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Design Modification of Cluster Gear Shaft of Synchromesh Gearbox in Tractor

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Abstract: A cluster shaft is a rotating member/machine element, which is used to transmit power from one place to another. A cluster shaft is a shaft that runs parallel to the main shaft in a gearbox, and carries the pinion wheels. The failure of the second gear mounted on the cluster shaft occurred due to wear and tear. The objectives of the paper is to study the existing cluster gear shaft, and providing the proper solution so as to avoid the failure of cluster gear shaft. There are various reasons due to the gear may fail, few of them could be application error, design error, manufacturing error or application error. According to American gear manufacturing association, the failures of gear can be classified into four major categories namely surface fatigue, wear, plastic, and breakage. It has been observed that in most of the cases the failure starts from the bearing. After FEM analysis it is found that the maximum equivalent stress occurred on the second gear which is equal to 12.45 MPa.
Keywords: gear failure, wear, lubrication, misalignment.

I. INTRODUCTION

The fundamental function of gears is to convey power over a short distance. This is one of the most efficient and effective ways of transmitting power. For power transmission, gears are nearly always used in mechanical machines. Gears are used to transfer power and forces from one shaft to another in a variety of machinery. Two criteria, notably the number of teeth and the radius of the gear, are used to identify it. Typically, the gears are positioned on the shaft or the base. Gears are commonly grouped into three groups based on the direction of the axes: parallel axis (spur gear, helical gear), intersecting axis (bevel gear), and non-intersecting axis (non-intersecting axis gear) (spiral gear).

The primary purpose of a gear in a mechanical device is to transmit torque and motion from one component to another. The gears have the ability to change the direction of motion as well as increase or decrease output torque and speed. Various materials are employed depending on the purposes for which the gears are used. Steel, aluminium, wood, and plastic brass are just a handful of the materials utilized in gear production. Steel gears are more or less ductile, have a high modulus of elasticity, and have a high tensile strength, whereas cast iron gears have a high compressive strength, low modulus of tensile strength, and ductility. The worm is composed of steel, while the worm wheel is constructed of brass in the worm and worm wheel combination. The worm wheel is made of brass so it is easy to repair if it breaks. When the worm and worm wheel come into contact and wear, the worm brass wheel wears out faster than the steel worm. Analog watches, bicycles, drill machines, and cars are just a few examples of where gears are employed. Gear ratio, number of teeth, profile of gear, addendum, pressure angle, and damping ratio are the fundamental elements that are taken into account while constructing gears.

The objective of this paper is to find out the cause of failure of cluster gear shaft and analyze it with the help of Ansys software.

II. LITERATURE REVIEW

One of the most critical stages in gear design and manufacture is gear analysis. Several theories have been offered by various scholars to improve the gearing system's performance. Netpu et al. [1] investigated helical gear used in continuous hot rolling mills and found that it failed prematurely. The gears collapsed owing to pitting corrosion and severe loading, according to a thorough study. The original 300KW motor was replaced with a new 600KW motor without being fully studied in order to roll thicker billets. Due to the replacement of the motor, the contact pressures on the helical gear were 3.2 times greater than the material's permissible stress. To determine the actual reason of failure, Siddiqui et al. [2] looked into an aircraft's rear wheel gear hub. The break's microstructure indicated a river pattern, and finite element analysis demonstrated that the stress concentration was in the same location near the crack. The bending stresses on the involute gear tooth profile were reduced by Kadir Cavdar et al. [3]. The computer software was created by the authors to study contact ratio and bending stress fluctuations. To decide the value of stress concentration factor and tooth shape, several elements such as tool radius, pressure angle, and so on were chosen.

Poor pitting resistance, noise during operation, and low bending strength are all downsides of the involute gear tooth shape. Non-involute have so been recommended [4, 5], however they are unaffected by centre distance. Modifications to the design of the addendum of the pinion or the mating gears can enhance the bending strength of the involute gear tooth [6–8]. When the gear material was changed from C-45 to 19mncr5, Gagandeep Singh [9] attempted to study the gear life and noise frequency. The gear tooth profile was designed using the Buckingham formula and the Lewis equation. Tangential load and dynamic load should be smaller than tangential force and endurance load, according to the findings. The author was able to lower the noise level from 90 to 80 decibels.

The surface of a helical tooth profile was explored by Kahraman et al. [10] using a surface wear prediction model to assess the effects of tooth variations produced by manufacturing processes. In order to forecast sliding distance computation method, contact pressure, and wear between the contacting surfaces, FEM techniques were applied in the wear model. To anticipate wear rate, the authors suggested a design formula that took into account mismatch in slope of contacting surfaces. Tooth undercutting problem is more common in spur and helical gear with small number of teeth.

Gears with a modest number of teeth are rarely utilised in power transmission equipment. Helical gears, on the other hand, are widely employed in industry and may be produced by hobs, shapers, and rack cutters. Akira et al. [11] researched a pair of gears with a four-toothed pinion and tested them with a 10 x 106 rotation on a gear tester machine in order to acquire a greater load capacity. When tested under typical conditions, it was discovered that the gear with more than six teeth had a higher efficiency, around 93 percent, than the gear with three teeth. Gear undercutting reduces the contact ratio and the gear strength significantly. Increased tooth count is a well-known means of reducing gear undercutting, however this is not always practical. Chen et al. [12] created a mathematical model for helical gears with a minimal number of teeth, changed root and tooth fillets, and pinion gear clearance. Gear shifting has been discovered to be the most important factor in gear shifting.

More study has been concentrated on the application of polymer gears in the recent two decades, as metallic gears have several constraints such as efficiency, lubrication, weight, noise, and cost [13, 14]. Polymer gears have a number of benefits over metallic gears, including strong robustness, the ability to function with little or no lubrication, and superior damping capacity [15, 16]. These gears are currently widely utilised in a variety of applications, including the automobile sector, kitchen machineries, textile industries, and so on, due to the benefits described in terms of technical aspects and economics. According to a study, the use of polymer gears in the automobile sector lowered mass, inertia, and fuel consumption by 70%, 80%, and 8%, respectively [17]. Acrylonitrile butadiene styrene (ABS), Polyamide (PA), nylon, acetal, and high-density polyethylene (HDPE) are some of the most frequent gear materials utilized in the production of polymer gears.

When two gears mesh, the bigger gear is referred to as a gear, while the smaller gear is referred to as a pinion. Blanking, casting, powder metallurgy, extrusion, and forging are some of the manufacturing procedures used to make the gears. Positive drive gears are used, and the velocity of the gears stays constant during power transfer. When compared to other drives, the efficiency of a gear drive is quite high, and it may be employed for low-speed applications. The gears are small and capable of transmitting a lot of torque. Figure 1 depicts the failure analysis of cluster gear shaft.

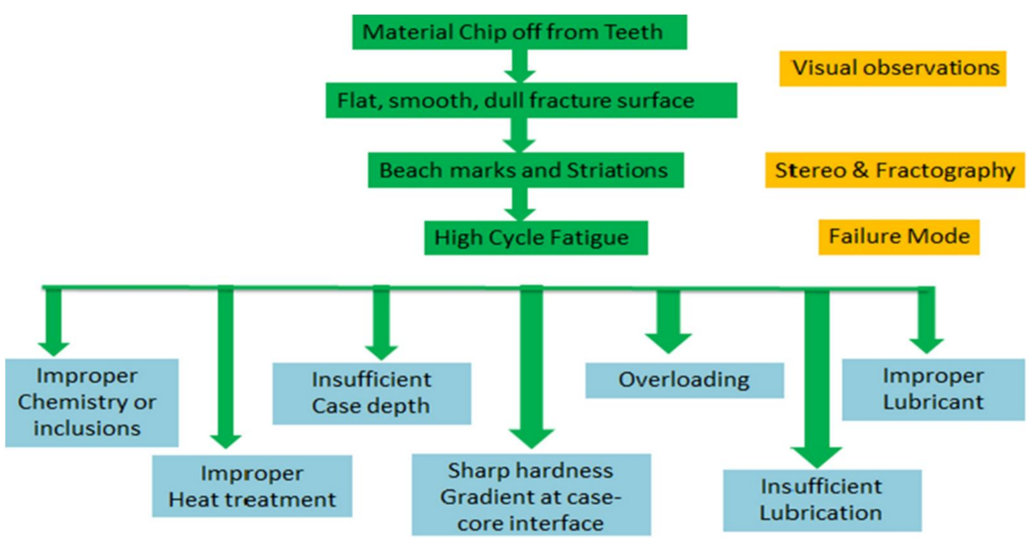

Figure 1: Failure analysis of cluster gear shaft

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When gears fail to execute the purpose for which they were built, we refer to this as gear failure. Excessive wear to catastrophic failure are all possible causes of gear failure. Polishing wear is a phenomena that occurs when metal layers are worn away or removed from the contacting surface. Due to metal-to-metal contact between the gears, wear happens at a relatively slow pace. This happens most often at low speeds, when the lubricant between the gears is insufficient. This can be prevented by running the gears at a high speed or using a lubricant with a greater viscosity, for example. Inadequate lubrication and a thin coating cause moderate wear. Another possible cause of mild wear is dirt in the lubricant. This form of wear can be prevented by using a lubricant with a greater viscosity or by choosing a more wear-resistant gear material. The material from the addendum and dedendum region is lost with moderate wear [18].

The contact surface of abrasive wear reveals grooves, radial scratch marks, or signs of lapped finish. Abrasive wear might be caused by a foreign particle in the lubricating layer between the contacting surfaces. This form of wear may be avoided by cleaning the gearbox and the lubrication system thoroughly [19]. Figure 2 shows the different types of failure of gear including polishing wear, abrasive wear, corrosion wear and fatigue wear.

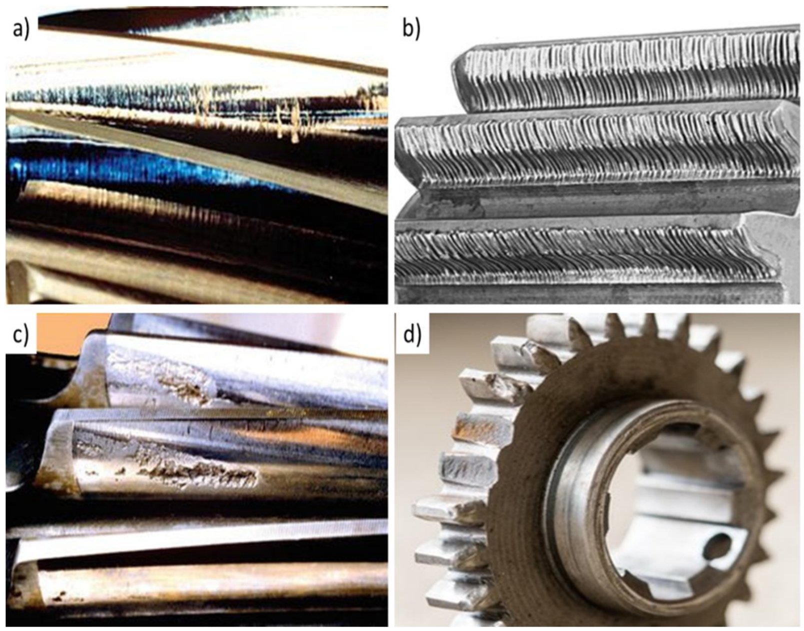

Figure 2: Failure of gear a) Polishing wear b) Abrasive wear c) Corrosion wear d) Fatigue fracture

The contact surface deteriorates owing to corrosive wear generated by chemical action. Moisture, additives, and acid may be present in the lubricating substance, causing chemical action and corrosive wear. The lubricating coating breaks and the chemical comes into contact with the surface, resulting in surface pitting. Cleaning the gearbox and replacing the lubricating oil on a regular basis might help prevent this wear.

Another cause of gear failure is fracture failure, which occurs when the entire tooth or a significant portion of the tooth breaks away. The failure begins with a crack that begins at the gear's root and spreads outward. This form of failure occurs when the weight is much more than the gear's endurance limit. It may be prevented by constructing the gear tooth to distribute the load in such a way that it is less than the endurance limit. Another technique to avoid fracture failure is to choose the right heat treatment to achieve top structure and reduce stress.

III. METHODOLOGY

A cluster shaft is a revolving machine piece that transmits power from one location to another. In a gearbox, a cluster shaft runs parallel to the main shaft and transports the pinion wheels. The clutch shaft and its input gear drive a shaft in a manual gearbox. The counter shaft rotates in the opposite direction as the engine. Following the industrial visit, it was discovered that when gear teeth were meshing at various rotational speeds, they failed to engage and generated a loud noise. The necessary gear changing arrangement was not supplied, resulting in damages. The current gearbox was incapable of handling fluctuating loads. Figure 3 shows the gear box and damaged gear.

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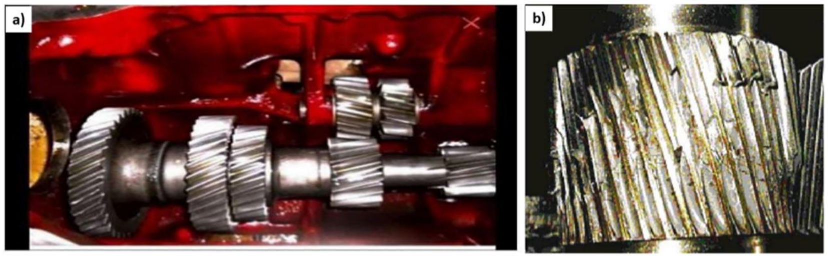

Figure 3: a) Gear box b) Damaged gear

The following objectives have been determined based on the preceding observations and problem identification. To tackle the issues, researchers must examine the present cluster gear shaft design utilised in tractor synchromesh gear boxes. A new design and modelling of the cluster gear shaft must be carried out after evaluating the old design and obtaining all data. Validation of the changed model requires the use of appropriate analysis software. The material of the cluster shaft and its qualities are shown in Table 1. The cluster gear and its placement on the gearbox are shown in Figure 4.

Table 1: Material of cluster shaft and its properties

Material	20MnCr5
Surface hardness	58-62 HRc
Effective case depth at 530 HVI	0.6-0.9 mm
Core hardness	32-42 HRc
Microstructure	Tempered martensite, retained austenite< 15%

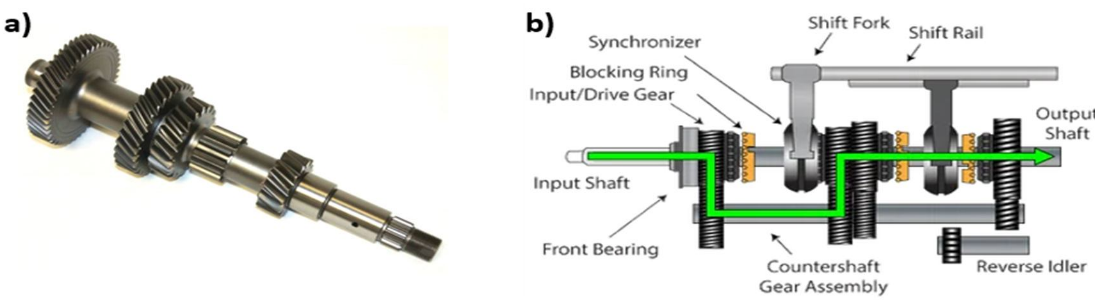

Figure 4: a) Cluster gear shaft b) Cluster gear shaft assembly

IV. CALCULATIONS

The cluster shaft is attached to an engine with the capacity of 50 HP, 2200 RPM, and number of cylinders 3.The calculations are done by using this data.

Engine power = 50 HP = 37.1 KW
Number of teeth on pinion T_p = 19
Helix Angle $\alpha = 30.27^0$
Pressure Angle = 20^0
RPM of pinion N_p = 1800 RPM
RPM of gear N_G= 600 RPM
Overhang = 150 mm
Shear stress τ = 50 MPa
Normal stress σ = 50 MPa
Design of pinion and gear
Torque transmitted by pinion and gear

$$T = \frac{P\,x\,60}{2\,\pi\,\mathrm{Np}} = 196820 \text{ N-mm} \quad (1)$$

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Since both the gears are made up of similar material, therefore, the pinion is weaker. Thus the design will be based on the pinion. We know that,

Equivalent number of teeth $Te = \frac{Tp}{cos^3 \alpha} = 30$ (2)

Peripheral velocity, V= π D_p N_p =107.44 mm/min (3)

Module, m =3

Face width, b = 4πm = 75 mm (4)

Pitch circle diameter D_p = m T_p = 114 mm (5)

Number of teeth on gear T_g = 3 T_p = 57 mm (6)

Pitch circle diameter of gear = 342 mm

Tangential load on pinion W_t = 3452 N

Axial load on pinion W_a = W_t tanα = 2014.56 N (7)

Since the overhang = 150 mm

Bending moment on pinion shaft due to tangential load M1= W_t x overhang = 517800 N-mm

Bending moment on pinion shaft due to axial load M_2 = 114841 N-mm

Equivalent moment = 530382 N-mm

Equivalent torque = 565723 N-mm

Diameter of pinion = 40 mm

Principle shear stress induced

$$\tau = \frac{16Te}{\pi Dp^3} = 45.01 \text{ MPa} \quad (8)$$

Direct stress due to axial load

$$\sigma = \frac{Wa}{\pi Dp^3} = 1.6 \text{ MPa} \quad (9)$$

Principle shear stresses = $\frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$ = 51.35 MPa (10)

V. MODELLING OF CLUSTER GEAR SHAFT

A. CAD Model Of Cluster Gear Shaft

The cluster gear shaft is modelled in CATIA software using the calculations provided in the previous section. On the cluster shaft, there are four gears. One of the four gears is a spur gear, while the other three are helical gears. CATIA V5 R21 software is used to model and construct all four gears and shafts. Figure 5 depicts a cluster gear shaft CAD model.

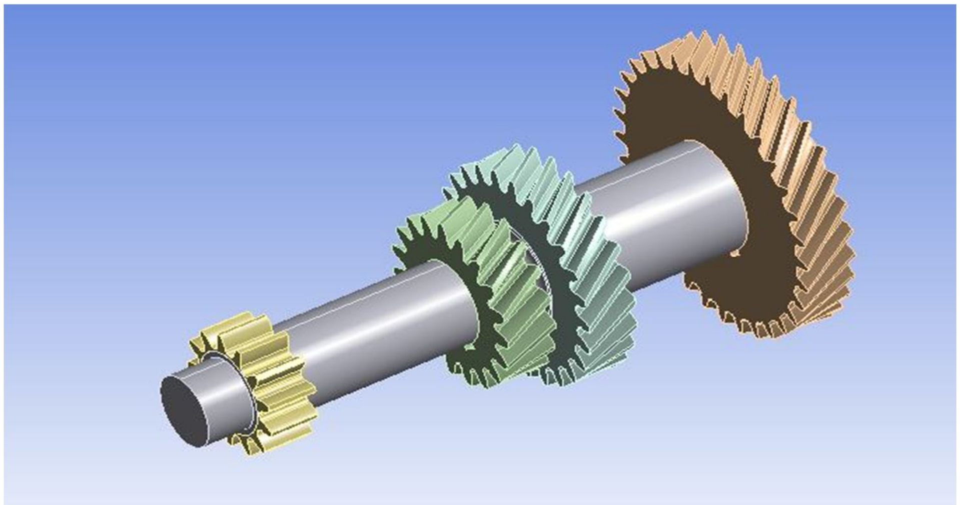

Figure 5: CAD Model of cluster gear shaft

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B. Drafting Of Cluster Gear Shaft

After each gear has been modelled and built, the drafting tool in the CATIA software is used to sketch each component. The dimensions of each part are shown in the drafting image. The drafting of a cluster gear shaft is shown in Figure 6.

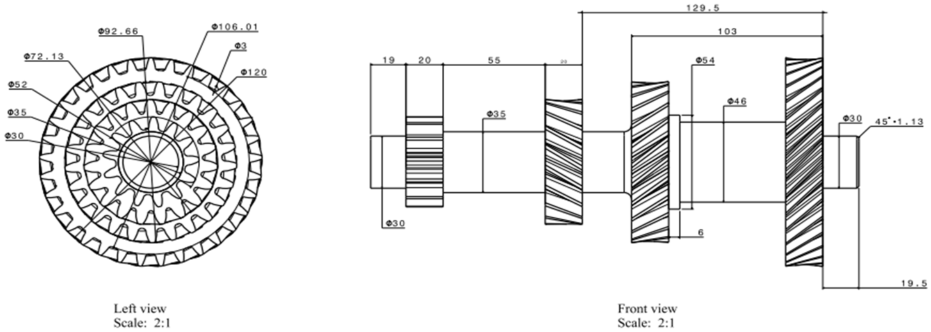

Figure 6: Drafting of cluster gear shaft

C. Meshing Of Cluster Gear Shaft

In the next step the analysis of the cluster gear shaft with Ansys software is carried out. The meshing of cluster gear shaft is done in the ansys software. Figure 7 shows the meshing of cluster gear shaft.

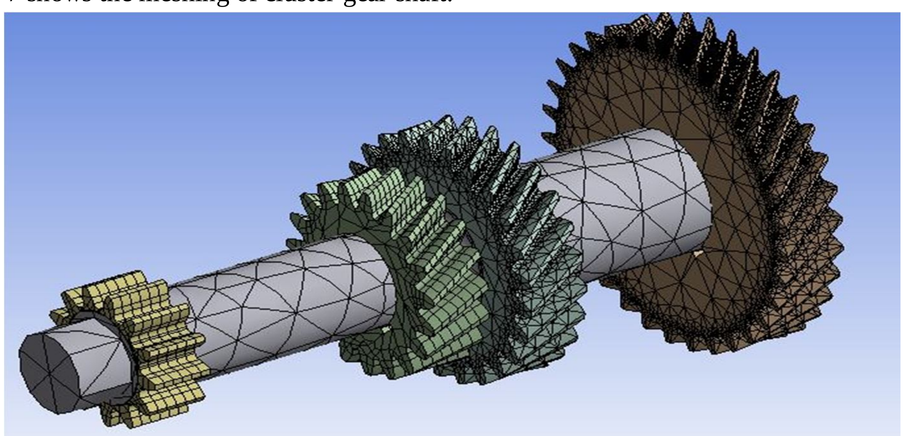

Figure 7: Meshing of cluster gear shaft

D. Maximum Principle Stress On Cluster Gear Shaft

After meshing the cluster gear shaft the maximum principle is calculated and presented in figure 8. The maximum principle stress is 175 MPa.

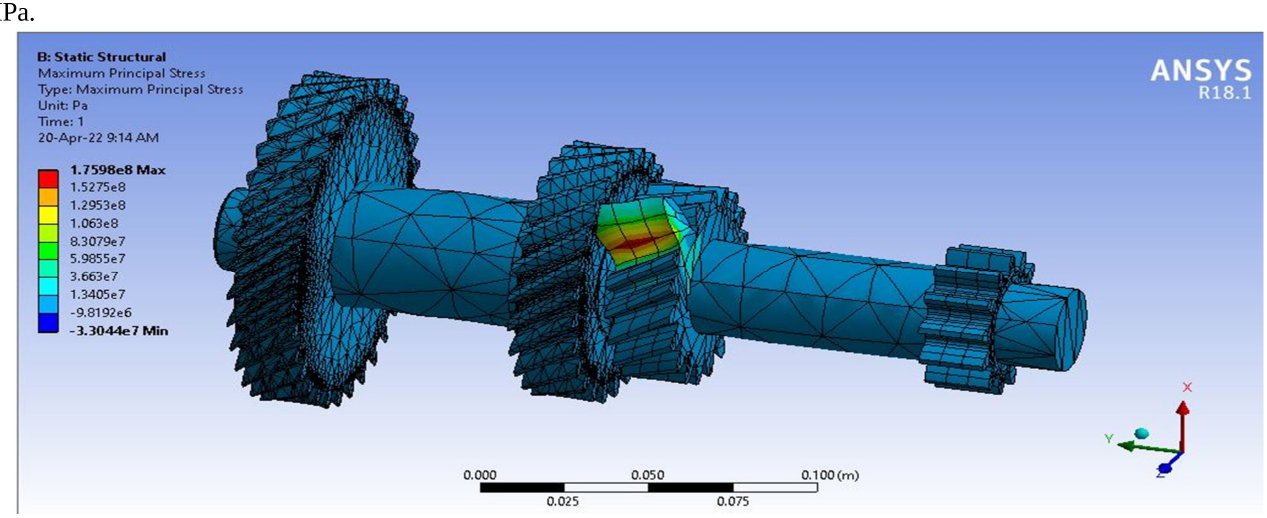

Figure 8: Maximum principle stress

E. Maximum Shear Stress

The maximum shear stress is calculated and presented in Figure 9. The maximum shear stress on the cluster gear shaft is 92.43 MPa.

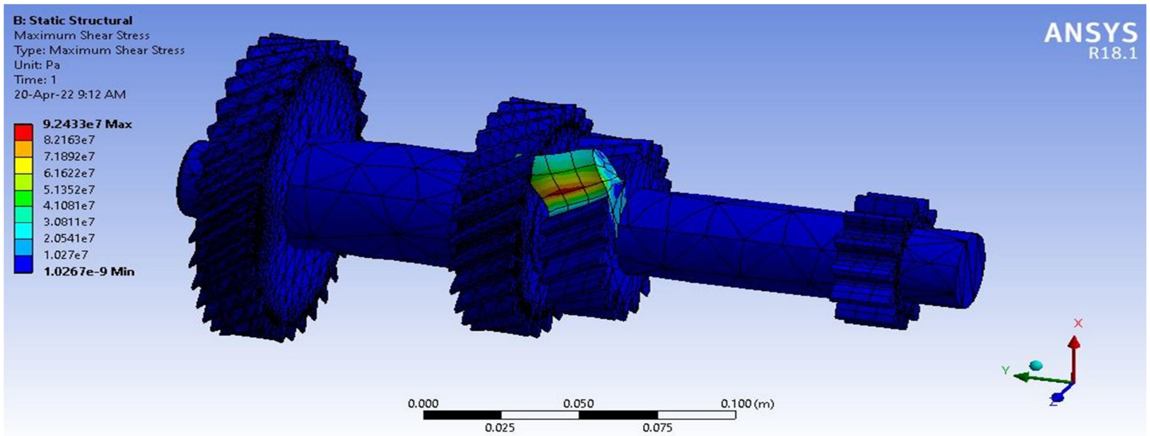

Figure 9: Maximum shear stress

F. Normal Stress Acting On Cluster Gear Shaft

After calculating the maximum shear stress, the normal stresses were also calculated and presented in figure 10. The value of maximum normal stress is 108.15 MPa.

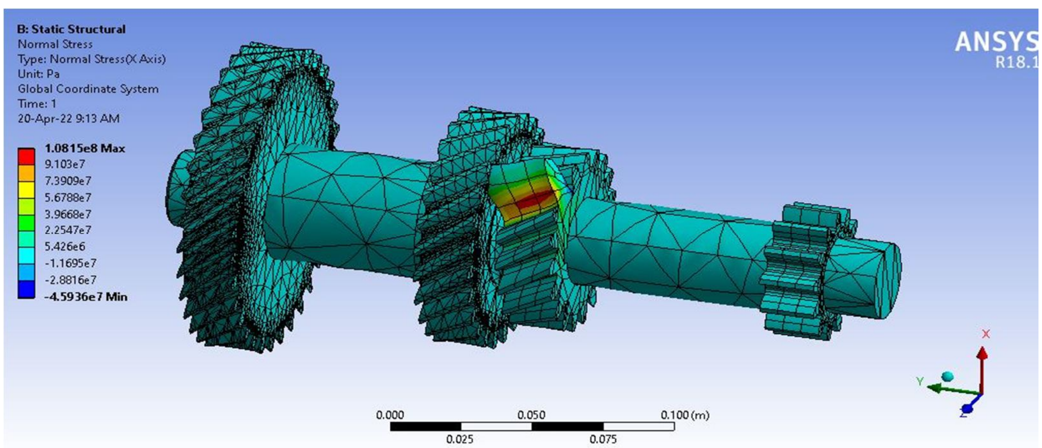

Figure 10: Normal stress on cluster gear shaft

G. Stress Intensity Of Cluster Gear Shaft

The stress intensity of the cluster gear shaft is also calculated and presented in Figure 11. The value of maximum shear stress obtained as 184.8 MPa.

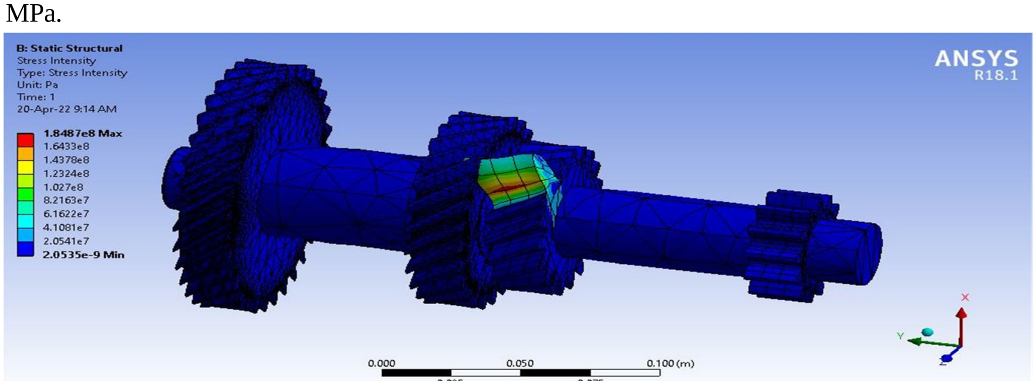

Figure 11: Stress intensity of cluster gear shaft

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H. Total Deformation Of Cluster Gear Shaft

The total deformation on the cluster gear shaft is also calculated and presented in figure 12. It is clearly seen in the figure that the maximum deformation occurs on the second gear mounted on the shaft. The maximum deformation on the cluster gear shaft is 1.78 * 10^{-5} m.

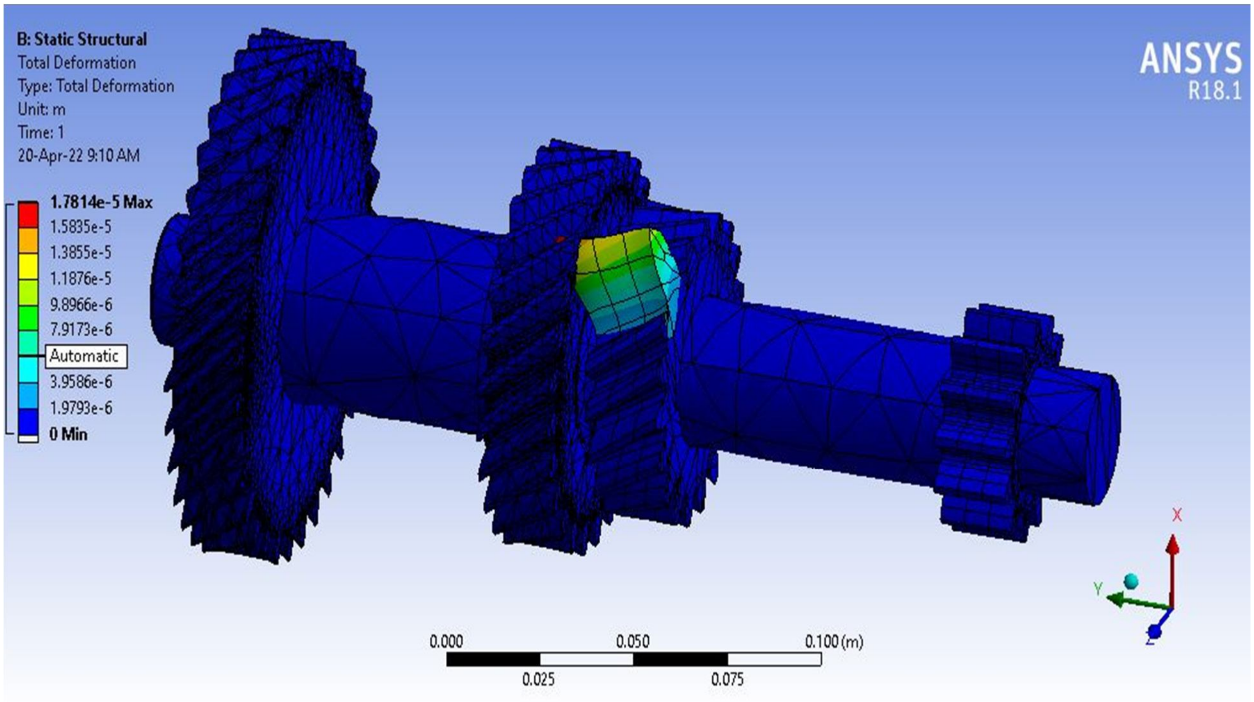

Figure 12: Total deformation of cluster gear shaft

I. Outcomes of FEM Analysis

After carrying out the FEM analysis of cluster gear shaft it is come to know that the maximum stress is acting on the second gear of the cluster shaft. As we have already discussed and shown in figure 3, the second gear is subjected to wear and tear. In the next section the material of the gear is changed on calculated the stresses on the second gear of cluster gear shaft.

J. New Material Suggested

The new material has been suggested for the second gear of the cluster gear shaft based on the literature review and the inputs from the industry. The AISI 8620 has been finalized as the new material for the cluster gear shaft.

Table 2: Chemical composition and mechanical of AISI 8620

Sr. No.	Element	Percentage	Properties	Metric
1	Carbon	0.18-0.23	Tensile strength	530 MPa
2	Chromium	0.4-06	Yield strength	385 MPa
3	Manganese	0.15-0.25	Elastic modulus	210 MPa
4	Molybdenum	0.15-0.25	Bulk modulus	140 MPa
5	Nickel	0.4-0.7	Poisson's ratio	0.3
6	Phosphorus	0.035 max	Hardness (Brinell)	149

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K. Directional Deformation of Cluster Gear Shaft

After selecting new material AISI 8620, the directional deformation of cluster gear shaft along X axis is calculated and presented in figure 13. The maximum directional deformation along X axis of cluster gear shaft is 9.15 e-7 m which is much smaller than the previous case.

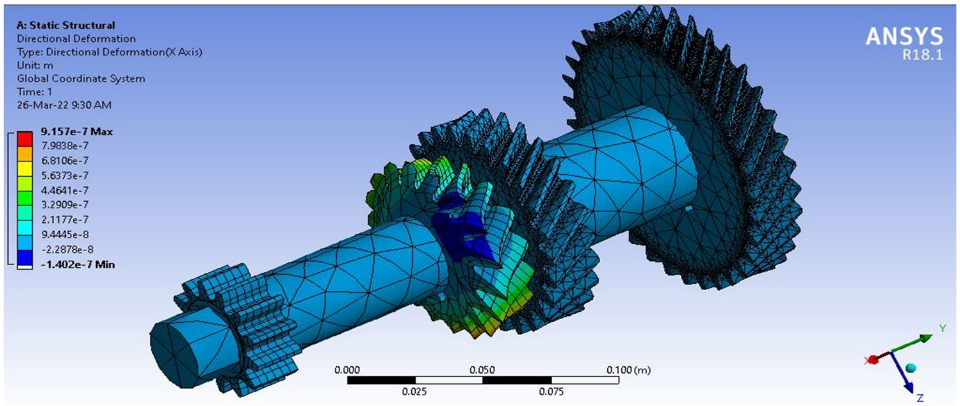

Figure 13: Directional deformation along X axis

L. Maximum Shear Stress

After calculating the directional deformation along X axis, the maximum shear stress of the cluster gear shaft is calculated and presented in figure 14. The maximum shear stress on the cluster gear shaft is 6.68 MPa which is much smaller than the previous case.

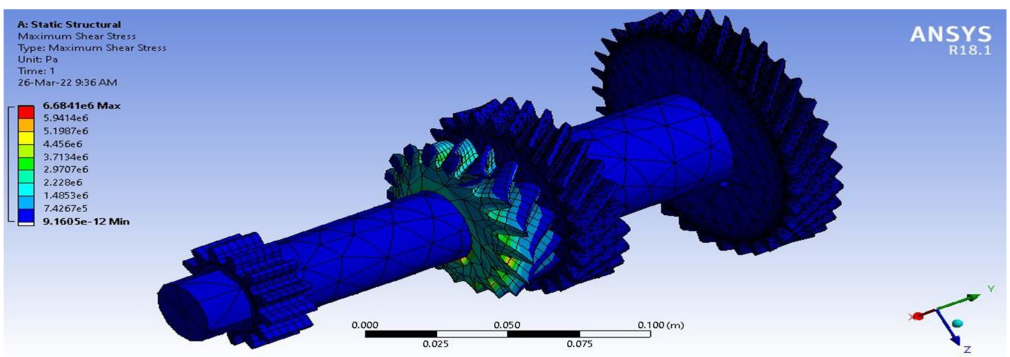

Figure 14: Maximum shear stress

M. Normal Stress on Cluster Gear Shaft

After calculating the directional deformation of the cluster gear shaft the normal stress is calculated and presented in Figure 15. The normal stress on the cluster gear shaft is 7.48 MPa.

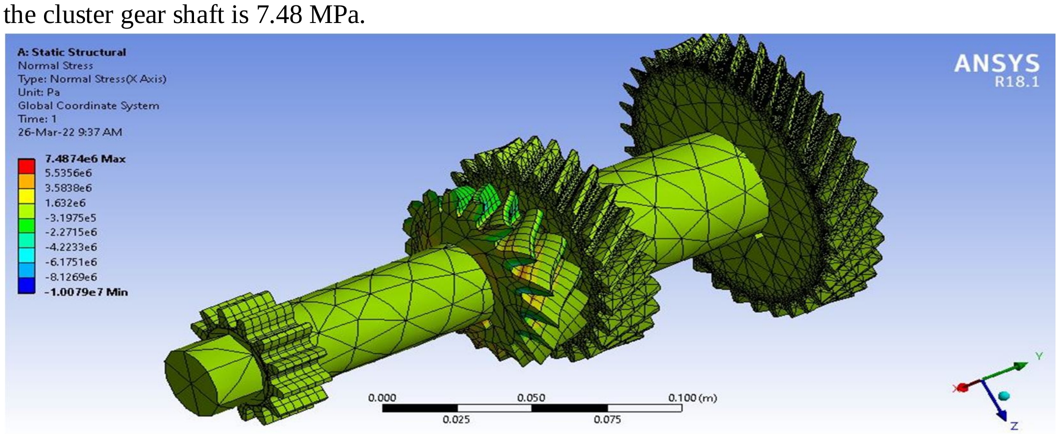

Figure 15: Normal stress on cluster gear shaft

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N. Total Deformation of Cluster Gear Shaft

The total deformation of the cluster gear shaft is calculated and presented in figure 16. The total deformation of cluster gear shaft is 1.19 e-6 m and which is smaller than the previous case.

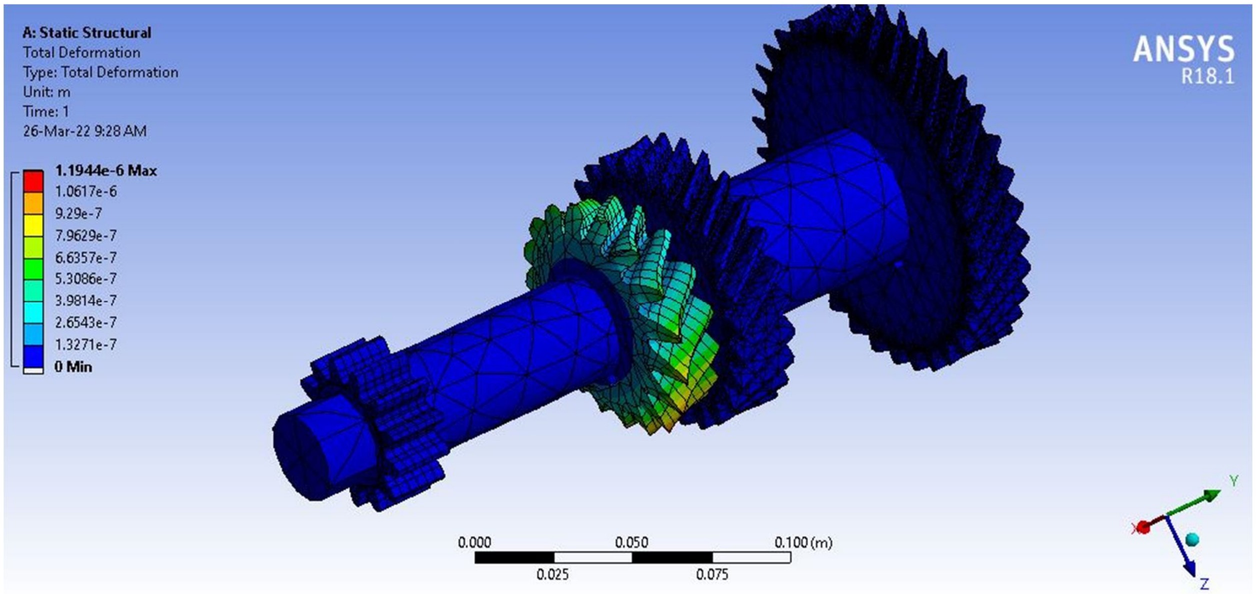

Figure 16: Total deformation of cluster gear shaft

O. Equivalent Stresses on Cluster Gear Shaft

The equivalent stress on the cluster gear shaft is calculated and presented in figure 17. The equivalent stress on the cluster gear shaft is 12.45 MPa.

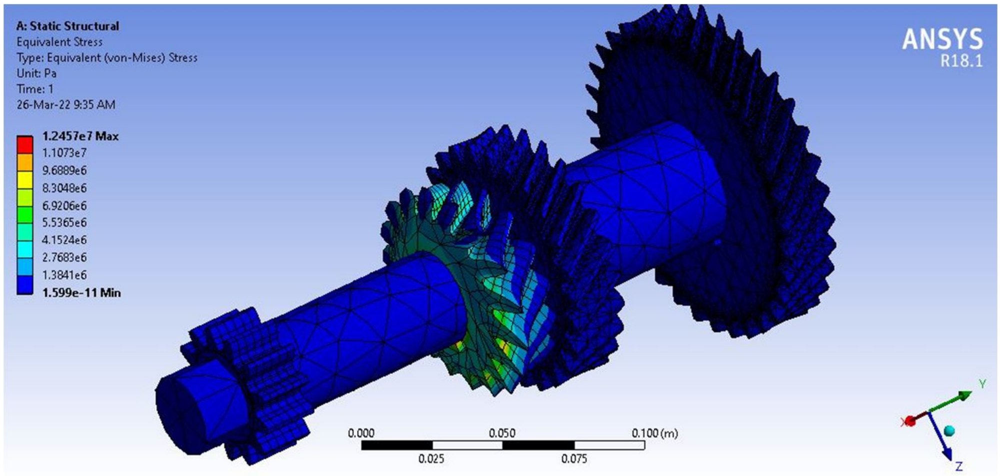

Figure 17: Equivalent stress on cluster gear shaft

P. Comparison of FEM Results

Table 3 shows the comparison of the results of finite element analysis of cluster gear shaft. The total deformation, maximum shear stress and normal stress is compared for the 20MnCr5 and AISI 8620.

Sr. No.	Material	Maximum shear stress (MPa)	Normal stress (MPa)	Total deformation (m)
1	20MnCr5	92.4	108.2	17.85 e-6
2	AISI8620	6.68	7.48	1.19 e-6

VI. CONCLUSION

An attempt has been made to solve the industry based problem of failure of cluster gear shaft of tractor engine. Analysis of cluster gear shaft is carried out by using analytical method and using ANSYS software. The Ansys result showed that maximum stresses are generated near the portion of second gear. With the existing 20MnCr5 material the stresses are comparatively more. The new material is suggested based on the literature review and input from the industry. The maximum shear stress, Normal stress and total deformation for the suggested material AISI8620 is much less than the 20MnCr5 material. Hence, AISI8620 material can be recommended.

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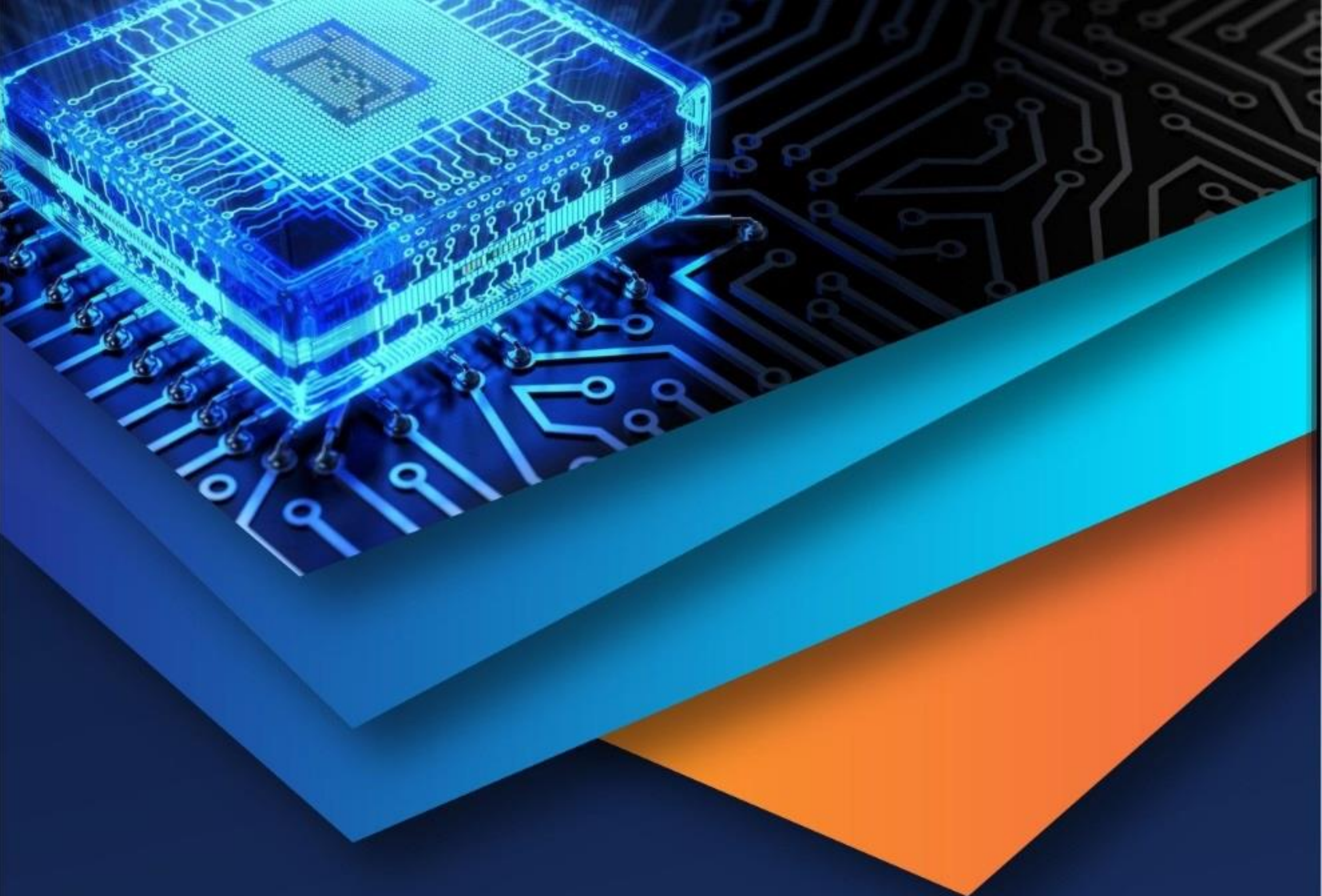

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