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An Experimental Study on Identification of Defect Severity in Deep Groove Ball Bearing using Vibration Analysis for End Mill Spindle

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Abstract: Rolling element bearings are critical components and widely used in many rotating machines such as automobiles, aerospace, weaving, machine tools that frequently fail. The defects in the rolling element bearings may come up mainly due to the following reasons; improper design of the bearing or improper manufacturing or mounting, misalignment of bearing races, unequal diameter of rolling element, improper lubrication, overloading, fatigue and uneven wear. The vibration of the bearing-rotor influences the security, performance of the rotating machines and working life of the whole plant. Although several techniques have been reported in the literature for bearing fault detection and diagnosis, it is still challenging to implement a bearing condition monitoring system for real-world industrial applications because of the complexity of bearing structures and noisy operating conditions. the purpose of the study is to investigate the vibration and noise producing characteristics of large rolling element bearings by vibration analysis, with the ultimate aim of devising means to reduce vibration and noise caused by these bearings for all audio and subsonic frequencies.
Keywords: Rolling element bearing, condition monitoring, subsonic frequency, vibration analysis, overloading

I. INTRODUCTION

Rolling element bearings are used in their tens of millions in rotating machinery to minimize friction between adjacent parts moving at different speeds. They are not only one of the most critical components but also one of the first to fail. The problem is a major one because, as it has been explained, fewer than 20% of bearings achieve their design life and other research has found bearing failures account for more than 50% of all motor failures. The economic loss due to bearing failure in terms of machine down time, and even human life, is huge compared to the cost of the bearing itself. Therefore, bearing condition monitoring (CM) and diagnosis has attracted substantial attention over the past four decades as economic pressure to increase machine speed has accelerated.

Rolling element bearings have been subject to extensive research over many years to improve their reliability. However, the large number of bearings associated with any given process increases the likelihood of system failure due to one of them failing, and such system failure can occur in a very short period of time. There are many reasons for early failure, including; excessive loading, inadequate lubrication, insufficient internal bearing clearance due to an excessively tight fit, etc. Bearing faults can be categorized into three sets: primary damages, secondary damage and general damage.Primary Damage includes Wear, Indentation, Smearing, Surface Distress, Corrosion (rust), etc. and Secondary Damage cover Spalling (flaking), Cracks, Bearing Cage Damage, Scoring (galling), Rollout, etc.

Detecting mechanical faults in bearings has been recognized for some time as an important aspect for preventing catastrophic failure and planning effective maintenance. There are several approaches used to diagnose faults on a bearing system including thermal analysis, oil debris analysis, and vibration analysis.

A. Thermal Analysis

Thermal analysis is defined as a tool used to generate warnings about the overheating of the bearing system. The thermocouples or other temperature monitoring devices usually employed at the inlet and outlet of the test chamber indicate two points of interest to study any temperature gradient of the bearing component. However, thermal analysis cannot be used to identify the type and size of the defects in a bearing system.

B. Oil Debris Analysis

Lubrication of a bearing may be provided in liquid, grease, or solid form and the type of lubrication is generally chosen depending on the operating conditions. Debris analysis does have a rare application on grease or solid form but generally used with oil lubricants. Bearing failures in some machines such as helicopter transmissions and aircraft turbine engines generate significant debris in their oil systems. Oil analysis program on a bearing consists of oil sampling, analytical tests and data interpretation. There are number of oil debris analysis techniques such as elementary spectroscopy, wear particle analysis, fine particulates analysis, molecular analysis, and electrochemical chemistry used to diagnose a failure on a bearing. These oil debris analyses provide information on quantity, form, and size distribution o f the debris, which can lead to damage type detection.

Practical experiences and researches have shown that combining oil debris analysis along with vibration analysis in a bearing condition-monitoring program provides information in greater detail and more reliable information than each individual system.

C. Vibration Analysis

Each rotating machine has its own vibration signature as a result of the rotation of shafts, gears and bearings. Rolling bearing elements, an essential part of rotating machinery, are known to play a significant role in machine vibrations. First, structural element of the bearing acts as a spring and also adds some mass to a system. As such, bearings define, in part, the vibration response of the system to external time-varying forces. Secondly, bearings act as excitation forces, producing time-varying forces that cause system vibration. This excitation is natural in the design of rolling bearings. However, these forces can be greatly amplified as a result from imperfections or defects on the bearing components.

Detection of progressive bearing deterioration during operation by vibration measurements has been in use for a long time and this technique has become more economical and reliable in recent years. The overall level of vibration indicates the general condition of the bearing system, the cause of vibration, including such factors as unbalance, misalignment, and bearing defects. Vibration diagnostics are usually concerned with the extraction of features from a signal and associating these features with healthy or faulty components of the bearing.

A healthy bearing under constant load and speed is likely to move toward steady state dynamic equilibrium, because of the natural symmetry in a rolling bearing element. The strength of the vibration increases when a defect occurs on one of the bearing components. Due to the defect, a transient force takes place each time another bearing component contacts the defective surface, resulting in rapid acceleration of the bearing components.

II. EXPERIMENTAL SETUP

An experimental setup is employed in this research to collect the vibration signals for two purposes: to study the vibration signatures generated by incipient bearing faults, and to verify the techniques to be developed. This experimental setup is shown in Figure 1. The system is driven by a 1-hp induction motor, with the speed range between 20 and 4200 rpm. The shaft rotation speed can be controlled by a speed controller. An optical encoder is used for shaft speed measurement. Thus, the shaft rotation speed is known directly from the reading of this speed controller, which can be further verified by applying the FT on the signals from the optical encoder. A flexible coupling is utilized to damp out the high-frequency vibration generated by the motor. Two ball bearings are fitted into the solid housings. Accelerometers are mounted on the housing of the tested bearing to measure the vibration signals along two directions. Considering the structure properties, the signal that is vertically measured is utilized for analysis, whereas the signal that is horizontally measured is used for verification. A static load and variable load are applied by load suspended mechanism. A data acquisition board is employed for signal collection. Technical Specifications of different parts are mentioned in table 1.

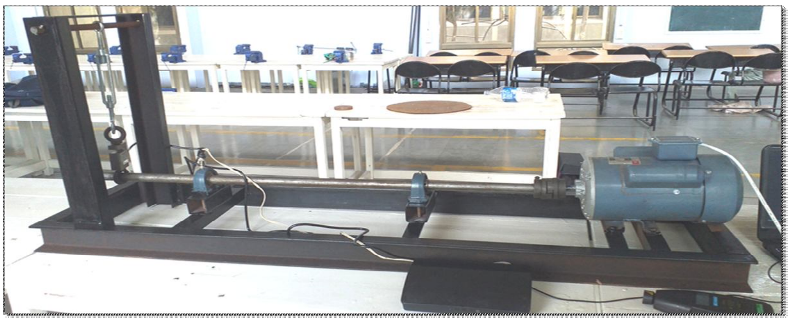

Figure 1. Photograph of experimental setup (Laboratory)

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Table 1. Technical Specifications

Major parts / Instruments	Specification	Application
Induction motor	Output power: 1hp Speed:4200 rpm Rated voltage: 220V	Continuous rotation
Accelerometer	Piezoelectric Sensitivity: 9.75 m/Vg	Vibration measurement
Tachometer	Measuring range: 2.5 to 5000 rpm Accuracy: ±0.05%+1d	Speed measurement
Data acquisition system (DAQ)	Input type: DCV (20Mv) Measuring accuracy: (0.01% of rdg + 5μV)	To interpret the collected data
S-type Load cell	Model No.: STI-60310C Capacity: 500 kg	Applying load at one end of shaft
Bearing sample (2 nos.)	Number of balls (N_b): 8 Shaft speed (ω-inner): 35Hz Ball diameter (d): 7.9mm Pitch diameter (D): 33.5mm	One healthy and one faulty bearing

III. EXPERIMENTAL PROCEDURE

The bearing rig was allowed to run 5 minutes to warm up before starting data collection. Of course errors such as manufacturing error, speed relative errors and ball estimation error might be presented and the accuracy cannot be 100%, however, the ten bearing conditions were tested with the assumption that the bearings have no clearance, no lubrication and no slippage error.

The bearing with no faults introduced was tested and used as a reference. Vibration signals were collected from the accelerometer mounted as already described on the bearing housing. Experiments were conducted to study bearing fault detection and diagnosis. Three sets of data were taken for each bearing condition, the three data sets of each bearing condition were taken in the same day, each set of data contains sex tests to ensure that the signals obtained were self-consistent, one of the sets was used to create the S and A archetype matrices and the other sets of data were used to create the matrices. All experiments were conducted in equipped Laboratory that maintains the same weather condition; therefore, all tests were supposedly carried out under the same conditions and also under full shaft rotational speed of 2500 rpm to enhance the vibration produced by running on high speed. As known in real condition there are different kinds of vibration conditions; axial, torsion and radial loads, therefore, different load was applied vertically on the shaft that is connected to the bearings in every test where the vibration is also measured vertically and picked from the housing that contains the bearing 6204-2z tested, the other supporting bearing was not subject to experiments because the study concerns heavy duty bearing and also avoid adding other modifications to the pre-existed rig (e.g. adding other kind of bearing or extra sensors) which would cause more difficulties and more time consuming to a fixed time research, and also to prevent potential disturbing for existing ones. These loads are applied to the rig, firstly to simulate real conditions in industry, and secondly to be sure that they are permissible by the rig tolerance. The bearings experiments have taken two week to be conducted; and the time-consuming part of the experiments was changing bearings. Swopping a bearing takes one hours. First the rig needed to be dismantled and the shaft taken out. Then the first tested bearing was slid out and the next bearing to be tested slid onto the shaft. This part of the process required the use of a pressing machine. Then the bearing was replaced and the rig re-assembled. This procedure had to be repeated every time with all bearings. The order of the experimental procedure was healthy bearing, bearing with outer race fault, bearing with ball fault and finally bearing with inner race fault. In each case the 30% fault was tested first followed by the 60% fault and then the 100% fault.

Table 2. Test program

Load (KN)	Defect size width (mm)	Speed (rpm)
L1=0.25	D1= 0.2	N1=500
L2=0.5	D2=0.4	N2=700
L3=0.75	D3=0.6	N3= 900
L4=1	D4=0.8	N4=1100
	D5=1.0	N5=1300
	D6=1.2	N6=1500
	D7=1.4	N7=1700
	D8=1.6	N8=1900
	D9=1.8	N9=2100
	D10=2.0	N10=2300

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A. Outer Race Fault

The behaviour of an outer race fault is similar to that of inner race damage. Since the location of the defect is stationary and the probability of impact generation is high.

Table 3. Vibration RMS velocity in (mm/sec) at various defect sizes on Outer Race and RPM at 0.25KN Load

RPM	Defect size (width) in mm on Outer Race									
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
500	0.12	0.15	0.21	0.23	0.26	0.28	0.34	0.37	0.41	0.45
700	0.14	0.18	0.24	0.29	0.31	0.34	0.38	0.42	0.48	0.52
900	0.19	0.22	0.28	0.35	0.39	0.46	0.51	0.58	0.64	0.70
1100	0.24	0.28	0.35	0.42	0.49	0.52	0.58	0.64	0.68	0.78
1300	0.32	0.38	0.42	0.48	0.56	0.61	0.68	0.72	0.81	0.89
1500	0.40	0.46	0.53	0.61	0.68	0.74	0.78	0.84	0.89	0.97
1700	0.48	0.56	0.67	0.71	0.78	0.85	0.91	0.98	1.04	1.11
1900	0.56	0.64	0.72	0.84	0.89	0.96	1.02	1.10	1.22	1.28
2100	0.64	0.72	0.81	0.92	0.98	1.12	1.23	1.30	1.42	1.48
2300	0.71	0.78	0.84	0.94	1.08	1.17	1.28	1.42	1.51	1.62

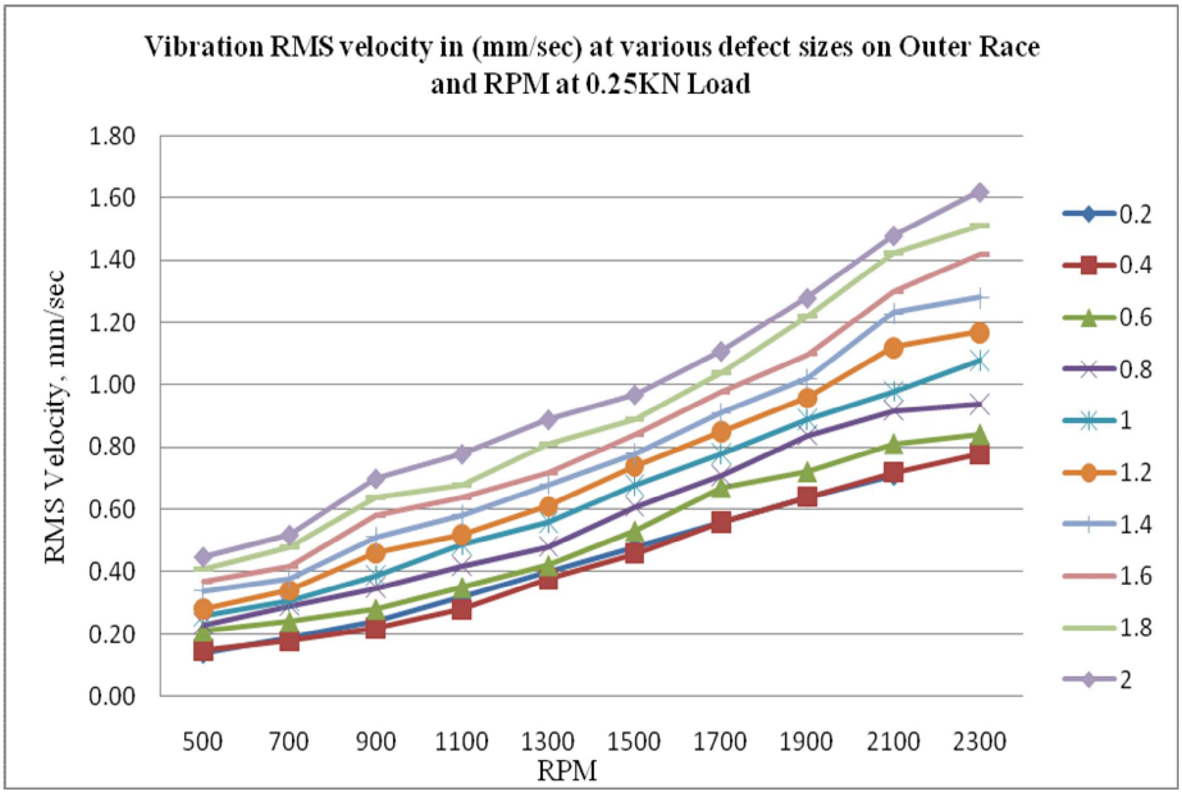

Figure 2. Vibration RMS velocity in (mm/sec) at various defect sizes on Outer Race and RPM at 0.25KN Load

B. Inner Race Fault

As expected, the small dimple generates more peaks in the vibration signal, increasing the level of vibration. When the damage is excessive, the continuous generation of impulses in the vibration signature increases the variance of the signal, subsequently diminishing the pattern of peaks.

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Table 4. Vibration RMS velocity in (mm/sec) at various defect sizes on Inner Race and RPM at 0.25KN Load

RPM	Defect size (width) in mm on Inner Race									
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
500	0.21	0.26	0.32	0.41	0.52	0.61	0.68	0.75	0.81	0.92
700	0.24	0.31	0.38	0.48	0.59	0.68	0.72	0.78	0.88	1.02
900	0.28	0.36	0.42	0.53	0.65	0.75	0.78	0.88	0.94	1.09
1100	0.35	0.42	0.48	0.59	0.71	0.81	0.85	0.95	1.02	1.18
1300	0.42	0.51	0.55	0.65	0.78	0.89	0.96	1.01	1.13	1.24
1500	0.52	0.59	0.65	0.72	0.81	0.91	1.05	1.11	1.19	1.32
1700	0.57	0.65	0.71	0.81	0.92	0.98	1.12	1.22	1.26	1.41
1900	0.68	0.73	0.78	0.89	0.98	1.08	1.18	1.31	1.35	1.49
2100	0.75	0.81	0.89	0.95	1.08	1.15	1.25	1.36	1.46	1.58
2300	0.82	0.88	0.98	1.11	1.21	1.26	1.32	1.41	1.52	1.65

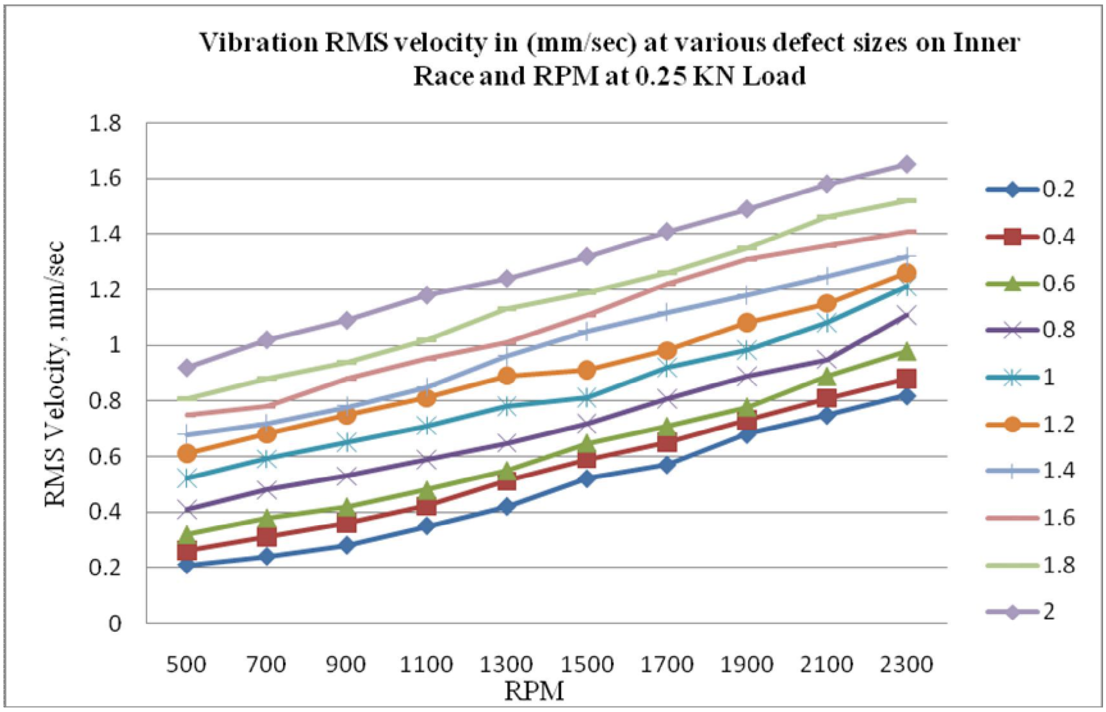

Figure 3. Vibration RMS velocity in (mm/sec) at various defect sizes on Inner Race and RPM at 0.25KN Load

IV. CONCLUSIONS

Experimental vibration studies with locally defective deep groove ball bearings have been carried out and reported in this paper by applying dynamic radial loading on the test bearings. Ten different circular sizes of defects on either race of bearings have been considered in the investigations for bringing out the broader generality in the observations. Based on the studies reported herein, the following conclusions have been drawn:

A. With healthy bearing under no load conditions, the vibration peaks at shaft rotational frequency with their harmonics are observed;

B. With dynamic radial loading of varying frequency applied on the healthy test bearings, the amplitude of vibrations at the shaft rotation frequency gets buried under other types of vibrations;

C. Overall vibration increases in presence of local defects in comparison to healthy test bearing under dynamic radial loading;

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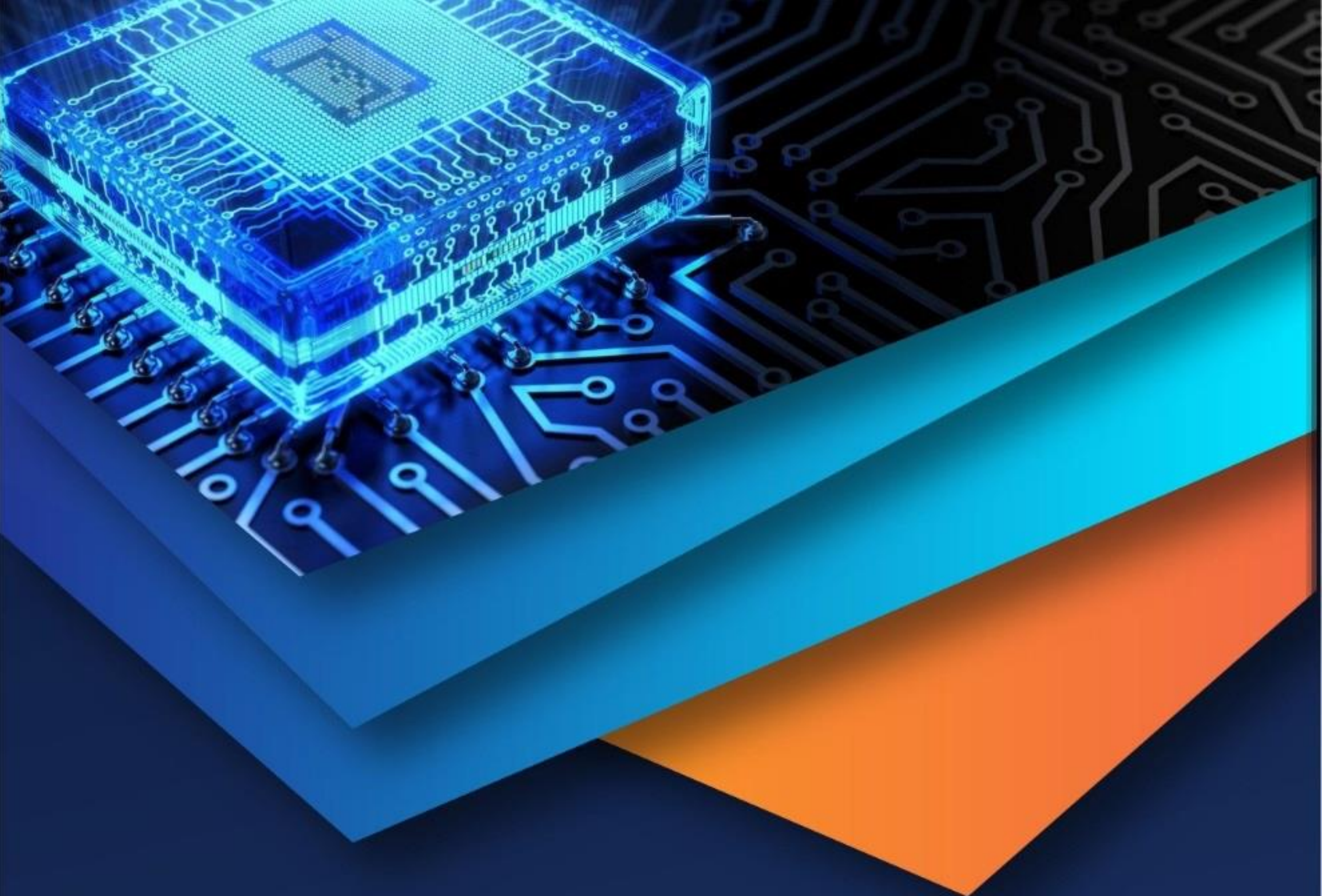

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