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Design and Analysis of High-Speed Spindle in Milling Machine

Hiregoudra Hanumanth Goud[1], VV S H Prasad[2]
[1, 2]ME Department, Institute of Aeronautical Engineering, Dundigal, Hyderabad, India 500043

Abstract: In today's prosperous industrial development, with the multifarious design of products and reduction of production cycle, high speed machining technology has been widely adopted by manufacturers. With the development of the science and technology, the high frequency spindles have been taken place of the normal mechanical spindles more and more, and also be used of the numerical control machine with great effects. In this research high speed motorized spindle is designed and analyzed under the given load conditions. The spindle used in this thesis is that used in a milling machine. The 3D modeling of spindle is designed in SOLID WORKS. The material used for spindles is AISI Steel. In this context, different material is analyzed for spindle. EN8 steel is replaced with AISI 1050 steel.
***Keywords*: Design, Analysis, High Speed, spindle**

I. INTRODUCTION

Milling machine is one of the most versatile conventional machine tools with a wide range of metal cutting capability. Many complicated operations such as indexing, gang milling, straddle milling etc. can be carried out on a milling machine. Milling machines were first invented and developed by Eli Whitney to mass produce interchangeable musket parts. Although crude, these machines assisted man in maintaining accuracy and uniformity while duplicating parts that could not be manufactured with the use of a file. Development and improvements of the milling machine and components continued, which resulted in the manufacturing of heavier arbors and high- speed steel and carbide cutters. These components allowed the operator to remove metal faster, and with more accuracy, than previous machines. Variations of milling machines were also developed to perform special milling operations. During this era, computerized machines have been developed to removing the errors and provide better quality in the finished product. This chapter deals with the types of milling machines and various types of milling processes. Milling Machines can be classified as the two types,

- Conventional machines
- Computerized machines.

Milling is a cutting process that uses a milling cutter to remove material from the surface of a workpiece. The milling cutter is a rotary cutting tool, often with multiple cutting points. As opposed to drilling, where the tool is advanced along its rotation axis, the cutter in milling is usually moved perpendicular to its axis so that cutting occurs on the circumference of the cutter. As the milling cutter enters the workpiece, the cutting edges (flutes or teeth) of the tool repeatedly cut into and exit from the material, shaving off chips (swarf) from the workpiece with each pass. The cutting action is shearing deformation; material is pushed off the workpiece in tiny clumps that hang together to a greater or lesser extent (depending on the material) to form chips. This makes metal cutting somewhat different (in its mechanics) from slicing softer materials with a blade.Conventional milling machines are used for simple work like face milling, plain milling, gear cutting, indexing, cutting slots and keyways etc. computerized milling machines, which can do complex jobs. Literature survey plays an imported part in formulating any work.

II. LITERATURE SURVEY

There are many papers available for the analysis of spindle of which few are selected based on the relevance of the statement of this paper. Based on these research papers, a different methodology will be chosen which is suitable for analysis of spindle. The referred papers are explained in brief as below. Osamu Maedaet.al [1] discussed an Expert spindle design system strategy which is based on the efficient utilization of the laws of machine design, dynamics and metal cutting mechanics. The configuration of the spindle is based on the specification of the work piece material, necessary cutting conditions and commonly used tools on the machine tool. The spindle drive mechanism, driving motor, bearing type and spindle shaft dimensions were selected based on the required applications. They iteratively find out the Frequency Response Functions (FRF) of the spindle at the tool tip using the Finite Element Method (FEM).

This work predicted the cutting operation at the required speed and depth of cut for different flutes of cutters. The arrangement of bearings was optimized using Sequential Quadratic Programming (SQP). Fig. 3 shows the design variables for bearing locations. Fig. 3: Design variables for bearing locations [1]. Chi-Wei Lin et.al [2] discussed that Development of high-speed spindle technology is critical to the implementation of High-speed machining (HSM). As Compared to the conventional spindles, motorized spindles are equipped with a built-in motors for good power transmission but the built in motors produces large amount of heat into the spindle system as well as extra mass to the spindle shaft, thus it affect to the dynamic behavior of the spindle. The author presents an integrated model with experimental validation and sensitivity analysis for studying various thermomechanical dynamic spindle behaviors at high speeds and the fallowing effects are observed that is the bearing preload effects on bearing stiffness, and overall spindle dynamics, high speed rotational effects. The results of this paper show that a motorized spindle softens at high speed because of the centrifugal effect on the spindle shaft.Dr. S. Shivakumaret.al [3] discussed the Design and analysis of lathe spindle in which alloy steel material was used for the spindle. Two bearings were supported by spindle with different spans. Bearings consist of balls with the certain amount of stiffness, which acts as cushioning effect to the spindle so they considered the spring in the Ansys for the analysis and also carried out static analysis and dynamic analysis of a spindle supported by the front and rear bearing. Bearing stiffness value was calculated by an iteration procedure and using numerical relations life of bearings was calculated. Fig. 4: Graph of bearing span v/s radial deflection [3]. Tobias Maier et.al [4] discussed modeling of the thermomechanical process effects on machine tool structures, in machine tools thermally induced deviations are key issues specially when considering the actual trends of high performance and dry cutting. The interactions between the cutting process and the machine tool structure are significant boundary conditions for the numerical prediction of the thermomechanical machine behavior. This paper presents an approach for the atomistic modeling of process effects, it includes process of heat, cutting forces and increased load on feed and main drives. Author provided an empiric data for the relation between cutting forces and active drive power. A.Ertuket.al [5] discussed the Effect analysis of bearing and interface dynamics on tool point FRF for chatter stability in machine tools by using new analytical model for spindle tool assemblies. It is observed that the bearing dynamics is controlled by rigid body modes of the assembly, where as the first mode is affected by spindle holder interface dynamics and second mode that is elastic mode is affected by holder tool interface dynamics. Individual bearing and interface translational stiffness andu'. From this paper it is concluded that rotational contact parameters do not affect the resulting FRF considerably. In this paper, the analytical method was presented for modeling spindle–holder–tool assemblies and predicted the tool point FRF. By using this model, the effects of bearing and interface dynamics on the tool point FRF were studied. TugrulOzel, Taylan Altan[6]presented paper titled Process simulation using finite element method prediction of cutting forces, tool stresses and temperatures in high speed flat end milling. End milling of die mold steels is a highly demanding operation because of stresses and temperatures generated on the cutting tool due to high hardness of work piece. Modeling and simulation of cutting processes have ability for selecting optimum conditions and improving cutting tool designs, especially in an application such as high-speed milling. The main objective of this study was to develop a methodology for simulating and predicting chip flow, cutting process in flat end milling, operation cutting forces, temperatures and tool stresses using finite element analysis (FEA). It was used in the application for machining of P-20 mold steel with 30 HRC hardness by using the commercially available software DEFORM-2D. Mr. Sahil, Mr. JitenSaini[7]has written a paper on Static, fatigue and modal analysis of connecting rod under different loading conditions. Connecting rod is an important link between crankshaft and piston, and its primary function is to convert reciprocating motion into rotary motion of crankshaft. Connecting rod is subjected to many stresses than any other Engine components. In this paper static and modal analysis was performed on the connecting rod and the S-N approach by modified Goodman criterion for predicting fatigue life of the connecting rods is presented. The model was created using Solid modeling software-Solidworks2013. Further author conducted finite element analysis using Ansys14 Workbench to determine the von-mises stresses and strains, fatigue life and modal frequencies under different loading conditions. R. A. Gujar, S. V. Bhaskar [8] presented paper on Shaft design under fatigue loading by using modified Goodman method. In this paper, shaft was used in an inertia dynamometer rotated at 1000 rpm. Considering the different parameters like torque acting on a shaft, forces it helps to calculate the stresses induced. With the help of FEA stress analysis carried out and the results which were obtained from FEA compared with the theoretical values. Consider the stress concentration factor to find the fatigue life. Wojciech Stachurski, Stanis law Mideraet.al [9] discussed the effect of processing conditions on the value of the cutting force (Fc), during straight turning operation. The process is based on equations in the form of power polynomials which were obtained from the results of experimental tests. The tests were conducted while turning C45 carbon steel metal with and without the use of cutting fluid. Here cutting forces were determined by using three-component piezoelectric dynamometer. Fig. 5 shows the influence of cutting parameters on cutting force. Fig. 5: Influence of cutting parameters (f, Vc) on the cutting force [9]. In this paper it is presented the static structural analysis of spindle at various speeds such as 4000 rpm, 6000 rpm and 8000 rpm.

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III.STATIC ANALYSIS OF HIGH- SPEED SPINDLE

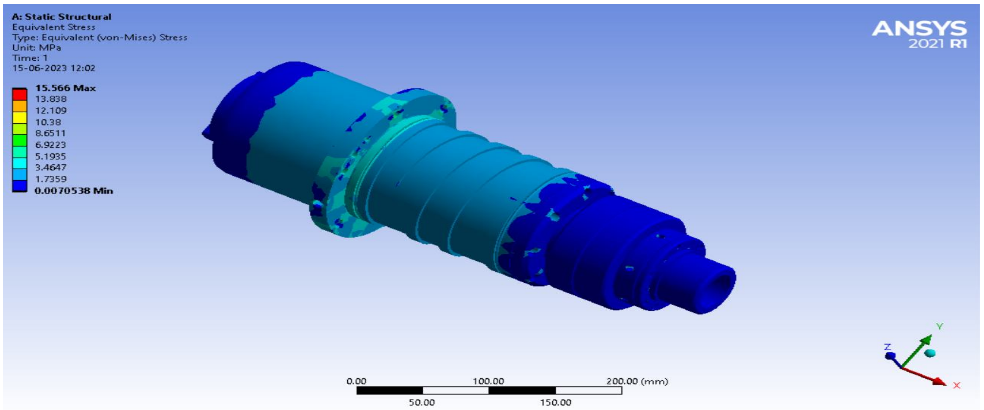

Fig: 1 Deformation of En 8 Steel Spindle at 4000 Rpm

Fig.1 represent the results of high spindle tool, when it undergoes with 4000 rpm with en8 material, it has maximum deformation result 0.0041523mm, and it has minimum deformation result 0mm.

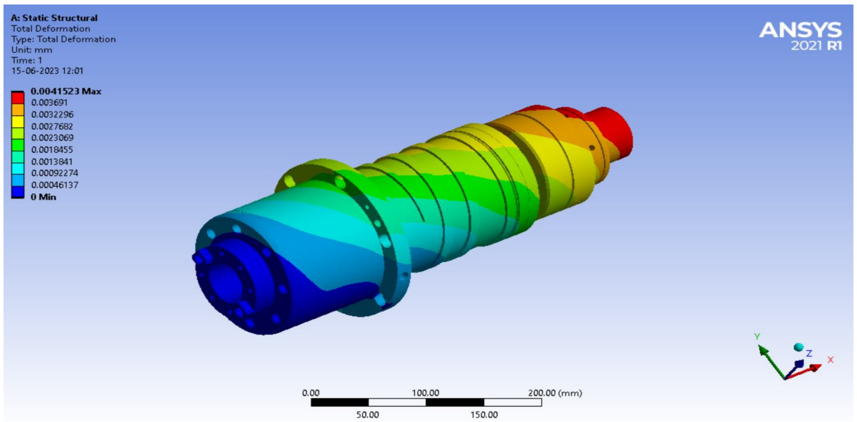

Fig: 2Stress of En 8 Steel Spindle at 4000 Rpm

Fig.2 represent the results of high spindle tool, when it undergoes with 4000 rpm with en8 material, it has maximum stress result 15.566Mpa, and it has minimum stress result 0.0070538Mpa.

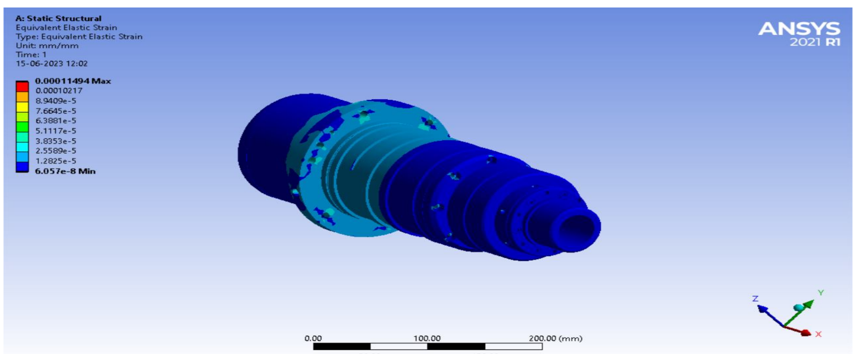

Fig: 3 Strain of En 8 Steel Spindle at 4000 Rpm

Fig: 3 represent the results of high spindle tool, when it undergoes with 4000 rpm with en8 material, it has maximum strain result 0.00011494, and it has minimum strain 6.057e-8.

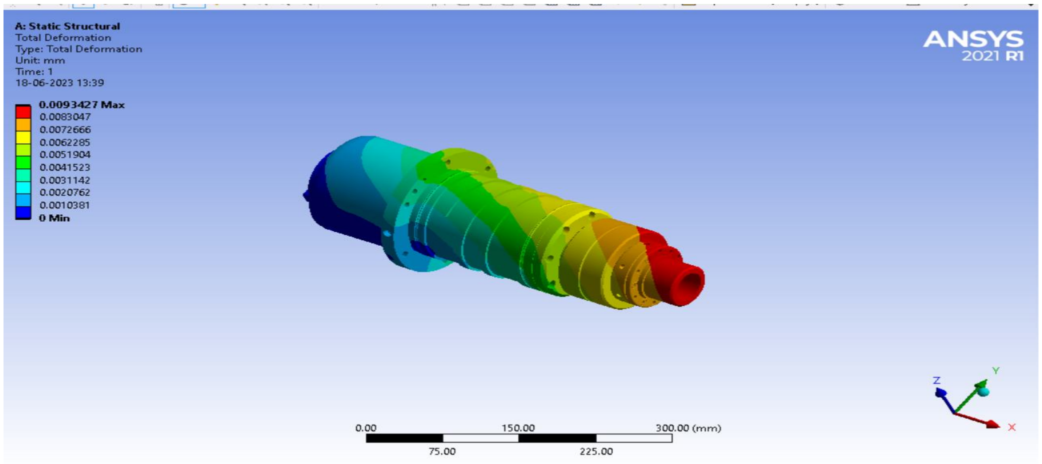

Fig:.4 Deformation of En 8 Steel Spindle at 6000 Rpm

Fig: 4 represent the results of high spindle tool, when it undergoes with 6000 rpm with en8 material, it has maximum deformation result 0.0093427mm, and it has minimum deformation result 0mm.

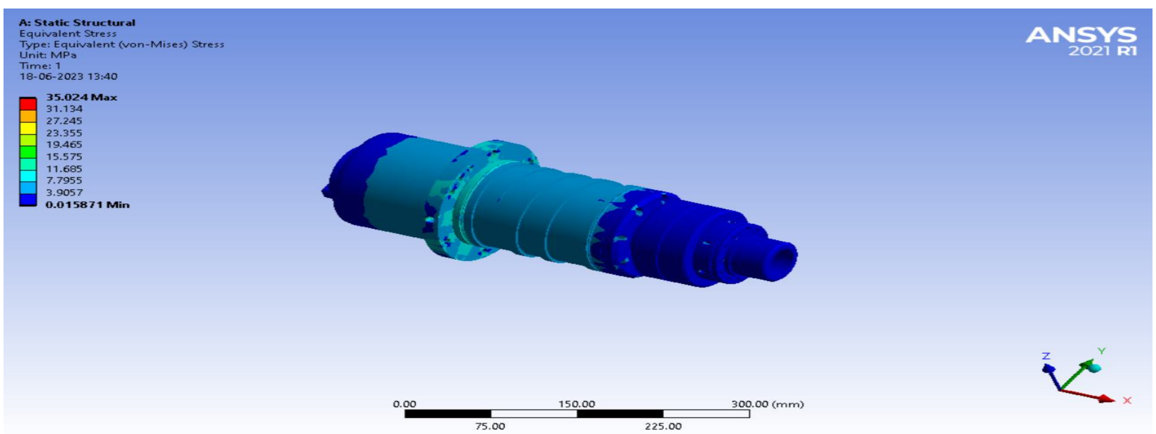

Fig: 5 Stress of En 8 Steel Spindle at 6000 Rpm

Fig: 5 represent the results of high spindle tool, when it undergoes with 6000 rpm with en8 material, it has maximum stress result 35.024Mpa, and it has minimum stress result 0.01571Mpa.

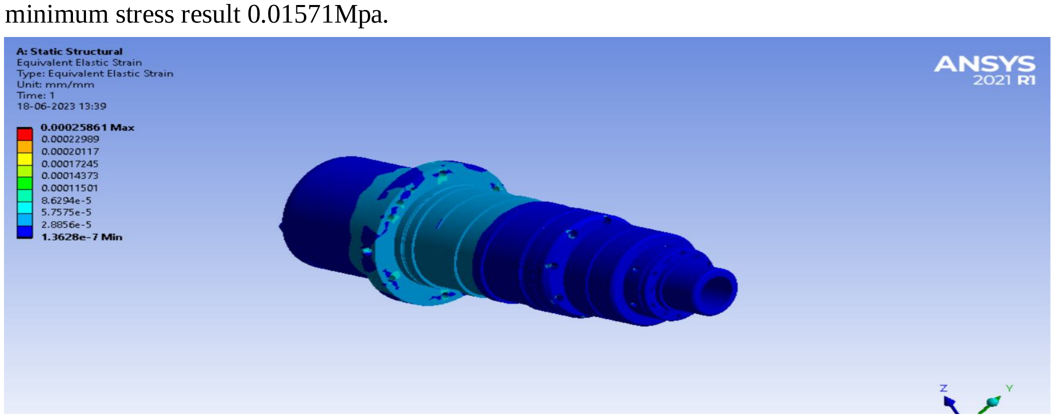

Fig:6 Strain of En 8 Steel Spindle at 6000 Rpm

Fig.6 represent the results of high spindle tool, when it undergoes with 6000 rpm with en8 material, it has maximum strain result 0.00025861, and it has minimum strain 1.3628e-7.

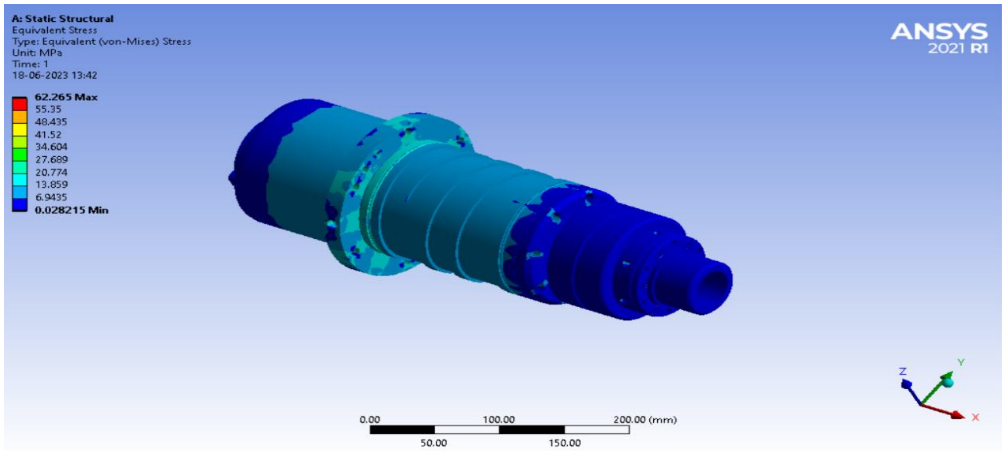

Fig: 7 Deformation of En 8 Steel Spindle at 8000 Rpm

Fig.7 Represent the results of high spindle tool, when it undergoes with 8000 rpm with EN 8 Steel material, it has maximum deformation result 0.016609mm, and it has minimum deformation result 0mm.

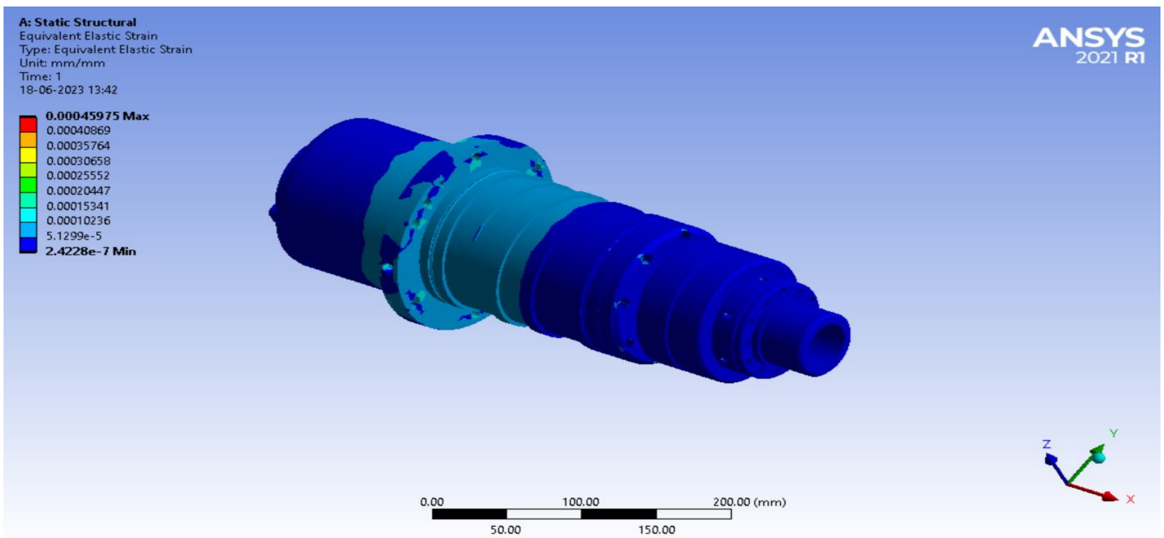

Fig:8 Strain of En 8 Steel Spindle at 8000 Rpm

Fig.8 represent the results of high spindle tool, when it undergoes with 8000 rpm with EN8 Steel material, it has maximum strain result 0.00045975, and it has minimum strain 2.4228e-7.

IV. CONCLUSIONS

In this research high speed motorized spindle is designed and analyzed under the given load conditions. The 3D modeling of spindle is designed in Solid Works. The material used for spindles is EN8 Steel. EN8 Steel is replaced with AISI 1050 Steel. It is concluded that at maximum speed of spindle the deformation and stresses values are higher.

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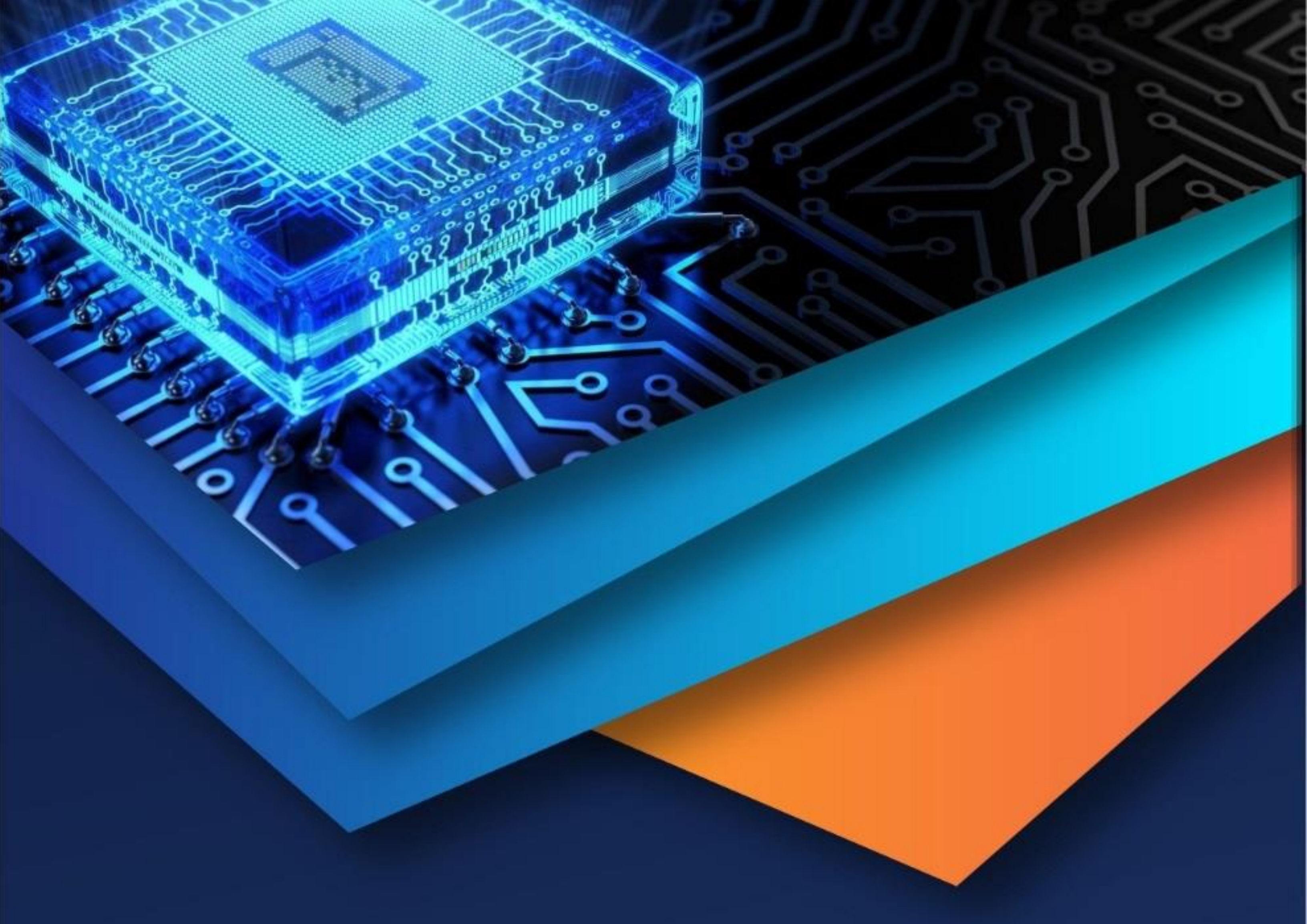

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