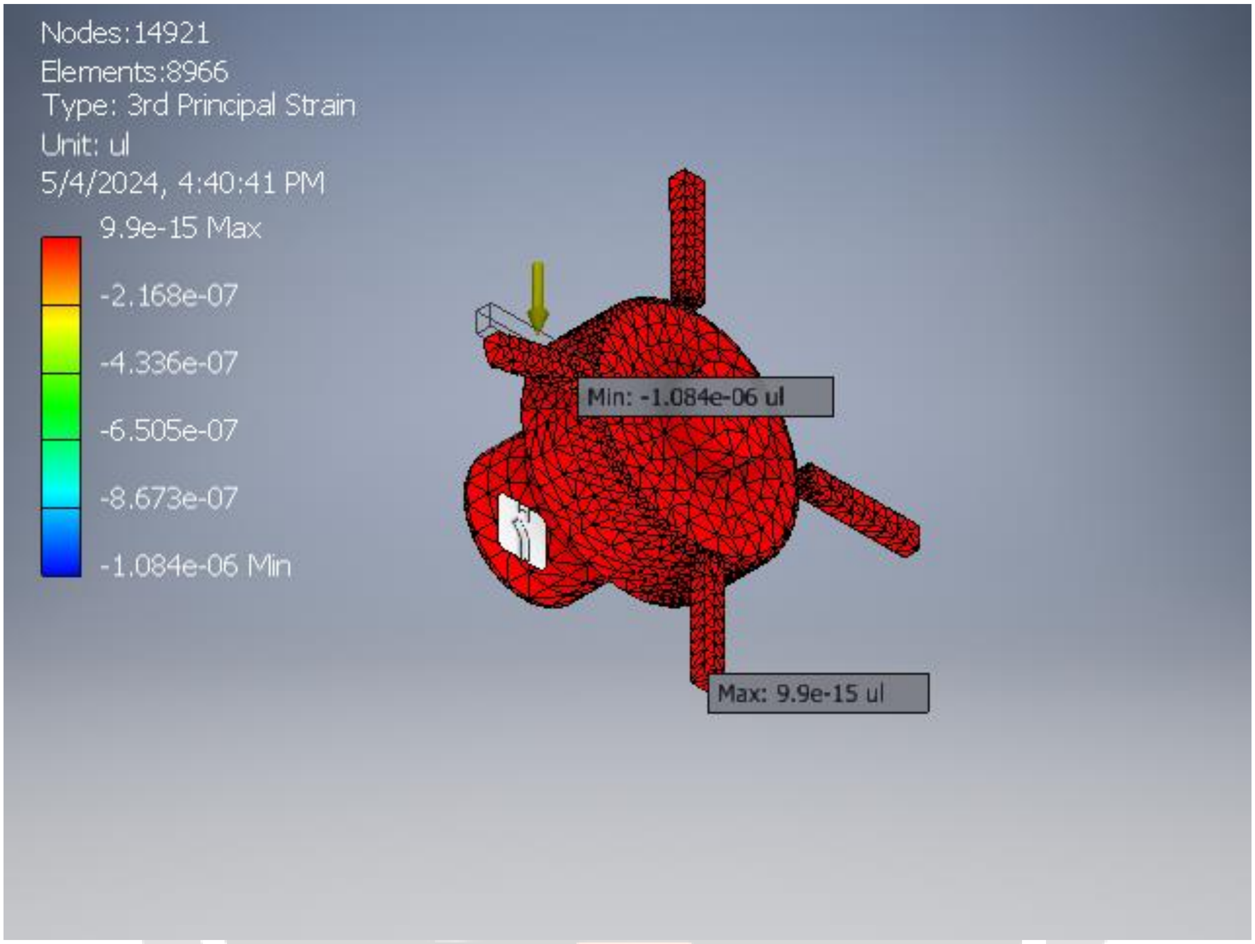

Fig5.0 (b): 3RD Principal Strain

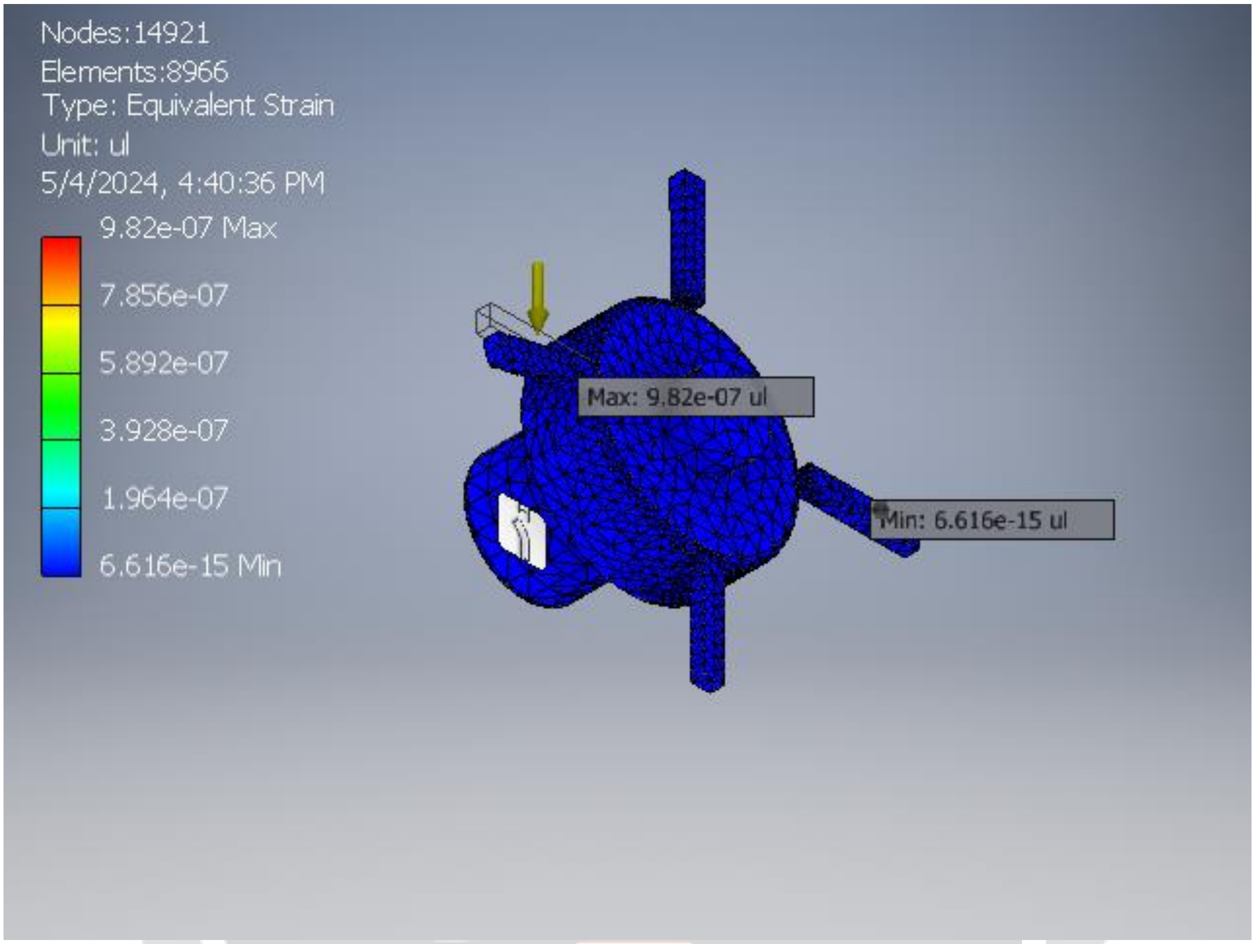

Fig6.0(a): Equivalent Strain

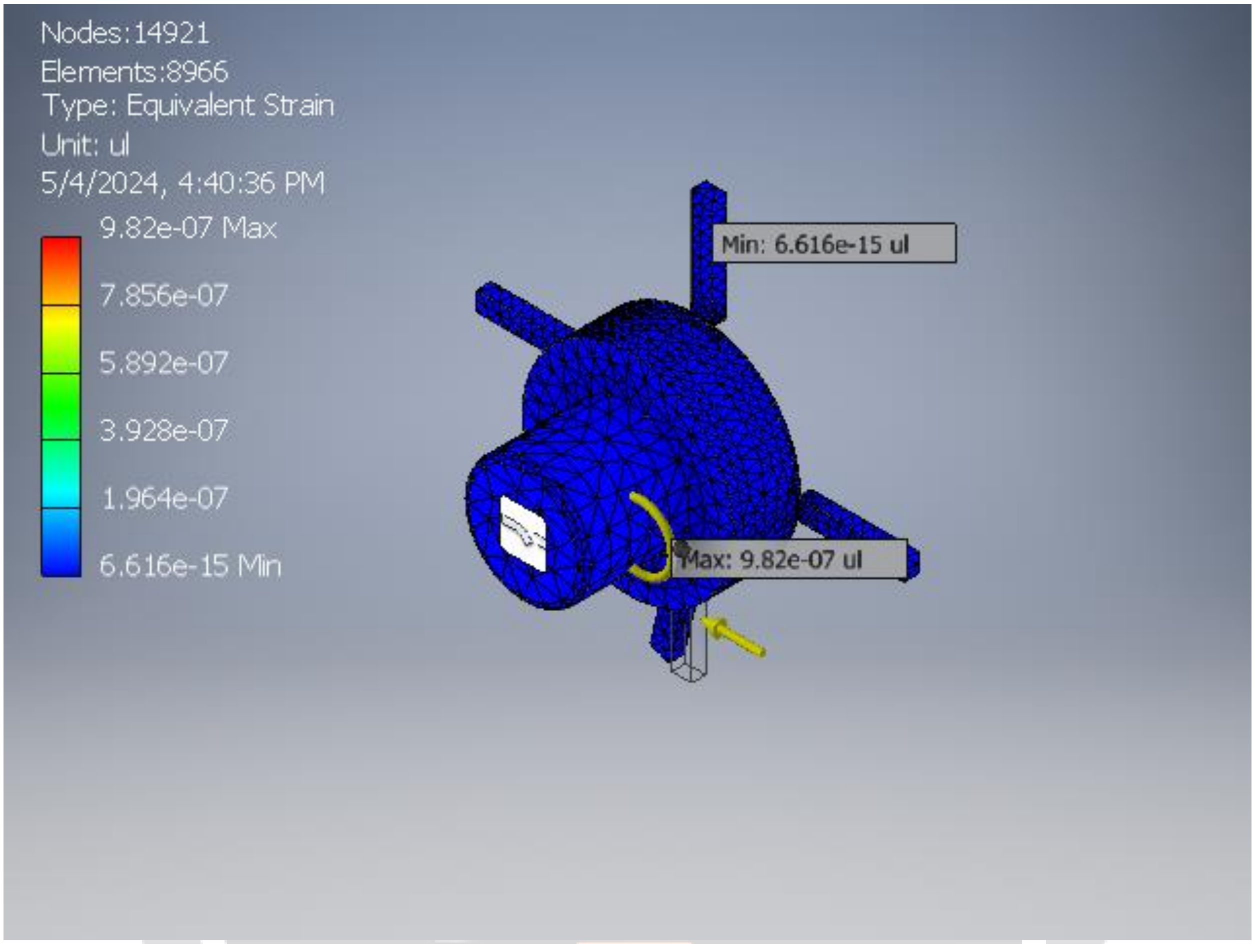

Fig6.0(b): Equivalent Strain

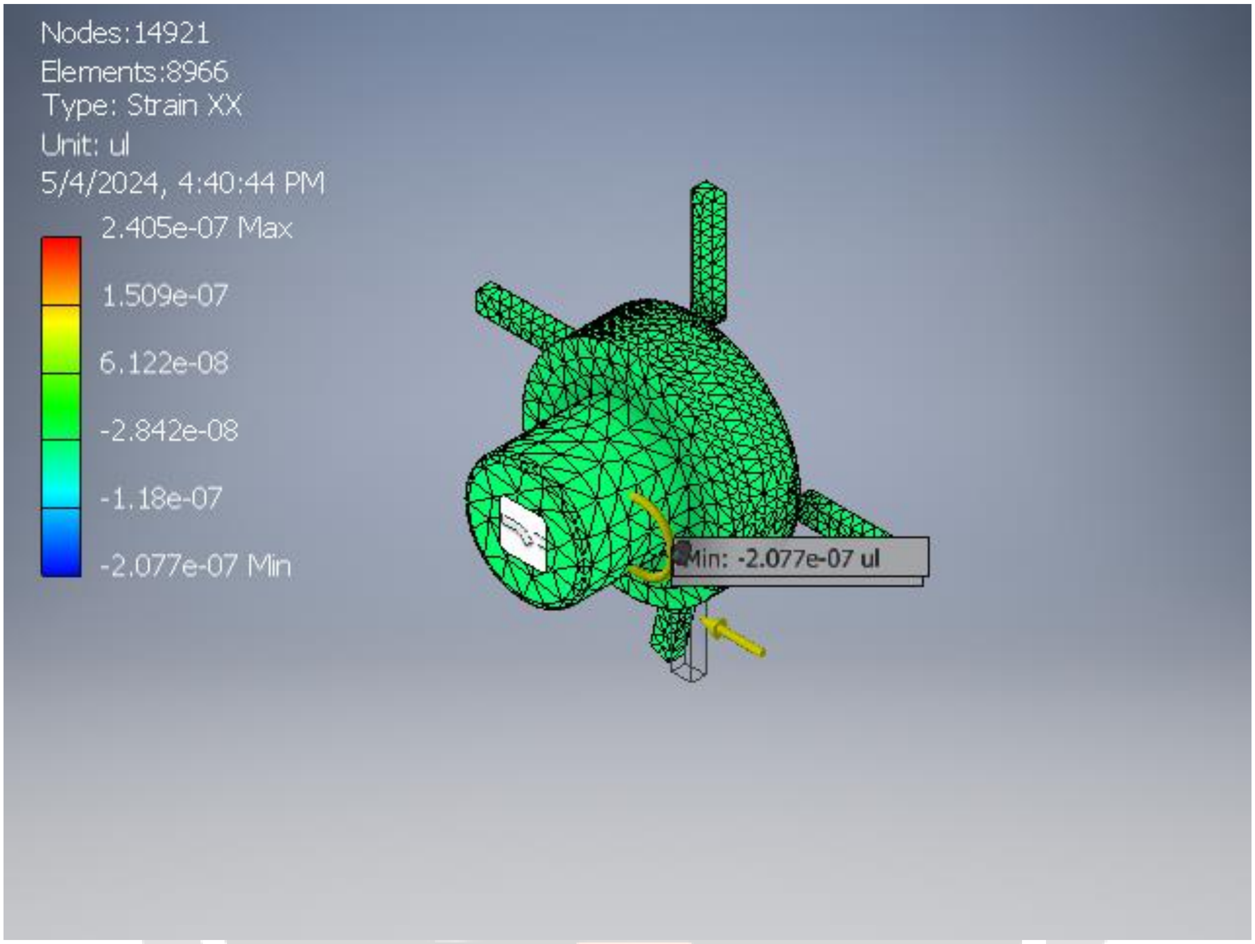

Fig7.0: Strain XX

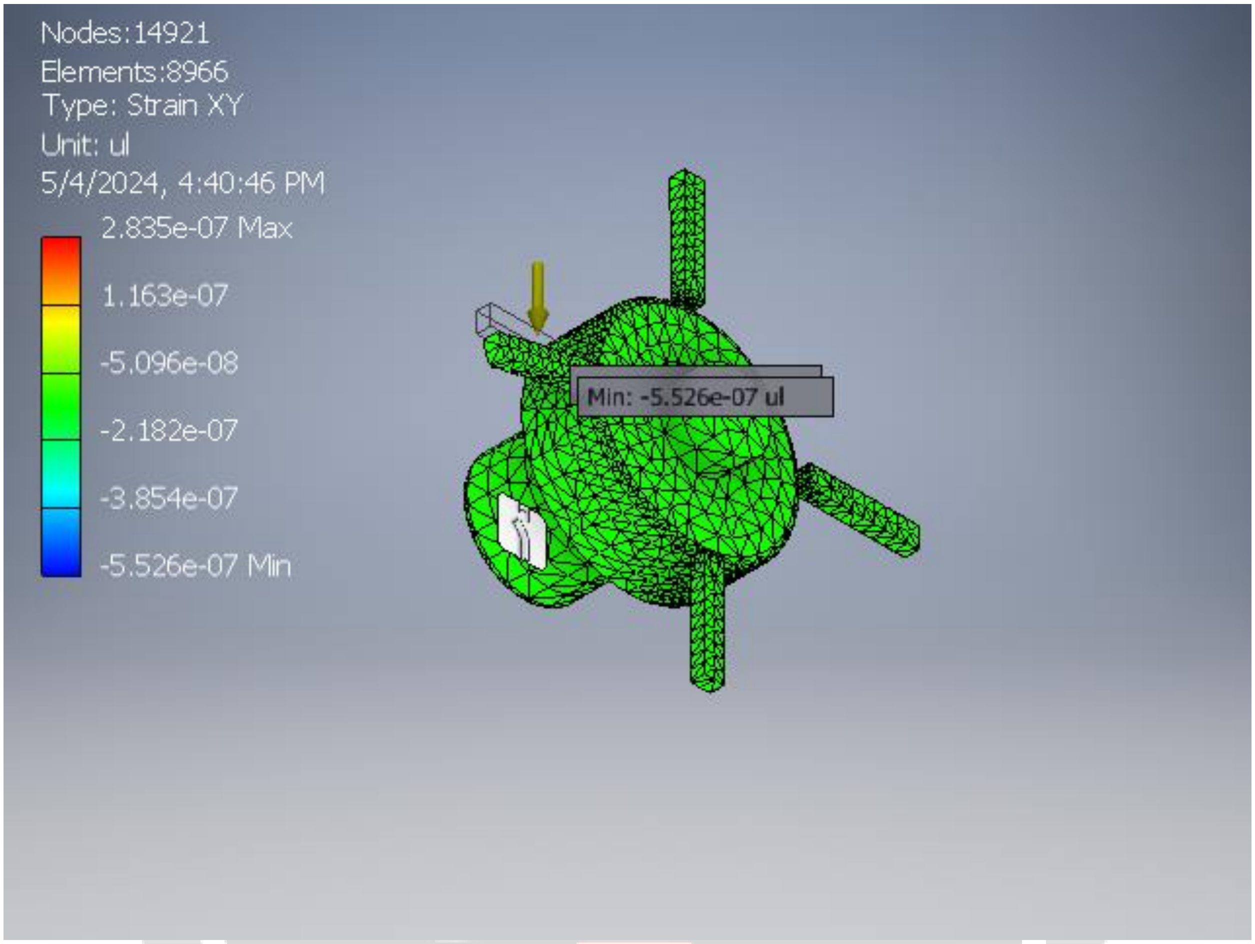

Fig8.0: Strain XY

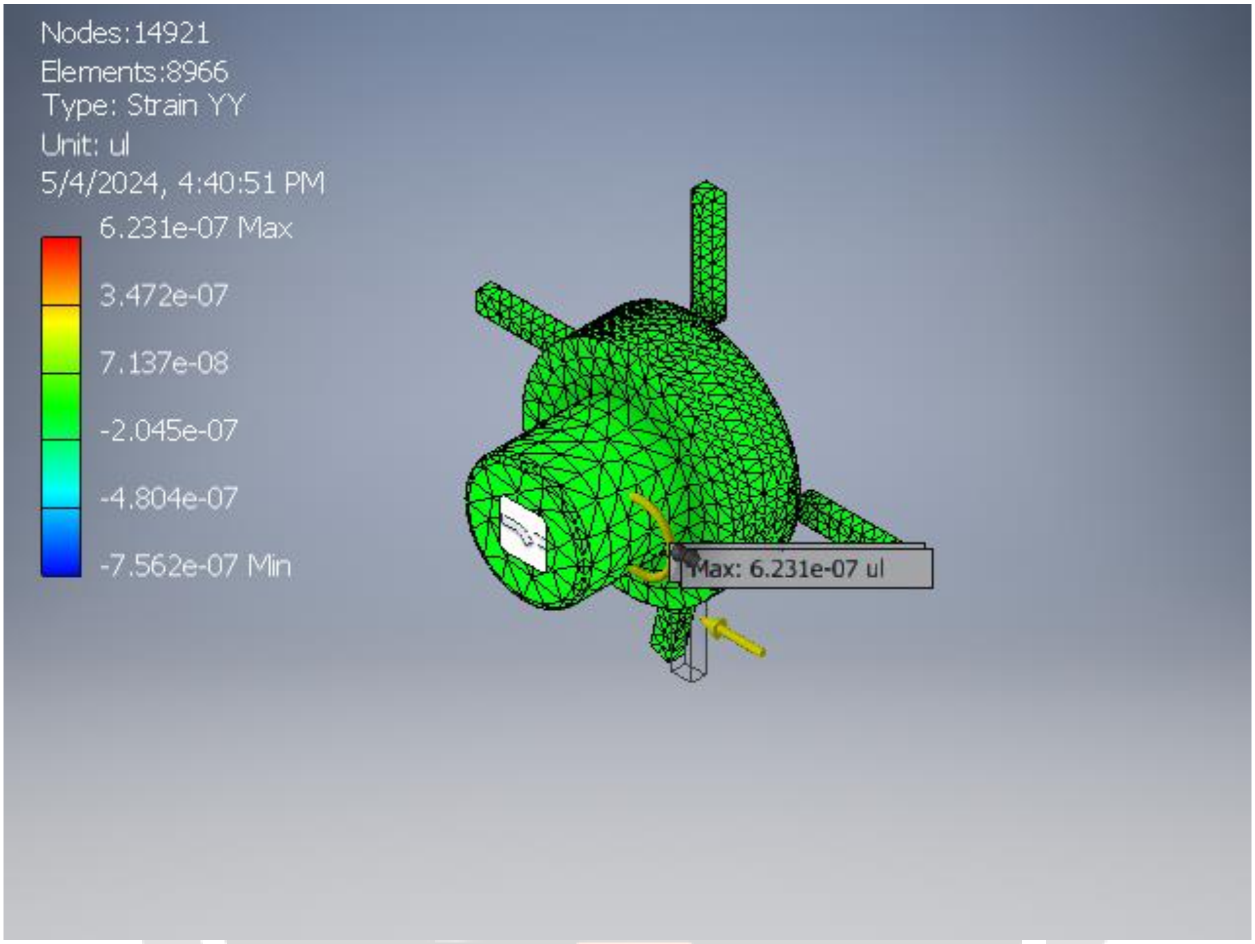

Fig9.0: Strain YY

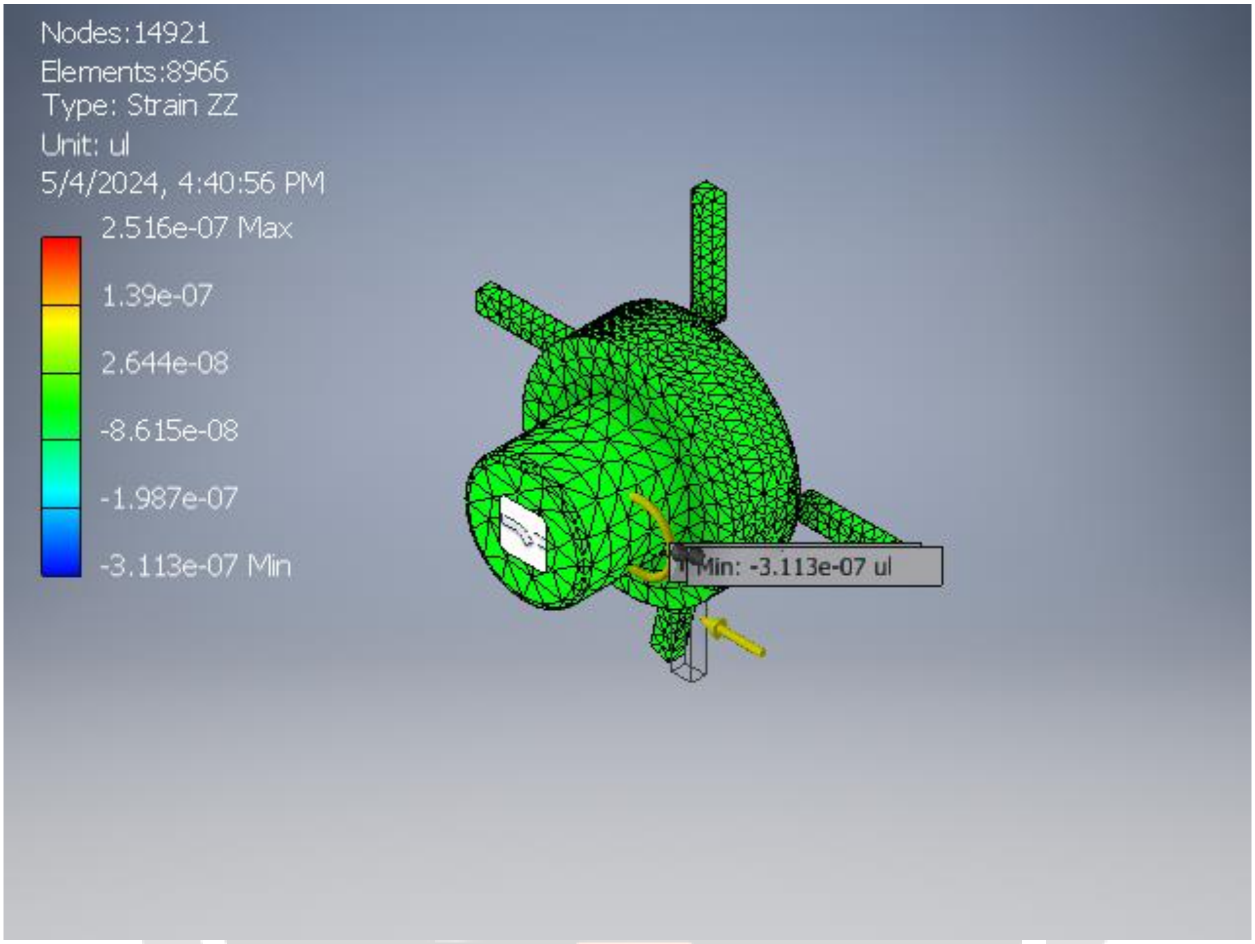

Fig10.0: Strain ZZ

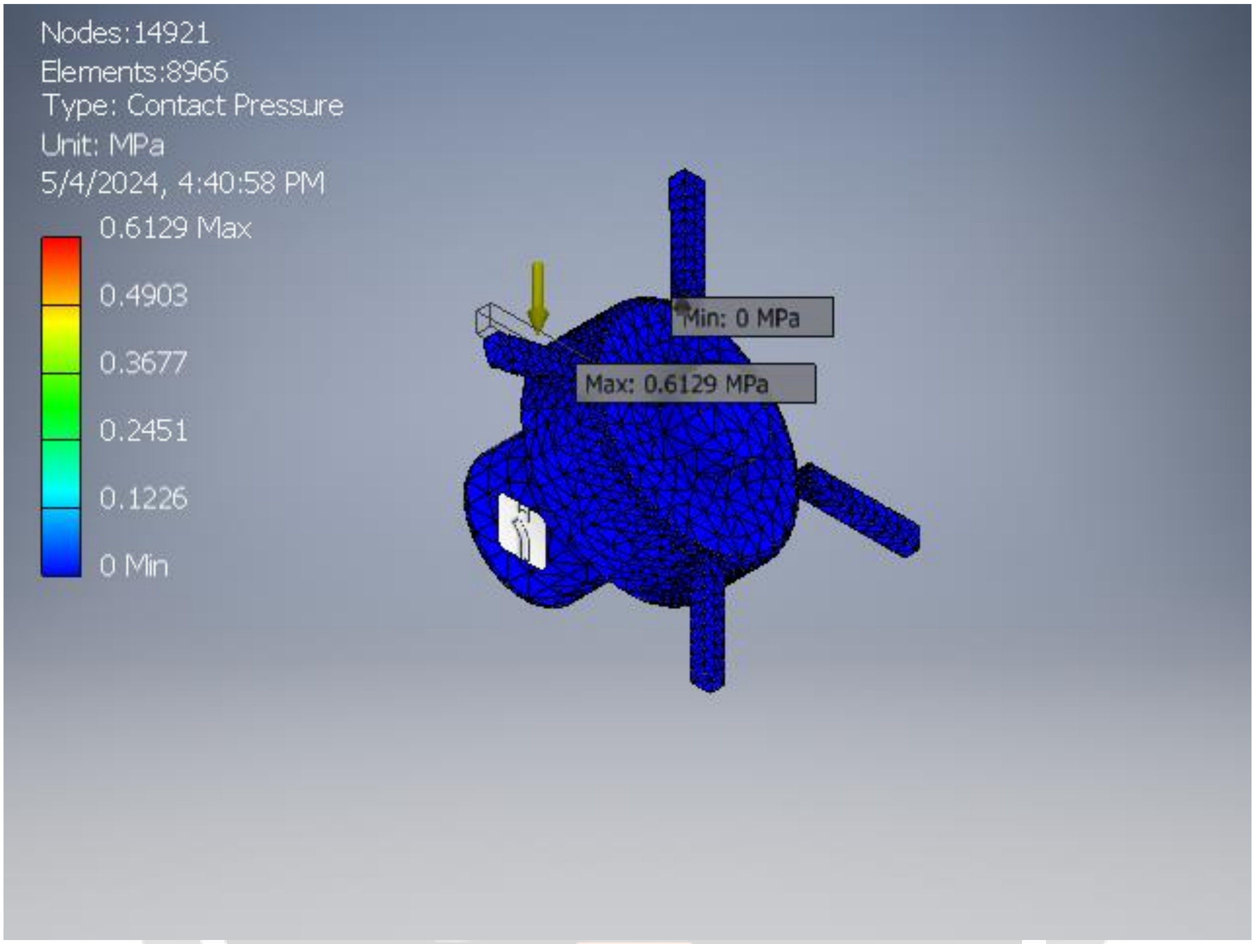

Fig11.0: Contact Pressure

Table1.0: Result Summary

Name	Minimum	Maximum
Volume	91594.2 mm^3	
Mass	0.732753 kg	
Von Mises Stress	0.00000000142243 MPa	0.211202 MPa
1st Principal Stress	-0.00466748 MPa	0.153905 MPa
3rd Principal Stress	-0.2211 MPa	0.029736 MPa
Displacement	0 mm	0.0000547862 mm
Safety Factor	15 ul	15 ul
Stress XX	-0.0902965 MPa	0.0452271 MPa
Stress XY	-0.0820391 MPa	0.0420843 MPa
Stress XZ	-0.0320043 MPa	0.0135775 MPa
Stress YY	-0.144473 MPa	0.143273 MPa
Stress YZ	-0.0678283 MPa	0.0513054 MPa
Stress ZZ	-0.0605311 MPa	0.0314822 MPa
X Displacement	-0.0000521033 mm	0.000000731181 mm

Y Displacement	-0.00000359963 mm	0.00000830858 mm
Z Displacement	-0.0000156754 mm	0.000000444462 mm
Equivalent Strain	0.0000000000000661577 ul	0.000000981997 ul
1st Principal Strain	0.0000000000000101263 ul	0.000000694726 ul
3rd Principal Strain	-0.00000108412 ul	0.0000000000000990017 ul
Strain XX	-0.000000207683 ul	0.000000240484 ul
Strain XY	-0.000000552595 ul	0.00000028347 ul
Strain XZ	-0.000000215573 ul	0.0000000914548 ul
Strain YY	-0.000000756233 ul	0.000000623108 ul
Strain YZ	-0.000000456875 ul	0.000000345581 ul
Strain ZZ	-0.000000311315 ul	0.000000251606 ul
Contact Pressure	0 MPa	0.612853 MPa
Contact Pressure X	-0.288977 MPa	0.0242916 MPa
Contact Pressure Y	-0.504862 MPa	0.338131 MPa
Contact Pressure Z	-0.19286 MPa	0.0485497 MPa

4.0 DISCUSSION

According to **Fig 4.0** and **Fig 5.0**, the maximum values of 1^{st} and 3^{rd} principal strains were found to be 0.000000694726 and 0.0000000000000990017 respectively. These results indicated that the blades material would fail due to tensile strain rather than compressive strain; this result, suggested that to improve reliability and stability of operation, excessive wind impact on rectangular blades of the wind turbine at XY, YY and ZZ axes must be avoided, since they showed maximum strain values. Strain concentration was found to be much at the blade tips and bonded or welded points, according **fig 6.0 to 10.0.** Also, according to Fig 6.0, the equivalent strain was found to be 0.000000981997 and it was within permissible limit. This indicated that the rectangular blade geometry would give lower strain value and long lasting blades when used in the operation of wind turbine.

5.0 CONCLUSION

According to the findings, it could be deduced that the value of principal strains that could fail wind turbine rectangular blades during operation, is tensile strain in nature and maximum along XY, YY and ZZ axes. Therefore, installing a wind turbine with site orientation of the blades away from the mentioned axes, could contribute to maximum power development by reducing strains and blade sudden failure.

6.0 RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) Excessive wind impact on rectangular blade along XY, YY and ZZ axes must be avoided to reduce strains within permissible limit.
2) Rectangular blade material for wind turbine must have higher tensile strain energy rather than compressive strain energy, since failure due to tensile load impact from wind is predominant.
3) This research could also be done in future using different geometrical blade designs and other advanced software for generalization.

7.0 DISCLOSURE OF CONFLICT OF INTEREST

We hereby declare that this research article is original and the corresponding author confirms that co-authors participated actively in the development of the paper and have read and approved the manuscript with no ethical issues and with declaration of no conflict of interest.

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