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Assessment of Additive Manufacturing Technology for Rotor Fixture used in Gas turbine Assembly

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Abstract: The study involves an examination of the rotor fixture assembly to understand its functionality under standard boundary conditions. The fixture components were modelled in NX CAD. To achieve the desired weight reduction and equivalent stiffness, Finite Element Analysis was conducted both before and after the Topology Optimization process using the Density-based method in ANSYS. The objective was to optimize rotor fixture design for additive manufacturing to reduce weight and lead time. Finite Element Analysis and topology optimization were used to redesign the fixture, resulting in a 16.3% mass reduction for the solid model and 27.5% for the shell model while maintaining stiffness. Metal additive manufacturing reduced lead time by 46% despite a 17% increase in cost compared to conventional machining. Future work may involve lattice structure design and part distortion prediction using Ansys additive software for further improvements.

I. INTRODUCTION

In the ever-evolving landscape of additive manufacturing (AM), where intricate and precise component assembly is crucial, the role of rotor fixtures has become increasingly vital. These fixtures, designed to secure and stabilize rotor components during assembly, play a pivotal role in ensuring the integrity and functionality of a wide range of machinery and systems. The assembly of rotors, central to various industries such as aerospace, automotive, and energy production, demands meticulous attention to detail to achieve optimal performance, safety, and longevity. This assessment embarks on a comprehensive exploration of rotor fixtures used in the context of additive manufacturing, aiming to delve into their design intricacies, functionality, and the impact they have on the overall quality of rotor assemblies.

Additive manufacturing, often referred to as 3D printing, has revolutionized the way we produce complex parts and components. Its versatility and ability to create intricate geometries have led to widespread adoption in various industries. However, with this advancement comes a unique set of challenges, particularly in the realm of rotor assembly. Unlike traditional manufacturing methods, additive manufacturing introduces factors such as layer-by-layer deposition, material properties, and thermal considerations, all of which can significantly influence the assembly process and the final quality of the rotor.

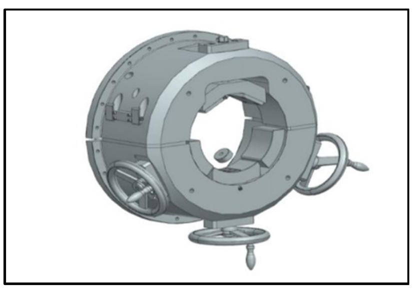

Fig 1 Fixture for Rotor centering and support

A. *Design Consideration*

Development of Conceptual Model of Rotor Fixture:

This step involves creating an initial design or concept for a rotor fixture. It's important to consider factors like the rotor's size, shape, and the specific requirements of the fixture to hold it securely.

Topology Optimization for Rotor Fixture to Reduce Mass with Same Stiffness - Topology optimization is a computational approach used in engineering to optimize the material distribution within a given design space. In this case, you're aiming to reduce the mass of the rotor fixture while maintaining its stiffness. This involves running simulations and calculations to identify areas where material can be removed without compromising structural integrity.

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Redesigning the Rotor Fixture with Reference to the Topologically Optimized Design - Once the topology optimization is complete, you'll use the results as a reference to redesign the rotor fixture. Involves translating the optimized material distribution into a practical.

Comparing the Original Design and Manufacturing Process with the New Design and Manufacturing Process of the Rotor Fixture - After redesigning the rotor fixture, it's crucial to perform a detailed comparison between the original design and manufacturing process and the new design and manufacturing process. This comparison should take into account factors such as mass, stiffness, cost, and ease of manufacturing. It's likely that the new design will offer advantages in terms of reduced mass, but it's essential to ensure that other critical factors are also considered.

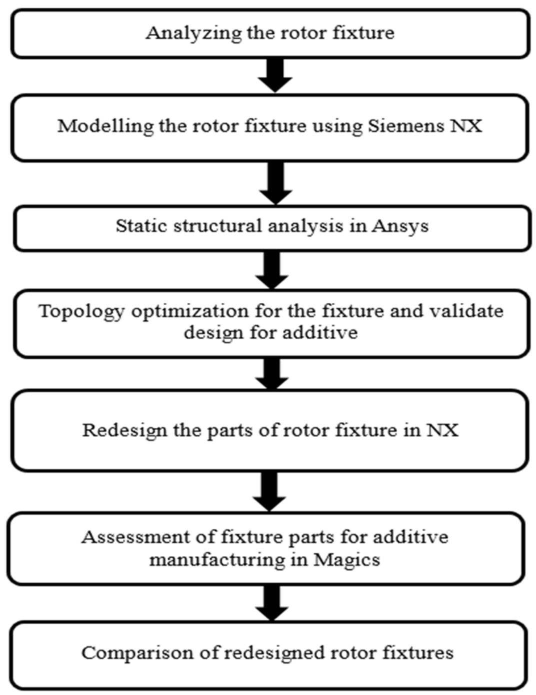

Fig 2 Project methodology flowchart

II. METHODOLOGY

A. *Static Structural Analysis*

For conducting the static structural analysis, required components are considered from the rotor fixture and other components are suppressed for analysis in the geometry section. The figure displays the components used for static structural analysis of rotor fixture.

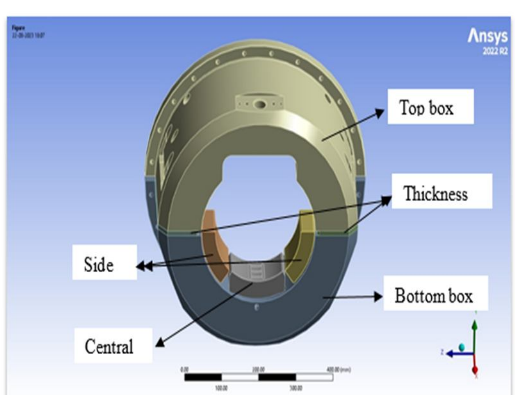

Fig 3 Rotor fixture for analysis

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B. *Material Property Consideration*

The Material used for top box half and bottom box half is 39NiCrMo3. The user defined material assignment is created. The properties of 39NiCrMo3 are given in Table is the Overall weight of both top half and bottom half is 202.46 kg.

Table 1 Properties of 39NiCrMo3

Serial No.	**Property**	**Value**
1	Density	7850 kg/m^3
2	Young's modulus	205 GPa
3	Poisson's ratio	0.33
4	Tensile yield strength	685 Mpa
5	Compressive yield strength	685 Mpa
6	Tensile ultimate strength	1080 Mpa

C. *Contact Regions*

The pre-defined contacts from Ansys mates are corrected. Contact connections are defined referring to the 2D drawing. The contact region of top box half and thickness plate. The other six contact regions are defined respectively, the contact regions are between the bottom box half, central pad and side pad.

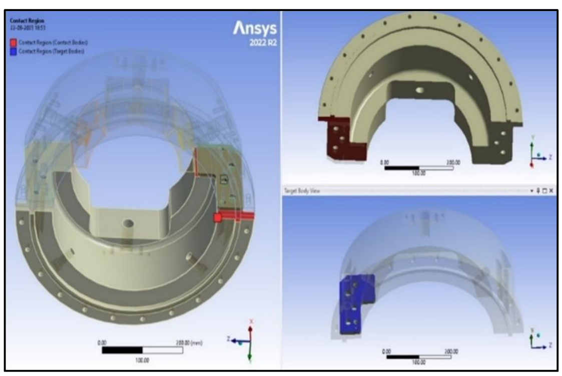

Fig 4 Contact between Thickness plate and Top half

D. *Meshing*

The mesh generation process was carried out with ANSYS meshing. Mesh element size is 5mm, Mesh element type is tetrahedral element because they can handle complex geometry where intricate shaped geometries are present.

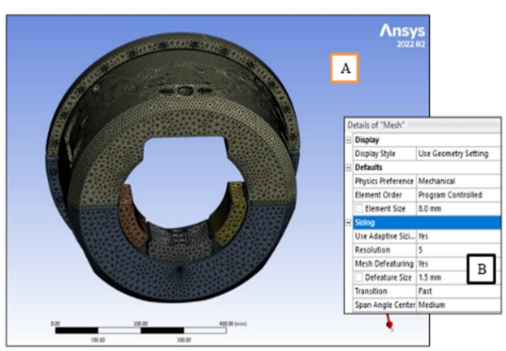

Fig 5 Meshed Model-Rotor fixture

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Good element quality implies that the finite elements closely resemble their ideal shapes and maintain favourable characteristics, such as angles and side lengths. On the other hand, poor element quality can lead to issues like inaccurate stress distribution, instability, and unreliable predictions of physical behaviour. From the figure it is indicated that the most element quality lies between 0.7- 1, it can be considered as accurate meshing.

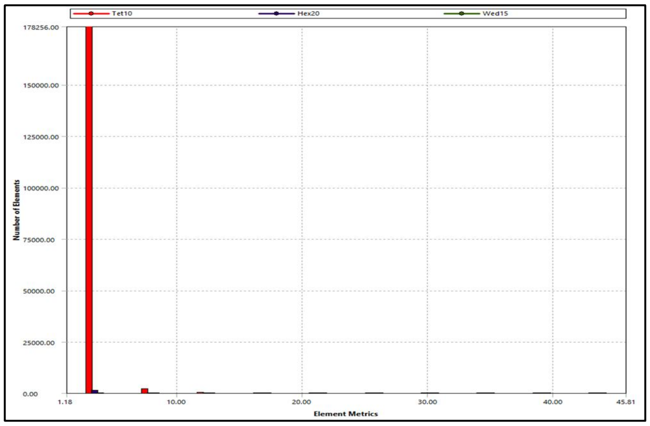


Fig. 6 Mesh element quality

E. Calculation for Boundary Conditions

Given data: L = 2501 mm, X = 1302 mm, W = 2445 KG = 2445 x 9.81 = 23985.45 N

Ra + Rb = 23985.45 N---------(1)

Moment acting at A,

Rb x 2.501 = 23985.45 x 1.302

Rb = 12486.63 N

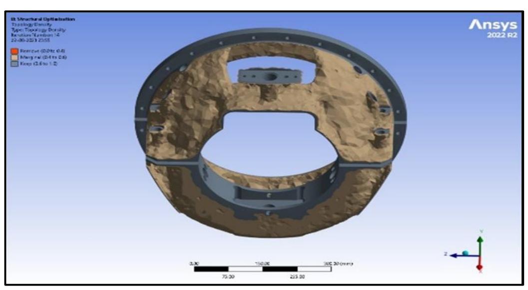
Substituting Rb in equation (1)

Ra + Rb = 23985.45 N

Ra + 12486.63 = 23985.45

Ra = 23985.45 – 12486.63

Ra = 11489.83 N



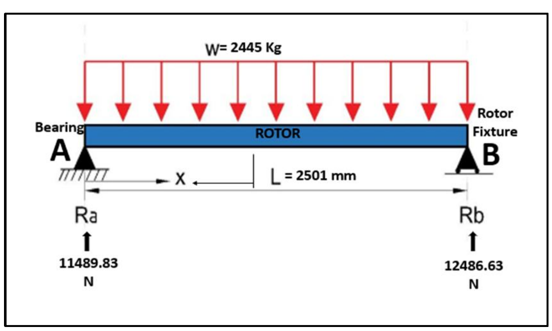


Fig. 7 Calculation of Boundary condition

The axial rotor is 2501mm long and weighs 2445 kg. A fixture supports it with a dead weight applied on both the bearing and rotor fixture. The fixture is modeled as a simply supported beam with uniform load. The reaction force Ra on the bearing is 11489.8 N, and Rb on the rotor fixture is 12486.6 N. 60% of the dead weight is on the central pad, with 20% each on the side pads. The boundary conditions include the rotor fixture flange connected to the compressor casing with fasteners, bearing loads of 7492 N at the central pad and 2497 N on each side pad.

F. Topology Optimization of Rotor Fixture

Topology optimization is a technique that aids in designing efficient and high-performing creations. However, before engaging in the optimization process, it's crucial to comprehend how the initial design behaves. This is where preliminary Static Structural analysis comes into play. It reveals the design's reactions under real-world circumstances.

III. OPTIMIZATION REGION

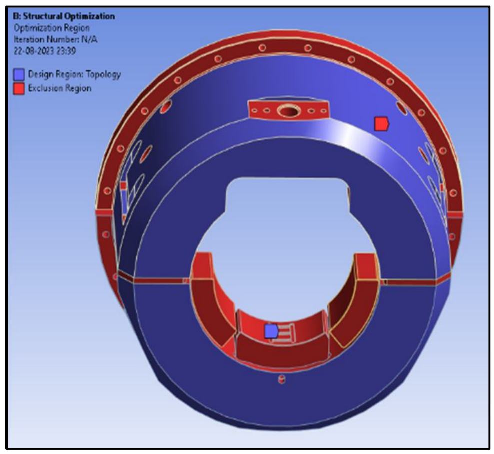


Fig. 8 Optimization region

A. Topology Optimization Results

The final model obtained through topology optimization represents an optimized structural configuration that meets the desired performance objectives, design constraints, and manufacturability requirements. It offers an efficient material distribution that maximizes performance while minimizing weight and material usage, leading to more effective and lightweight designs values.

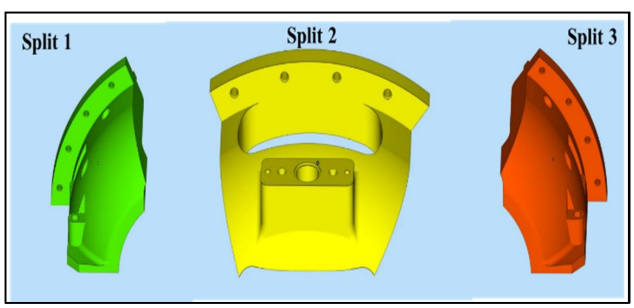


Fig. 9 Topology Optimization Result

Table 2 Topology Optimization result

Description	Value
Original Volume (in mm^3)	2.5791e+007
Final Volume (in mm^3)	1.5681e+007
Original mass (in kg)	202.46
Final mass (in kg)	123.1
Percentage of mass retained (in %)	60.8

B. Optimizing the Output Design

Shrinkwrap the smoothened output part to increase the surface quality by size 1mm and angle threshold 40º as shown in Figure by preserving the features of the optimized part. Let's assume steel is chosen as the material for the motor mount due to its strength and durability. The yield strength of steel is typically around 250 MPa.

Fig 10 Shrinkwrap design

IV. ASSESSMENT FOR ADDITIVE MANUFACTURING

The final redesigned model of the rotor fixture was assessed for manufacture by using powder bed fusion. PBF is one of the most commonly used Selective Laser Additive Manufacturing methods. Rotor Fixture play a critical role in ensuring the precise and repeatable positioning of axial rotor into compressor casing while assembly.

Table 3 Comparison of Design weights

Components	Existing Design	New Design – Solid Body	New Design – Shell Body
Top Half Box mass	100.01 kg	64.12 kg	35.21 kg
Bottom Half Box mass	101.55 kg	84.37 kg	61.22 kg
Total mass of Top half & Bottom half	201.56 kg	148.49 kg	96.43 kg
Total Assembly mass	240.7 kg	196.86kg	143.43 kg

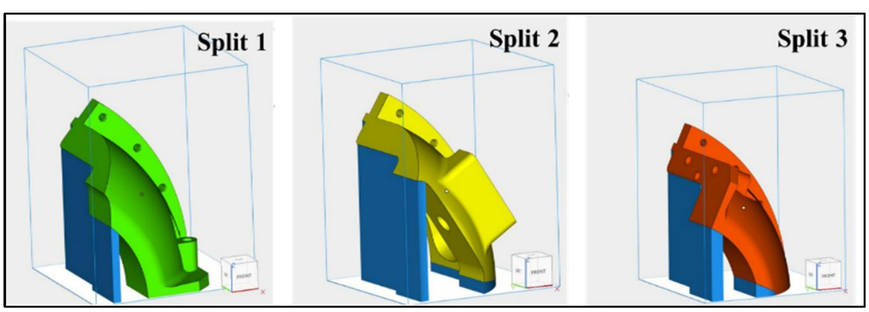


Fig. 14 Bottom Half Split orientation

A. Parts Splitting

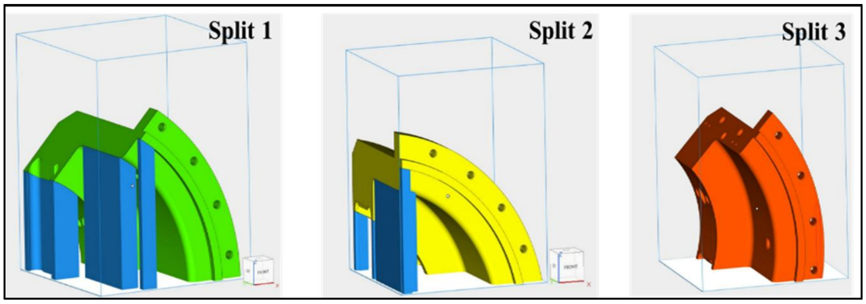


Fig. 11 Top half Part splits

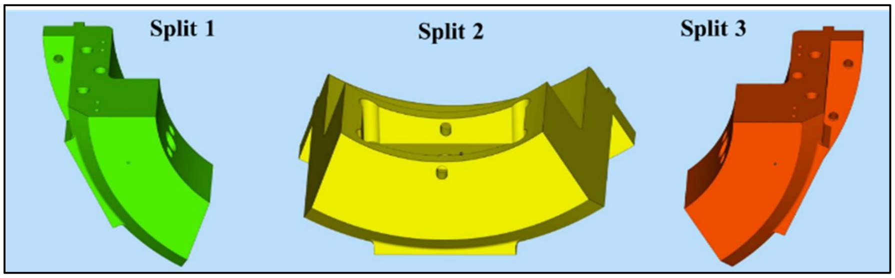


Fig. 12 Bottom half Part splits

B. Parts Orientation

Part orientations would have been more time-consuming and created more material waste during manufacturing. The amount and the volume of the supporting material have a significant influence on the printing process and the final result. Supporting material provides significant heat dissipation and minimizes deformations when the part is printed. The split parts orientation is carried out to place the part on the printing platform by adding supports to the split parts to have a feasible orientation and less extra material and manufacturing time for the printing

V. RESULTS

After topology optimization the topology density of fixture is reduced from 202.46 to 123.1 kg as shown in table To validate the design two cases are considered, one with a solid body which weighs 16.3% less – 196.86 kg and another is shell body which weighs 27.5% less – 143.43 kg.

Conventional machining cost for rotor fixture is € 9450 which will have a Leadtime of 63 days. But the Metal Additive Manufacturing cost for printing rotor fixture is 17 % higher which is € 11440, and which will have a 46% reduction in Lead time of 34 days as shown in table

Table 4 Comparison of Manufacturing Process

Method of Manufacture	Cost	Lead time(approx.)
Conventional machining (Casting & CNC)	€ 9450	63 Days
Metal Additive Manufacturing (EOS M 280)	€ 11440	34 Days
Savings / Loss	- € 1950 (17%)	29 Days (46%)

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VI. SUMMARY

In conclusion, the rotor fixture is redesigned to reduce the weight and keeping the same or more stiffness of material by applying the Topology optimization method using mass response constraint. Optimizing the components by redesigning to satisfies the research objectives. Static structural analysis is carried out to know the behaviour of stress and deformation in the rotor fixture. For existing design, the maximum stress value of rotor fixture is 6.9153 MPa and the maximum deformation is 0.00251 mm. For new solid body design, the maximum stress value of rotor fixture is 9.8341 MPa and the maximum deformation is 0.00275 mm. For new shell body design, the maximum stress value of rotor fixture is 27.487 MPa and the maximum deformation is 0.00709 mm. Conventional machining cost for rotor fixture is € 9450 which will have a Leadtime of 63 days. But the Metal Additive Manufacturing cost for printing rotor fixture is 17 % higher which is € 11440, and which will have a 46% reduction in Lead time of 34 days.

The project involved assessment of additive manufacturing by reducing the weight of the rotor fixture by applying topology optimization. Further, the work can be broadened by Applying lattice structure design to the rotor fixture parts could reduce the mass even more than by using only Topology Optimization. A new Mechanism could be incorporated along with the movement of the central and side pads can be automated. Part distortion and part shape prediction simulation can be done using Ansys additive software.

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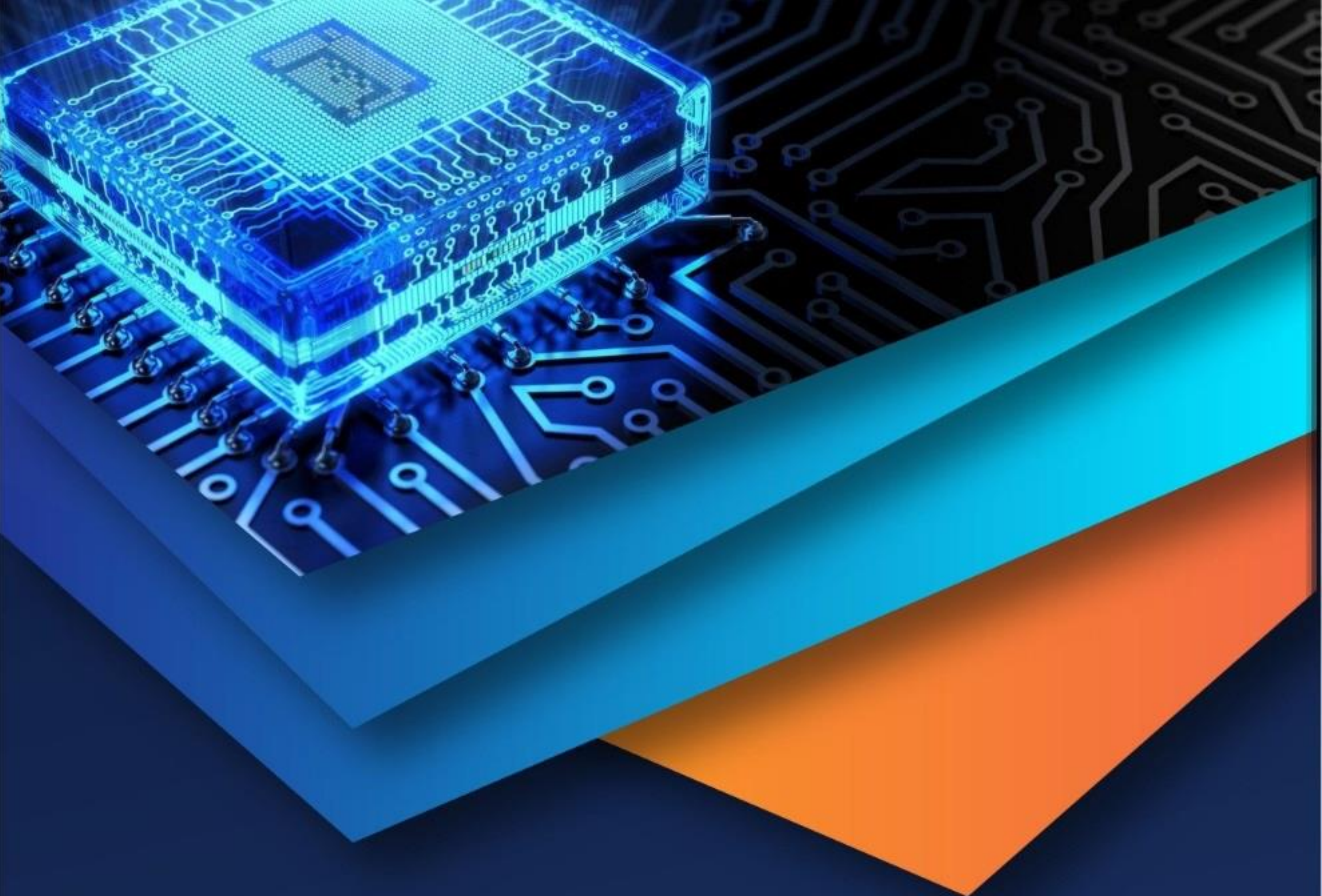

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