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Design and Stress Analysis of Crank Shaft of Four-Stroke Diesel Engine Using Photo-Elasticity and FEA

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Abstract* – The stress analysis of a component is an important role in mechanical engineering design. Here a thorough study is made for four stroke diesel engine crank shaft. First the crank shaft is designed and calculated for safe stresses. The photo-elastic model of designed crank shaft is prepared and analysed for stress distribution at various points through Research Polariscope. The results are compared with ANSY stress analysis and results are compatible. The advantages of the photo-elasticity method are easy to understand, through visualization of stress pattern and determine stress at any point on the model since the fringe value of the material is known.
Keywords- ANSY, Fringe value, Model, Photo-elasticity, Crank shaft, Stress analysis etc.

I. INTRODUCTION

Transportation is made possible through engines, power transmission etc. The designing of these parts and stress analysis are important aspect before continuing with their manufacture. The transportation of products and travellers are usually carried out with the specific design of the transportation system. Fundamentally all the types of vehicles works on the principle of internal combustion of air fuel mixture. The engine system consists of mainly piston, cylinder, connecting rod, crank shaft and cam shaft. Hence the design and fabrication all the components of an engine is the important aspect. [1]

The crank shaft is a shaft comprising of main journals, crank pins, crank webs and oil holes. The stress induced in the crank shaft is mainly due to the combined bending moment and the twisting moment. The bending stresses are due to the cylinder gas pressure, bending stresses caused are due to bending moment and the shear stresses caused due to twisting moment. [2]

The purpose of the project work is to design the crankshaft for a single acting four stroke single cylinder diesel engine. For this BAJAJ RE (DIESEL) MAXIMA vehicle is chosen for the design and stress analysis purpose. The crank shaft is designed for the engine when the crank is at the dead centre or at maximum bending moment and also for the maximum twisting moment.

A. Introduction to Crank Shaft

Crankshafts are produced with various materials and at the time of its operation because of cyclic efforts cracks are formed on its surface, resulting into breakage of crankshaft due to fatigue. Mode of fatigue failure is different for various modes of engineering application of crankshaft and effects of fatigue are also different. [2]. A crankshaft is utilized to transfer linear reciprocating movement of the piston into rotary motion or vice versa. The crankshaft consisting of its parts, which rotates in the main bearings the crank pins by which the big end of the connecting rod is engaged, the crank webs which are connected with the crankpins. Design modifications have always important problems in the crankshaft manufacturing industry, to manufacture a crankshaft a less expensive part with the reduced weight and desired fatigue strength and other functional necessities. These modifications provides in light weight and smaller engines with required fuel efficiency and larger power output. [3]

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B. Objectives of The Work

The main objective of the project work is to design and analysis for stresses using photo elasticity and FEA. For this purpose the crank shaft of a three wheeler single acting, four stroke single cylinder diesel engine of Bajaj RE Maxima is taken for the project work. The main objectives of the project work are given as follows;
To study the existing component design.
To design the crank shaft for single acting four stroke single cylinder diesel engine to enhance its output power.
To determine alternatives for the existing design in the form of change in Material or the properties of material using or change of Geometry of the material.
To analyse the stress distribution through 2-D photo elasticity.
To model and stress analysis of crank shaft through ANSYS-12.
To compare the stresses obtained for different concentrations.
To compare the results by all the methods and conclude its use for industrial application.

C. Review of Papers on Crank Shaft

An extensive literature review on crankshaft was performed by zoroufi and fatemi (2005). In this study operating conditions of crankshaft and various failure sources were reviewed, and effect of parameters such as residual stress and manufacturing procedure on the fatigue performance of crankshaft were discussed.
K. Thriveni et al was work on analysis of crank shaft and they are concluded by their study is that the maximum
deformation happens at the centre of the crankpin fillet surface. The maximum stress occurs at the fillet sections between the crankshaft journal and crank cheeks and near the central portion of journal. [6]
Jianmeng et al have been studied diesel engine crank shaft and they found deformation of the model by the modular
Examination of crankshaft. They concluded that result would give a related analytical determination for the optimization and development of engine design. The maximum stress appears at the fillets between the crankshaft journal and crank cheeks, and near the central point. The edge of main journal is high stress area. [7]
Abhishekchoubey and JaminBrahmbhatt They have Performed the analysis of the crank shaft by means of numerical
Analysis. Maximum deformation of the crank shaft occurs at the mid of crankpin neck surface. They concluded that maximum stress shows at the fillets and near the central point journal. The edge of main journal is high stress area. [8]
S. Bhagya Lakshmi, Sudheer Kumar V, Ch.Nagaraju was work on Dynamic Analysis of Crank Shaft of Honda Engine
and they determined fine with related to applied loads with the time frame of crank angle. The analysis results indicate the forces diagram of given connections at different crank angle. [8]

II. ANALYTICAL DESIGN OF CRANK SHAFT

To design for the crank shaft there are several factors to be considered with reference to its function in the engine. The care should be taken while designing of crank shaft for its maximum bending moment and maximum twisting moment and the related stresses.

A. Specifications of Bajaj RE Maxima

The specifications of three wheeler single acting four stroke singe cylinder diesel engine of Bajaj RE Maxima are as given below.
Engine type : Four stroke forced air and oil cooled CI engine
Number of cylinders : one
Bore : 86mm
Stroke : 77mm
Engine displacement : 447.3cc
Compression ratio : 24+1:1 or 24-1:1
Maximum net power : 8.32BHP @3400RPM

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Maximum net torque : 1.98kg-m @ 2600RPM
Injection timing : 8.5^0 to 9.5^0 BTDC
Maximum gas pressure: 20 bar.

B. Problem Statement

The objective of the project work is to design and analysis of a crank shaft by using carbon steel 40c8 for the single acting four stroke single cylinder diesel engine of BAJAJ RE MAXIMA. Further to determine the minimum induced stresses at the two positions of maximum bending moment and the maximum twisting moment at the extreme areas.

C. Analytical Design Of Crank Shaft

The crank shaft is a machined member or a component of an engine which is subjected to the combined weight of the piston, connecting rod, ring package and a small amount of oil are being continuously accelerated from rest to very high velocity. The design of crank shaft is carried out step by step in the following sections.

Let,
A= Area of cross section in mm^2
L= Length of stroke in mm
D= Bore diameter in mm
B= Width of crank cheek in mm
d_o= Diameter of crank pin in mm
$F_{comb\ (p)}$= Piston force in N
P= allowable pressure in N
σ_b= Allowable bending stress N/mm^2
l_o= Length of crank pin in mm
h= Thickness of crank web in mm
w= width of crank web in mm

1) Design Of The Crank Shaft When The Crank Is At The Dead Centre (Maximum Bending Moment): Force on the piston
F_p=Area of bore x maximum combustion Pressure
F_p= 11.617x10^3 N
Due to this piston load (F_p) there will be two horizontal reactions R_{h1} and R_{h2}.
R_{h1} = R_{h2} = 5.808x10^3 N

2) Crank Pin: Let σ_b= Allowable bending stress for the crank pin
σ_b= 83MPa
Bending moment at the centre of the crank pin
M_b= 499.55x10^3 N
Based on maximum bending moment
d_o= 39.43 mm
Length of crank pin
l_o = 26.78 mm

3) Design Of Crank Web At Left Hand Crank Web: Crank web is defined for eccentric loading. There will be two stresses acting on this. One is direct compressive stress and the other one is bending stress due to piston gas load (F_p).
The thickness of crank web is

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h = 0.35D = 30.1 mm
The width of the crank web is
w = 57.05 mm
To check the developed stresses
Direct stress σ_d = Reaction force/Area of cross section of crank web = 3.382 MPa
The maximum bending moment on the web
M = 509.129×10^3 N-mm
Section modulus for crank web
Z = 8614.64 mm^3
The bending stress induced in the crank web
σ_b= 59.1 N/mm^2
Total stress on crank web =σ_d+ σ_b= 62.48< 83MPa
Hence the design is safe.

4) Design Of Right Hand Crank Web: The dimensions of the right hand crank web (that is thickness width) are made to be equal to the left hand crank web from the balancing point of view.
Therefore,
Thickness, h = 30.1 mm
Width, w = 57.05 mm

5) Design Of Shaft: The bending moment on shaft is,
B.M = F_p x C (Assume C=15 mm) (2.1)
B.M = 174.25×10^3 N-mm
Twisting moment on shaft
T.M = 447.25×10^3 N-mm
Equivalent moment on shaft
$M_s=\sqrt{(B.M^2 + T.M^2)}$ (2.2)
M_s= 480×10^3 N-mm
From the maximum bending moment
$M_s= \pi/32\ (d_s^3 \times 59.1)$ (2.3)
d_s= 43.57 mm

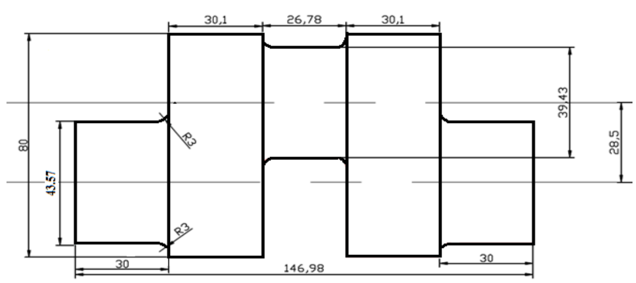

Fig. 1 Crank shaft model with designed dimensions

III. PHOTOELASTIC ANALYSIS

For the testing of photo elastic model to determine the stresses induced in the material the research polariscope is used. The device consists of analyser, polarizer, light source and the quarter-wave plate.
Material fringe value (F_σ)= 6.77 N/mm

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Model thickness (t) = 6 mm

The photo elastic stress analysis of crank shaft model is carried out for the three types of loading conditions as follows;

When the crank shaft is placed horizontally and the point load acting at the centre of the crank pin.

Crank shaft is placed vertically and the axial point load applied on the axis of the shaft.

Point load at the both ends of the shaft.

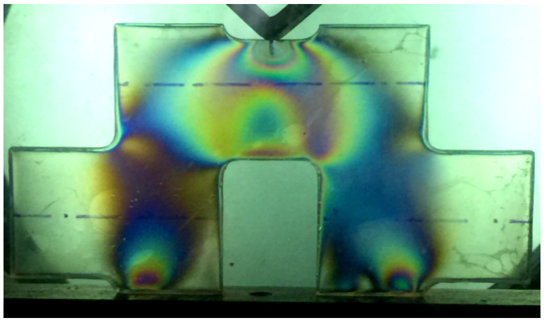

Fig. 2 Central point load on Crank pin

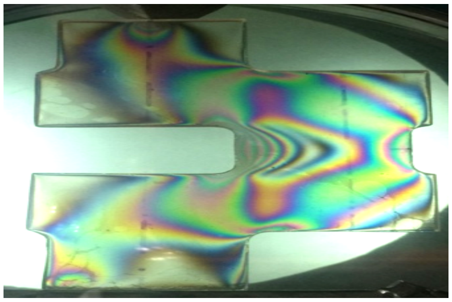

Fig.4 Axial point load on Crank shaft

TABLE 1: STRESSES FOR TWO LOADING CONDITIONS

Sl. No.	Load (N)	Stresses for central point load on crank pin										Stresses for axial point load on crank shaft									
		Point 1		Point 2		Point 3		Point 4		Point 5		Point 1		Point 2		Point 3		Point 4		Point 5	
		N	σ	N	σ	N	σ	N	σ	N	σ	N	σ	N	σ	N	Σ	N	σ	N	σ
1	25.8	0.6	0.6	0.2	0.3	0.2	0.3	0.7	0.8	0.7	0.8	0.7	0.8	0.2	0.3	1	1.1	1.0	1.1	1.0	1.1
2	45.5	0.7	0.8	1.0	1.1	1.0	1.1	1.2	1.3	1.2	1.3	1.2	1.3	1.6	1.8	1.0	1.1	1.2	1.3	1.3	1.5
3	65.1	1.0	1.1	1.2	1.3	1.2	1.3	1.3	1.5	1.3	1.5	1.0	1.1	1.6	1.8	1.2	1.3	1.6	1.8	2.5	2.8
4	84.7	1.3	1.5	1.6	1.8	1.6	1.8	2.5	2.8	2.5	2.8	1.0	1.1	1.3	1.5	2.5	2.8	2.6	3.0	2.6	3.0
5	104	2.3	2.6	2.5	2.8	2.5	2.8	2.6	3.0	2.6	3.0	1.2	1.3	1.0	1.1	2.6	3.0	2.5	2.8	3.6	4.0
6	123	2.6	3.0	3.1	3.5	3.1	3.5	3.6	4.0	3.6	4.0	2.5	2.8	2.6	3.0	3.1	3.5	3.6	4.0	4.1	4.6

IV. ANALYSIS OF STRESSES BY FEM

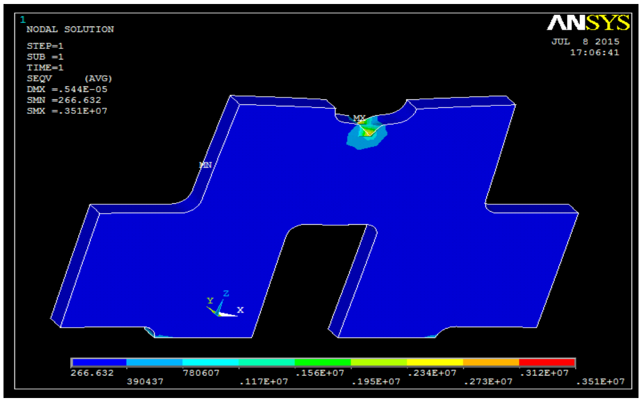

Fig. 5 Central point load on crank pin

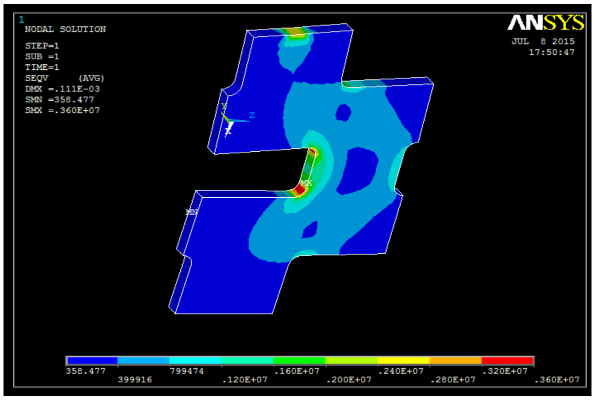

Fig. 6 Axial point load on crank shaft

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TABLE 2: VON-MISES STRESSES

Various point loads at the centre of crank pin							Various loads acting on the centre axis of the shaft				
Sl. No.	LOAD (N)	Point 1	Point 2	Point 3	Point 4	Point 5	Point 1	Point 2	Point 3	Point 4	Point 5
01	4158	0.74	0.55	0.55	0.74	0.85	1.04	0.52	1.18	1.24	1.56
02	7308	1.31	1.28	1.31	1.30	1.34	1.83	0.91	1.33	1.86	2.07
03	10458	2.16	1.49	1.41	1.85	1.86	2.62	1.31	1.85	2.25	2.56
04	13608	2.44	2.12	2.25	2.43	2.43	1.72	1.70	3.14	3.38	3.68
05	16818	3.01	2.94	3.03	3.01	3.01	2.11	2.11	3.32	3.75	4.12
06	19906	3.56	3.42	3.48	3.55	3.66	3.74	2.45	3.86	4.02	4.58

V. COMPARISON OF RESULTS

The stress analysis of crank shaft model is carried out by using two methods. For the comparison of induced stresses in the model with these two methods are discussed in this chapter. The relevant results are plotted by the graphs. The methodologies used for the determination of stresses and analysis of the model are;

Photo-elasticity analysis

Numerical method (FEA)

The results obtained from the above two methods with the crank shaft model is considered for the two extreme loading conditions are tabulated as follows;

TABLE 3: COMPARISON OF RESULTS OF EXPERIMENTAL AND NUMERICAL METHOD

Sl. No.	Load (W) N	Computed values of stresses (N/mm^2) for crank shaft model under central point load at the crank pin										Computed values of stresses (N/mm^2) for the crank shaft model under axial point load at the axis of the shaft									
		Experimental method					Numerical method					Experimental method					Numerical method				
		Pt. 1	Pt. 2	Pt. 3	Pt. 4	Pt. 5	Pt. 1	Pt. 2	Pt. 3	Pt. 4	Pt. 5	Pt. 1	Pt. 2	Pt. 3	Pt. 4	Pt. 5	Pt. 1	Pt. 2	Pt. 3	Pt. 4	Pt. 5
1	25.8	0.6	0.3	0.3	0.8	0.8	0.7	0.5	0.5	0.7	0.8	0.8	0.3	1.1	1.1	1.1	1.0	0.5	1.1	1.2	1.5
2	45.5	0.8	1.1	1.1	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.3	1.8	1.1	1.3	1.5	1.8	0.9	1.3	1.8	2.0
3	65.1	1.1	1.3	1.3	1.5	1.5	2.1	1.4	1.4	1.8	1.8	1.1	1.8	1.3	1.8	2.8	2.6	1.3	1.8	2.2	2.5
4	84.7	1.5	1.8	1.8	2.8	2.8	2.4	2.1	2.2	2.4	2.4	1.1	1.5	2.8	3.0	3.0	1.7	1.7	3.1	3.3	3.6
5	104	2.6	2.8	2.8	3.0	3.0	3.0	2.9	3.0	3.0	3.0	1.3	1.1	3.0	2.8	4.0	2.1	2.1	3.3	3.7	4.1
6	123	3.0	3.5	3.5	4.0	4.0	3.5	3.4	3.4	3.5	3.6	2.8	3.0	3.5	4.0	4.6	3.7	2.4	3.8	4.0	4.5

VI. ADVANTAGES, LIMITATIONS AND APPLICATIONS

A. Advantages

Provide the value of principal normal stress along the cross section of the Crankshaft model, where stresses are generally the largest.

Is adaptable to both static and dynamic investigations of the crankshaft model.
Crankshaft is strong enough to take the thrust of the piston during the power strokes without excessive distortion.
Provide reliable full-field values of the difference between the principal normal stresses in the plane of the Crankshaft model.

B. Limitations

Crankshaft bearing is the cause for engine failure.
When crankshaft get overworked or overheated, causing the bearings to wear.
Crankshaft should be inspected for soundness to check cracks, roundness and wear of journals and crankpins, balancing, cleanliness of oil galleries.
To reduce vibration in the engine to a minimum, crankshaft and flywheel are balanced separately.
Often tested for balance when mounted together.

C. Applications

Used in both heavy duty and low duty engines
Used in aerospace and marine engines which are heavy duty engines.
Used in Wood cutting machines for slitting purpose.
Used in power hacksaw machine for cutting the material.

VII. CONCLUSION AND FUTURE SCOPE

A. Conclusion

The conclusion stated as follows;
The relevant literature review is made with respect to crank shaft design and stress analysis through Photo-elasticity and ANSY12.
The photo-elastic models are fabricated and stress analysis is carried out through Research Polariscope in Design Laboratory.
The model through ANSY 12 is built and analyzed for stress distribution at various points considered.
The stress distribution by above methods shows that the values obtained are close.
It is concluded that the designed model of crank shaft is safe to use for industrial purpose.

B. Future Scope

The future scope for the project work carried out as followed;
One may consider other parts for the similar study.
Any intricate/complex design component may be analyzed using Photo-elasticity and ANSY software, one may take up the crank shaft design for other parameters like maximum twisting moment, for some other vehicle such as two stroke petrol or diesel or 4-stroke petrol or diesel engines.

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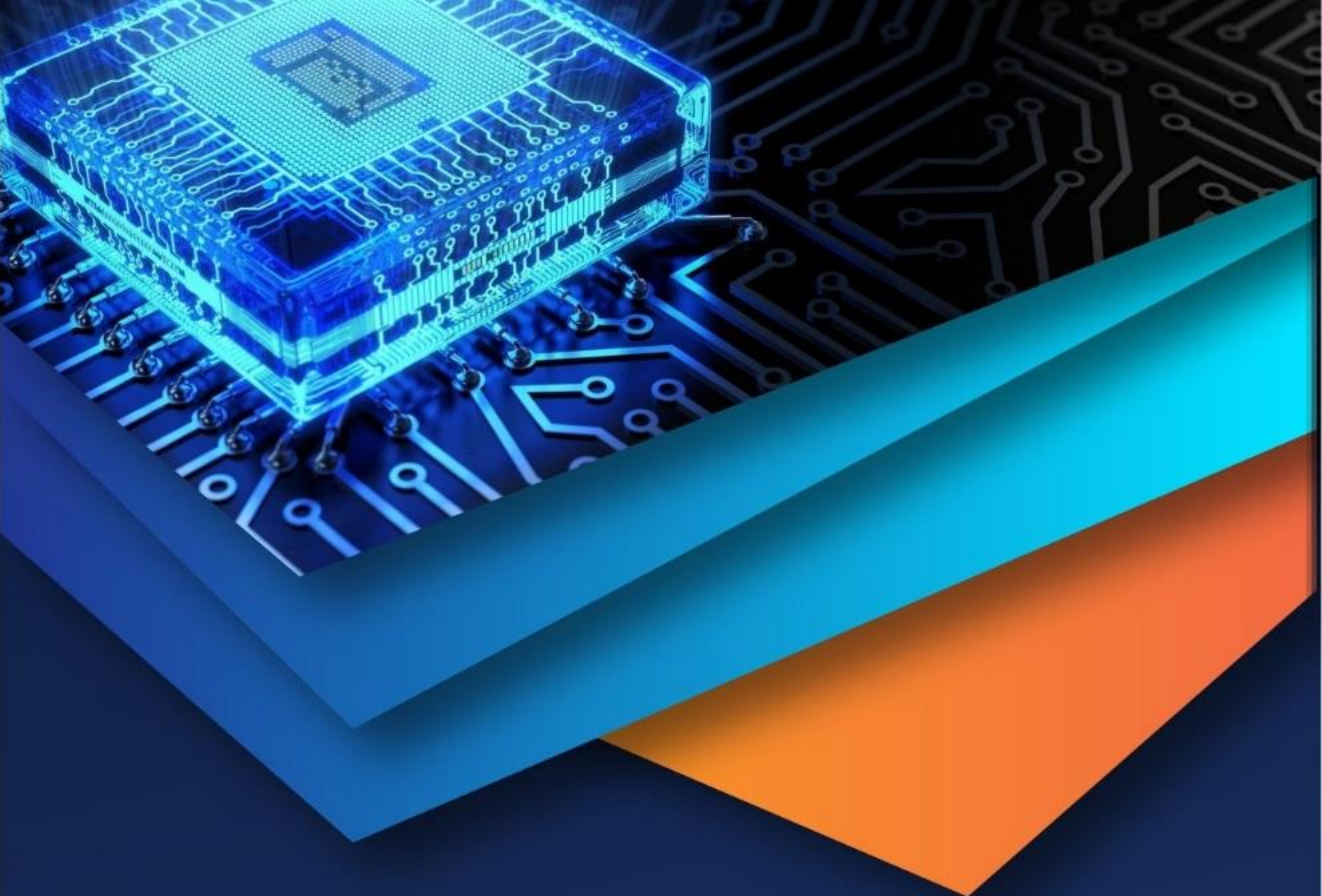

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