iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 **Issue:** V **Month of publication:** May 2024

DOI: https://doi.org/10.22214/ijraset.2024.61443

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue V May 2024- Available at www.ijraset.com

Structural Analysis and Optimization of Washing Machine Spider, Drum and Shaft

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Abstract: This project's thesis centers on identifying diverse loading scenarios and leveraging their outcomes to optimize two components of a washing machine. The initial phase of this report involves generating a numerical model of a washing machine. This encompasses assembling it in a mechanical software program (ANSYS) and defining specific boundary conditions and material properties for the problem. Decisions on simulation parameters, such as mesh size, types of elements, and the number of iterations in the calculations, will also be made. An examination of various loading scenarios is conducted to gain an overall understanding of the problem and select four specific cases for application in reconstructing the target parts (Spider and front cover). This examination involves calculating the worst relative angle between the Spider and the resultant force for two opposing loads inside the drum. The resulting angle is found to be 35º between the arm and the direction of the resultant force. By applying these diverse loading conditions to the model, the mechanical behavior of the parts will be determined, and this information will be utilized in the reconstruction. Mechanical behavior, in this context, refers to understanding the maximum levels of stress (tension, compression, and shear) and deformation (displacement and strain). Once the critical points of stress in the Spider and front cover are identified, various new shapes are created. The reconstruction parameters considered include volume reduction, stress level reduction, and deformation. Two of these shapes are selected and tested in the numerical model as a validation process.
Keywords: Washing Machine, Spider, Drum, Loading Cases

I. INTRODUCTION

Washing machines have become ubiquitous in homes worldwide, revolutionizing the once laborious and cumbersome task of cleaning clothes. These appliances operate by rotating clothes within a cylinder, combining them with water and cleansing agents. The efficiency of this process relies on the mechanical intricacies of the cylinder and the Spider responsible for transmitting rotational forces to it. Considering that wet clothes can exert substantial reaction forces on the rotating cylinder, it becomes crucial to precisely and safely calculate the mechanical properties of both the cylinder and the supporting Spider. This bachelor project is dedicated to determining the critical load and optimal position where reaction forces on these components reach their maximum, thereby preventing malfunctions in operational washing machines. The exploration also delves into the possibility of devising new configurations for the Spider and front cover, aiming to achieve a more even distribution of reaction forces and minimize the risk of part damage.The main objective with this project is to perform a research on the loading cases applied to a washing machine and to optimize the Spider and the front cover.

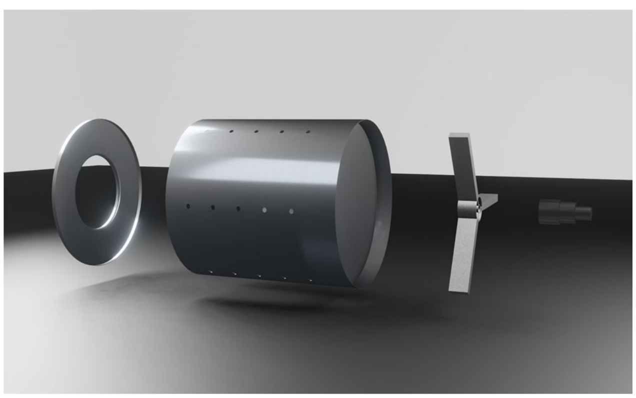

Figure 1. Main components in the assembly

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Figure.1 illustrates the key components of the washing machine. Among these elements, our focus for study and redesign, as recommended by ASKO following a recent cylinder modification, centers on the Spider (Figure 3) and the front cover (Figure 2).

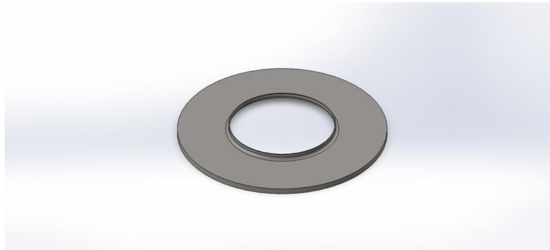

Figure 2. Original front cover that will be reconstructed

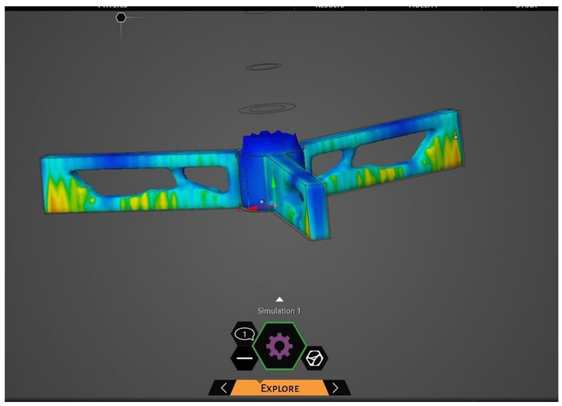

Figure 3. Original Spider that will be reconstructed

Various approaches to the problem will be explored to generate solutions that can be compared and evaluated to determine the most effective option.
Furthermore, novel solutions will be proposed, with the potential to address current issues or serve well in the ongoing evolution of washing machine technology.

II. DESIGN CONCEPT

The term design factor encompasses any feature or aspect that impacts the design of a specific element or, potentially, the entire system. Typically, multiple factors need consideration in a given design. Alternatively, there are instances where a single factor becomes pivotal, and if its conditions are met, the need to address other factors diminishes. In this thesis project, the following factors will be considered:Strength, Shape, Size, Flexibility, Stiffness, Joints

1) *Current design Spider*

The Spider comprises three arms, three connections with the cylinder, and one connection with the shaft. These specific regions are clearly depicted in Figure 4 and will be the primary focus of attention during this redesign.

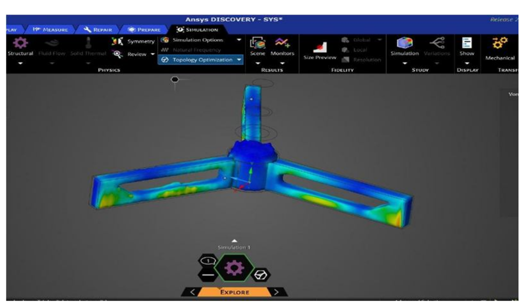

Figure 4. Current design of the Spider

These regions exhibit distinct characteristics, geometries, and functions. The connection with the shaft is represented by a sturdy cylinder featuring stiffeners to maintain its relative position with the rest of the component. The arm's primary characteristic is its cross-sectional profile, a critical consideration as its selection depends on the stresses arising under the working conditions explained earlier. Concerning the connections with the cylinder, they possess two key features. The first pertains to the surface in contact with the cylinder, while the second involves the mass where the screw will be positioned.

- *Material And Manufacturing Process*

The material chosen for producing this part is aluminum, and its properties are outlined in the materials chapter. Despite being lighter than steel, the consideration of manufacturing and production costs, coupled with the stress levels in this component, prompts the exploration of alternative materials such as steel or plastics.

The manufacturing process for aluminum involves die-casting, which necessitates a substantial production volume to achieve favorable cost efficiencies. In die-casting, molten metal is injected at high pressure and velocity into a split metal die, with aluminum being melted in a "cold-chamber." The key advantages of this process include high production rates and precision in both smooth surfaces and details. However, a drawback lies in the complexity and expense of the die, leading to a preference for cheaper dies that require surface finishing through tooling. Die casting becomes economically viable when the production quantity falls within the range of 5,000 to 10,000 pieces, making it the most cost-effective option for large quantities of parts.

2) Front Cover

In front-loaded washing machines, the cylinder is horizontally arranged, open from one of its bases, which connects to the door. This open base, referred to as the front cover, is constructed with a sizable hole to facilitate the entry and exit of laundry into the washer. The design of this component is specifically a metal ring that connects its outer edge to the cylinder through bending, with the inner edge left free (refer to the shape in Figure 5). This design facilitates the closure of the container with the door and rubber. The rubber, positioned between the external drum ``and the door, allows the drum to move freely without any clothes escaping.

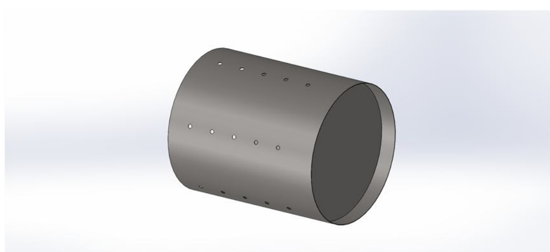

Figure 5. Inner cylinder, front cover and rubber

The redesign primarily focuses on enhancing the current situation by reducing stress and minimizing displacement on the piece. Additionally, considerations are given to the volume or size of the component with the aim of reducing the amount of material used in manufacturing, resulting in economic savings—a crucial aspect in any comprehensive study.

- *Material and Manufacturing Process*

The design of a manufactured part relies significantly on the chosen material and manufacturing process. For instance, the design approach for an aluminum die-cast part differs considerably from that of a steel sheet metal part, even though both serve identical functions.

The front cover, specified in the material's chapter, is crafted from stainless steel 18:9 (consisting of 18% chromium and 9% nickel), showcasing its unique properties.

Stainless steel encompasses various types tailored to desired characteristics. Its resistance to corrosion, minimal maintenance requirements, and familiar appearance make it an ideal material for diverse applications.

In applications where both steel properties and corrosion resistance are vital, stainless steel takes precedence. Its distinction from carbon steel lies in the chromium content. Unprotected carbon steel readily corrodes when exposed to air and moisture, with the formed iron oxide film accelerating further corrosion. In contrast, stainless steels contain sufficient chromium to establish a passive chromium oxide film, hindering surface corrosion and preventing its spread into the internal structure.

Upon exposure to oxygen, chromium forms a thin, invisible passivation layer of chromium oxide, preserving the metal's luster, impervious to water and air. This layer rapidly reforms when scratched, a phenomenon known as passivation, also observed in metals like aluminum and titanium, contingent on a high chromium proportion.

Additionally, stainless steel is entirely recyclable. On average, a stainless steel object comprises approximately 60% recycled material, with 40% originating from end-of-life products and 60% from manufacturing processes [12].

Due to its myriad benefits, stainless steel finds application in washing machine cylinders, offering resistance to water, soaps, and detergents. Its smooth surface prevents damage to clothes during the washing process, avoiding abrasions and cuts caused by irregular surfaces. Moreover, it protects against potential damage to zips, coins, buttons, keys, and similar objects at high machine speeds, a risk in cylinders made of coated materials.

Despite these advantages, the next chapter will explore the potential of transitioning to a different material with superior properties, enhanced results, or cost-effectiveness.

III. METHODOLOGY

1) Interaction

Effective interaction plays a pivotal role in the accurate design of the simulation, as the functionality of all components is defined by their interactions, ultimately influencing the quality of the outcome. In this context, all connections are treated as "tie" constraints. The Spider, for instance, is connected to the cylinder through three constraints.

Specifically, the front cover is affixed using a single tie constraint, mimicking the folded edge, establishing a connection between the cylinder and the front cover. This approach ensures a cohesive and realistic simulation of their interaction.

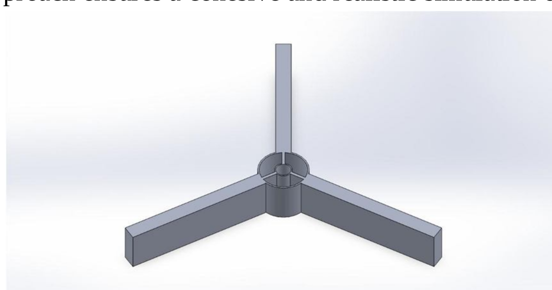

Fig 6 . Tripod CAD

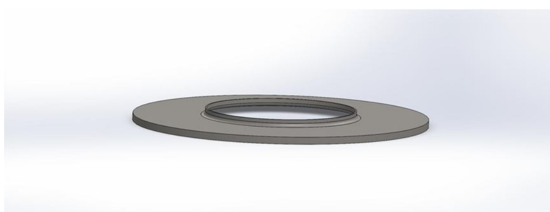

Figure 7. Front cover constrained

The loading process is treated as static, even though the cylinder undergoes rotation. This assumption is based on the consideration that the applied loads remain constant over time, both in magnitude and direction.

The chosen boundary conditions emulate a double-pinned axle. In this configuration, the model is constrained from translation and rotation in all directions, as depicted in Figure 8. This restriction ensures a stabilized and controlled analysis of the system.

2) Loading cases

This section aims to establish a series of loading cases that accurately represent the operational conditions of a washing machine. While acknowledging that some scenarios may be impractical in a real washing machine, the results derived from these cases contribute to a comprehensive understanding of the washing machine's behavior.

This analysis transcends numerical considerations, emphasizing a holistic understanding of the washing process as it relates to the real-world object. The applied loads are numerically representative of wet clothes pressed against the cylinder wall, positioned randomly in their natural state.

In each simulation, the rotational speed remains consistently at its maximum. However, the duration varies contingent on the load balance within the cylinder. Specifically, the rotational speed is set at 1735 rpm for 90 seconds when the cylinder is evenly loaded, and it is adjusted to 1690 rpm for 60 seconds in the case of an unbalanced cylinder. This approach ensures a comprehensive exploration of the interplay between rotational dynamics and load distribution, reflecting real-world washing machine conditions.

3) Load

An additional pivotal factor influencing the calculation of stresses within the cylinder is the applied load.
Loads in Each Simulation:
Two primary loads are considered in each simulation:
Centrifugal Force Load:
This load arises from the centrifugal force exerted when the cylinder is in rotation.Clothes and Water Mass Load:
This load is determined by the mass of clothes and water as they rotate within the cylinder. The calculation for this load is expressed by the following equation:

$$P = \frac{\omega^2 \cdot r \cdot m}{A}$$

The total maximum mass is determined by summing 7 kg of dry clothes and 40% of the water's mass, resulting in a total of 9.8 kg.
Distribution of Mass in Simulations:
In each simulation, the mass considered is a percentage of the total mass, contingent on the number of regions loaded in the cylinder:
Single Region Loaded:
Mass considered: 30% of the total mass (2.94 kg).
Two Loaded Regions:
Mass considered: 50% of the total mass (4.9 kg).
Three Regions Loaded:
Mass considered: 100% of the total mass (9.8 kg).

4) Number of Loads:

The number of loads, or regions, directly impacts the rotational speed. A single load or a double load applied to a large region cannot achieve balance. In this project, three cases are considered based on the application of loads in one, two, or three regions, with these regions defined by the position of the paddles.
One Region Loaded: In the case of a single loaded region, the cylinder will invariably be unbalanced.
Two Regions Loaded: For two loaded regions, the cylinder achieves balance if the masses are equal and positioned opposite each other.
Three Regions Loaded: With three loaded regions, balance is achieved if the masses are identical and equally distributed in a symmetrical pattern.

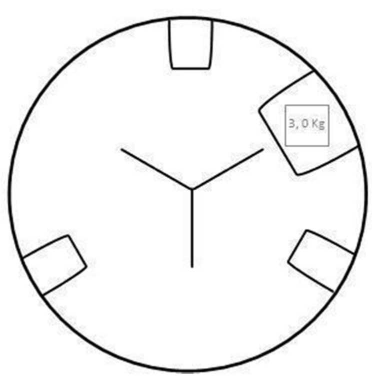

Figure 10. Model loaded in a single region

Figure 8. Model loaded in 2 regions

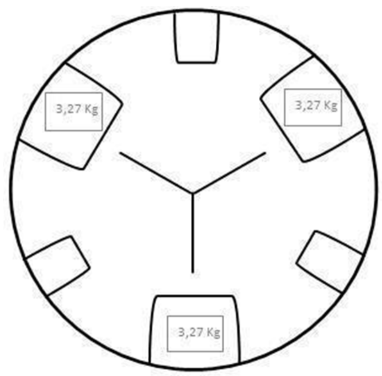

Figure 9. Model loaded in 3 regions

5) No. of Simulations

Three numbers of Simulations with the idea of submitting them to a deeper study, including maximum stress, stress gradient and influence of loads, areas and speed were done.

IV. RESULTS

1) Simulation 1. Single load

Loading Assumptions:

It is assumed that the washing machine is not fully loaded, considering the impracticality of concentrating all the pressure from loads in a single region. The assumption is made to reflect the real-world scenario where the pressure from loads is distributed across various regions.

Additionally, special attention is given to the Spider, as it is expected to endure maximum stress levels. This heightened stress is attributed to the deviation from its intended design function, resulting from the applied loads.

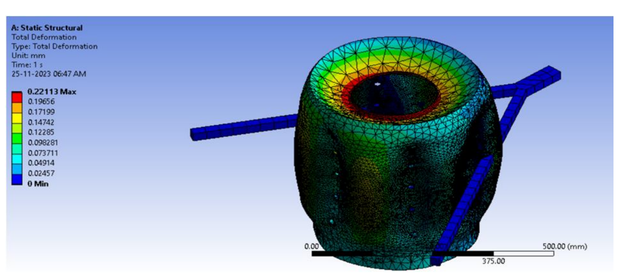

Figure 11. von Mises average stress in the cylinder with applied loads

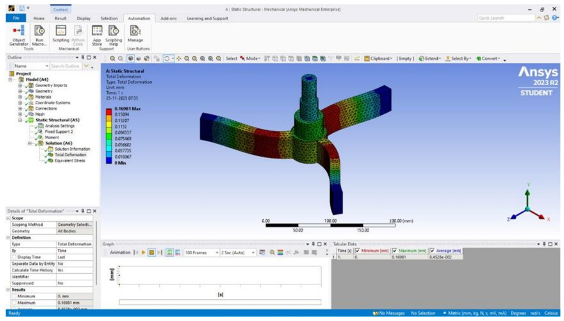

Figure 12. Spider von Mises stress distribution

2) *Simulation 2. Cylinder loaded with two opposite loads*

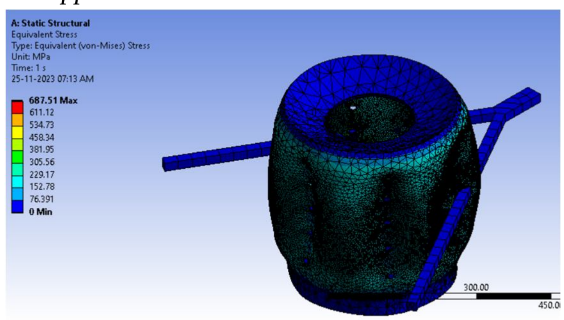

Figure 13. von Mises stress in the inner side of the cylinder, paddle, front and rear covers.

3) *Simulation 3. Cylinder loaded in 3 regions*

The most critical part is the cylinder and the most critical areas are those closest to the paddles.

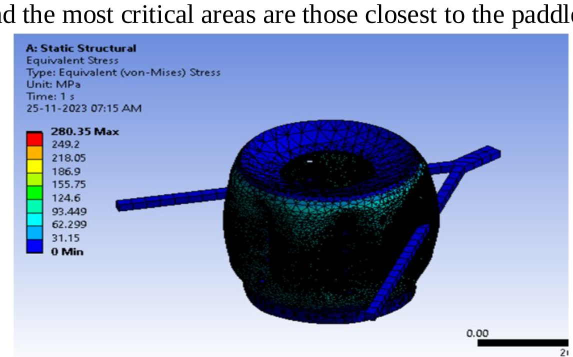

Figure 14. von Mises average stress in the cylinder viewed from its outer side.

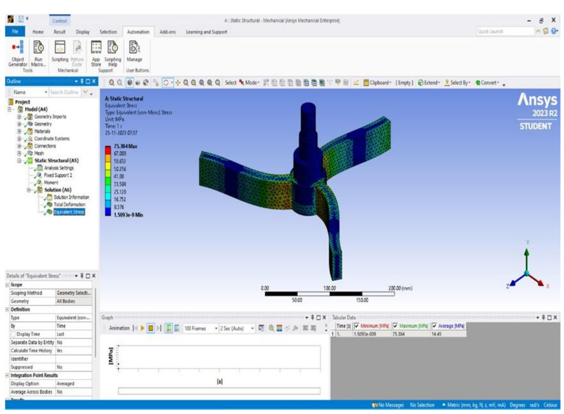

Figure 15. Spider with von Mises stress distribution

a) Spider Reconstruction

The initial focus in the reconstruction process of this thesis project is on the Spider, which serves as the crucial link between the shaft and the cylinder. This component plays a vital role in initiating the rotation of the cylinder, subjecting it to significant stresses and strain.

In Fig 16. A schematic illustrates the primary functions of the various parts, aiding in easy comprehension. Specifically, the connection functions highlight the interactions with other elements. These connections give rise to stress distributions, providing valuable insights into the structural behavior of the Spider and its impact on the overall system. Understanding these stress patterns is essential for ensuring the robustness and functionality of the Spider in the context of the washing machine assembly.

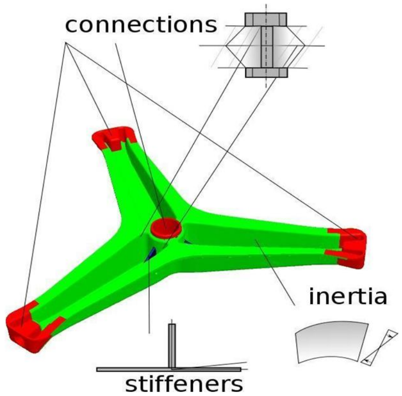

Figure 16. Main functions of the part

b) Optimisation of solution

The primary emphasis of Solution is the optimization of the existing model employed by ASKO in their washing machines. This optimization is informed by insights gleaned from simulations and a thorough study of the component's behavior. The aim is to enhance the current design based on the observed results.

The optimization process involves the exploration of various redesign ideas for the Spider, spurred by the findings and analyses derived from simulations. These new concepts are envisioned to address specific performance aspects, potentially leading to an improved and more efficient Spider design. The optimization journey is driven by a commitment to refining the current model to align with performance goals and industry standards.

c) Boundary conditions and mesh for solution

The boundary conditions for this part are the same that those applied to the original, so no new considerations have to be considered for this solution.

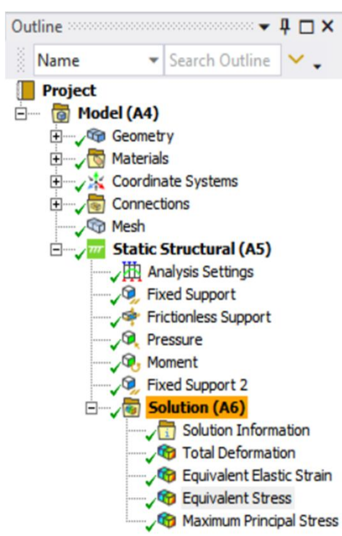

Figure 17. Mesh for solution in Spider reconstruction.

d) Boundary conditions and mesh for solution 1

The boundary conditions for this part are the same that those applied to the original, so no new considerations have to be considered for this solution.

V. CONCLUSION

The Project undertook a detailed examination of the mechanical elements within a washing machine, focusing particularly on the front cover and tripod components. Utilizing Abaqus for a comprehensive analysis, the project aimed to refine the topology of these parts to enhance performance, cost-efficiency, and structural integrity. The optimization strategies employed in revamping the tripod and front cover led to significant enhancements across various metrics.

For the tripod, Solution 1 demonstrated notable success by reducing displacement, stress, and material volume. The careful assessment of stress distribution and displacement, independent of singularities, revealed a strategic approach to bolstering the component's structural performance. Solution 2 for the tripod introduced an innovative design by switching to steel material and integrating functions with the rear cover. An economic analysis based on steel prices highlighted potential cost savings, underlining the project's focus on practical considerations.

Both Solution 1 and Solution 2 exhibited decreased displacement compared to the existing model, validating the effectiveness of the modified profile sections. Stress distribution analysis using von Mises criteria showcased significant improvements, with Solution 1 surpassing Solution 2 and the current model in stress reduction and safety factors. Volume comparison between different models emphasized the economic advantages of optimization, particularly with Solution 1 showing an 18.6% reduction in volume, indicating reduced material usage and associated costs.

To sum up, the project not only optimized critical washing machine components but also demonstrated tangible improvements in displacement, stress distribution, and material efficiency. These results underscore the feasibility and benefits of the proposed redesigns, offering valuable insights for the washing machine industry in terms of performance and cost-effectiveness. The meticulous optimization approach, complemented by thorough numerical validation, positions this project as a significant contribution to the field of washing machine design and manufacturing.

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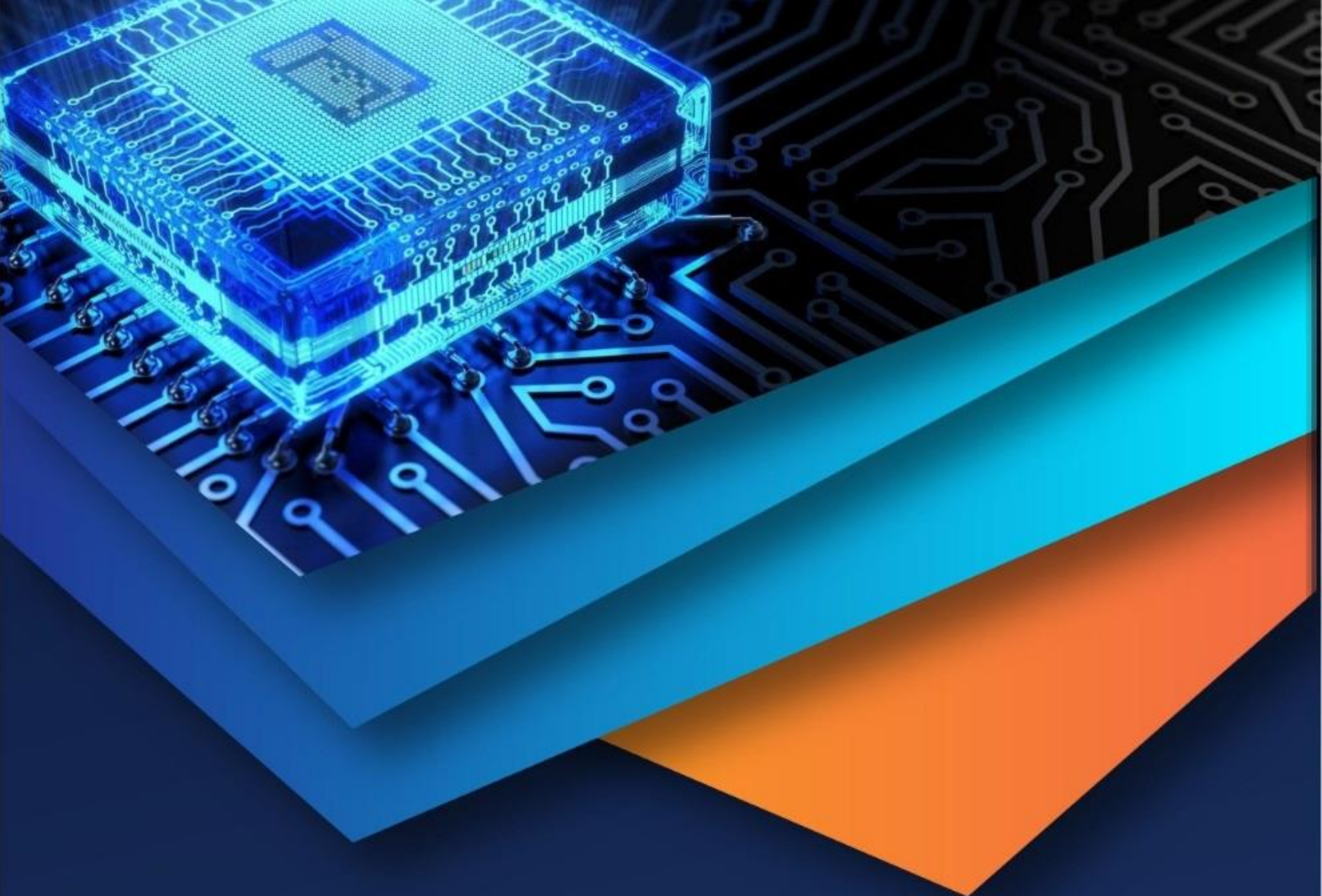

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