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Study of Vibrational Response of a Rotary System with Defective Rolling Element Bearing

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Abstract: Vibration issues pose major concern in rotating machinery. Rolling Element Bearing (REB) defect is one of the sources of vibration in rotating machinery. It causes serious threat to machine life and catastrophic failure of the instrument. This work is an effort to study experimentally, vibration characteristics of a mechanical system, associated with REB defects. Vibration signals are detected using an accelerometer mounted on one of the bearing housings. FFT signals obtained indicates steady state response for healthy and damaged condition of bearings under operating parameters. The results indicate that as the number of defects in bearing increases, vibration characteristics increase significantly.
Keywords: Rotating machinery, Rolling Element Bearing(REB), Frequency Response Function(FRF), Fast Fourier Transform(FFT).

I. INTRODUCTION

Vibration analysis is a technique of learning variations within the vibration pattern, and relating those variation to the behaviour of mechanical system. The internal condition of any mechanical system is described by the variation pattern and it's level in rotating machine[1]. Rolling element bearings are commonly subjected to unbalanced forces generated in the machine, which leads to different kinds of bearing defects such as inner race defect, outer race defect, ball defect and cage defect[2]. The faults are induced due to various parameters such as cyclic loading of machine, measurable tolerance limits provided while assembling, poor lubrication over a period of time etc. Defects produced due to these reasons can lead to catastrophic failure of bearing and costly breakdown of the system. Therefore condition monitoring of the system is necessary to identify the defect of bearing before they fail catastrophically and lead to costly breakdown of the mechanical system [3]. These bearings provide relative positioning and rotating freedom along with load transfer between shaft and housing. Among the available techniques, vibration spectrum analysis is effective in condition monitoring of the system. Recent studies have shown that performance and bearing life increases if defects, of REBs are detected and diagnosed early[4]. Bearing frequencies are those which repeats periodically in series. These bearing frequencies can be analyzed by analytical and experimental methods. The frequency multipliers depends on various parameters of the rolling element bearing such as pitch, ball diameter, angle of contact, and number of balls. The product of frequency multiplier and shaft rotational speed gives the defect frequency of bearing running at that speed of shaft[5]. The Objective of present work is to study of vibration response of a rotating system having different kinds of bearing defects condition under various operating conditions.

II. METHODOLOGY

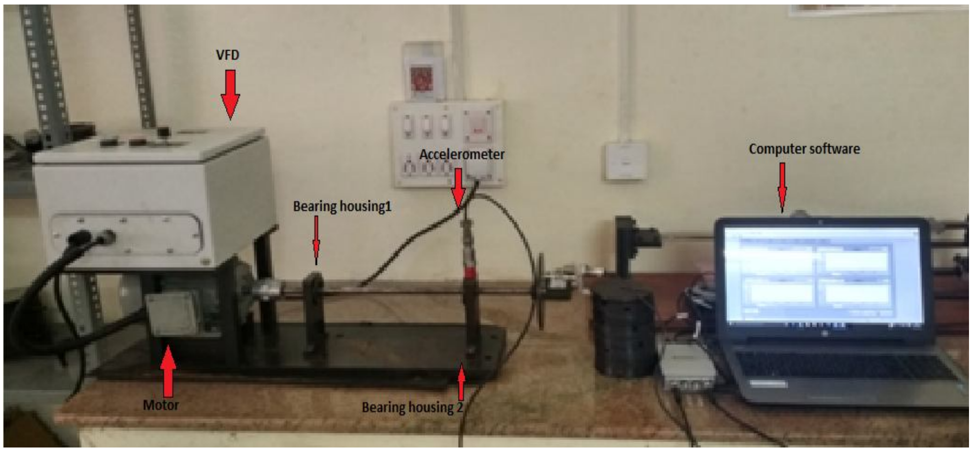

Fig 1: Experimental setup.

An experimental setup has been designed and fabricated to study the effects of bearing defect on vibration behaviour of a rotating system. Fig 1 shows experimental setup, which consists of an overhung shaft driven by variable speed motor. Two rolling element(ball) bearings are used for supporting the shaft. A disc with provision for adding unbalanced masses is mounted at the free end of the shaft. An accelerometer is mounted on bearing housing 2 for measuring vibration response as shown in fig. Accelerometer is further connected to the data acquisition system(DAQ) for acquiring and processing of collected data. Table 1 shows the details of operating parameters. For the purpose of the study, defects are induced in the bearings by creating 2mm diameter holes in outer race of the bearings in housing 2. EDNC(Electric Discharge Numerically Control) technique has been used for creating these holes. Fig 2 shows defects in the bearings.

Fig 2: Damaged bearings

Vibration data is acquired both for the healthy and damaged condition of the bearing at different operating conditions. Data acquired in time domain is then processed and converted to frequency domain signals using FFT technique. Impact hammer test has been conducted to obtain modal frequencies of the system.

TABLE 1
Operating parameters of the Experimentation.

Sl.No.	Experimental parameter	Value
1	Diameter of overhanging Shaft	15mm
2	Loading condition	No-load,25gm, 50gm
3	Speed of the shaft	400rpm – 1000rpm, in steps of 200

Table 2 shows the designation of bearings with different defect.

TABLE 2
Designation of bearings with different defects.

Healthy bearing	H
Outer race with 1 hole	OR1
Outer race with 2 holes	OR2
Outer race with 4 holes	OR4

Fig 3 shows the geometry of the bearing used and table 3 shows its specification.

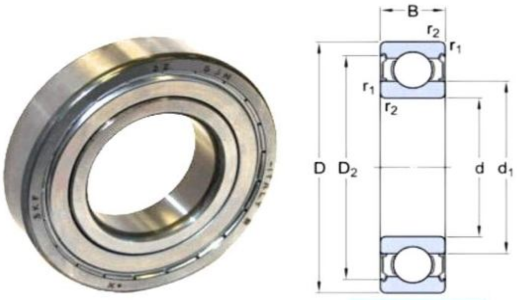

Fig 3:Geometry of the Bearing.

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TABLE 3
Specifications of the bearing used.

Bearing used	SKF 6202-2Z
Number of rolling elements[n]	8
Diameter of rolling element[d]	5.953mm
PCD of bearing[D]	25mm
Contact angle [α]	0^0 for Deep groove ball bearing

Ball pass frequency multiplier of outer race is calculated as follows:
Ball pass frequency multiplier of outer race[BPFO]=(n/2)(1-(d/D)cosα))
BPFO=(8/2)(1-(5.953/25)cos0))
BPFO=4*0.76188
BPFO=3.05
Where, n= Number of rolling elements,
d= Diameter of rolling element,
D=Pitch circle diameter of bearing,
α= Contact angle, which is the angle of load from the radial plane[6].
Ball pass frequencies = BPFO* shaft speed
=3.05*(400/60)
=20.33Hz

III. RESULTS AND DISCUSSION

A. Frequency response function(FRF)

Fig 4 shows FRF of the equipment obtained from impact hammer test. Some of the modal frequencies obtained from the FRF are 78Hz, 336Hz, 432Hz and 536Hz.

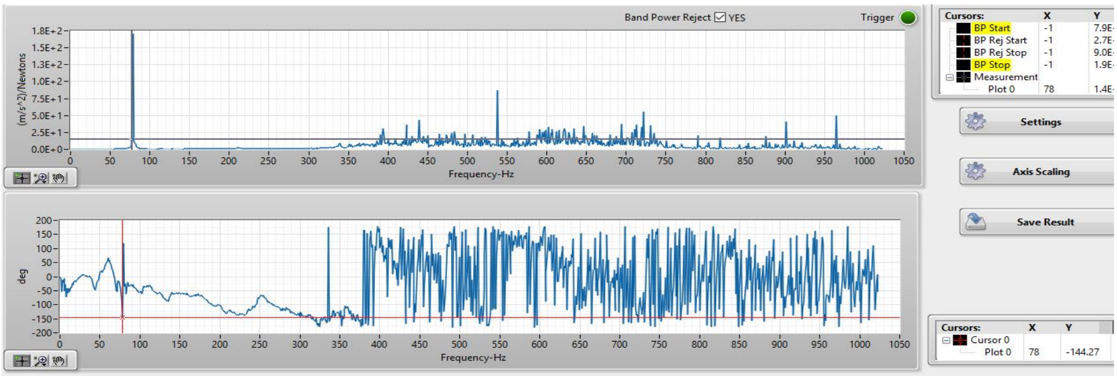
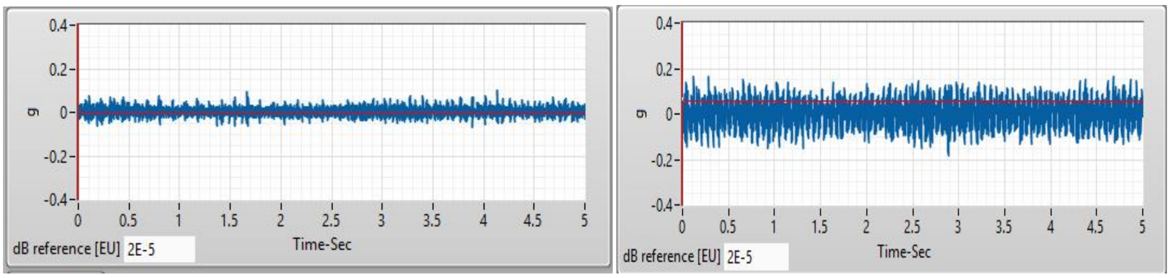


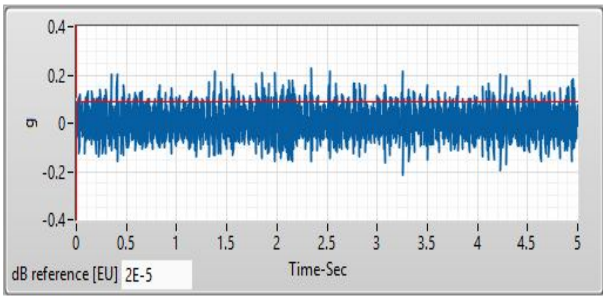
Fig 4:FRF test result.

B. Time domain analysis

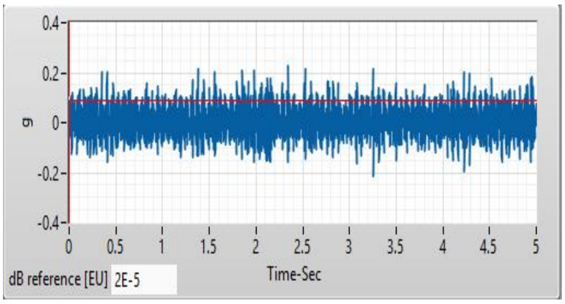
The time domain signals are shown in Fig 5. RMS values of the time domain signals are shown in fig 6.



a)H b)OR1



c) OR2



d)OR4

Fig 5:The time domain signals of bearing for healthy and faulty bearings.

C. *Variation Of Vibration Characteristics With Excitation Frequency*

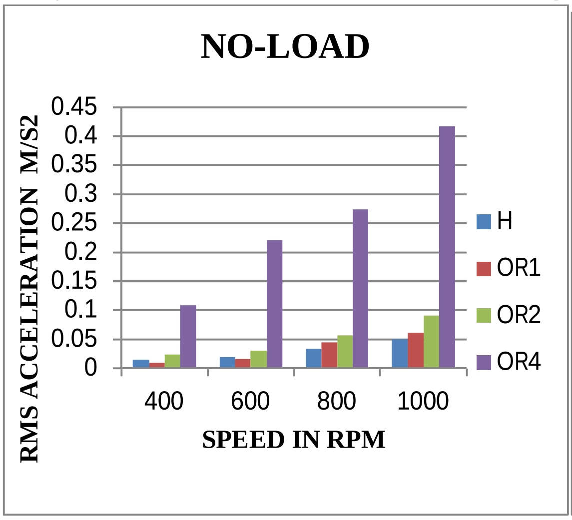


Fig 6(a): RMS Acceleration v/s speed for No-Load condition

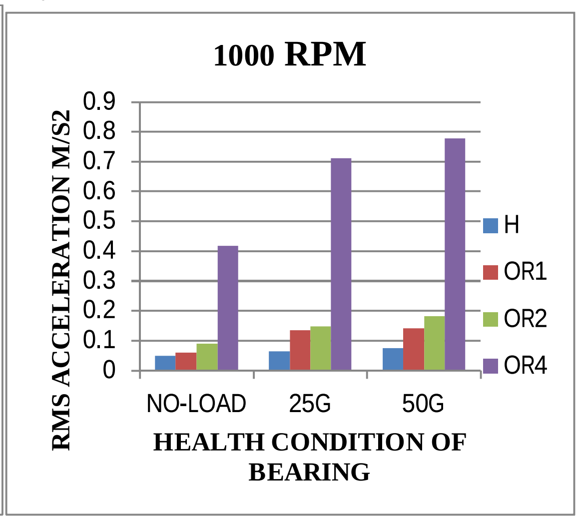


Fig 6(a): Acceleration v/s load for 1000rpm

It can be observed from the plots that the RMS values of the time series signal increase steadily with the speed and load conditions of the system. It can also be observed that there is distinct increase in the RMS level, with the increase in the number of defects in the outer race of the bearing.

D. Frequency Domain Analysis

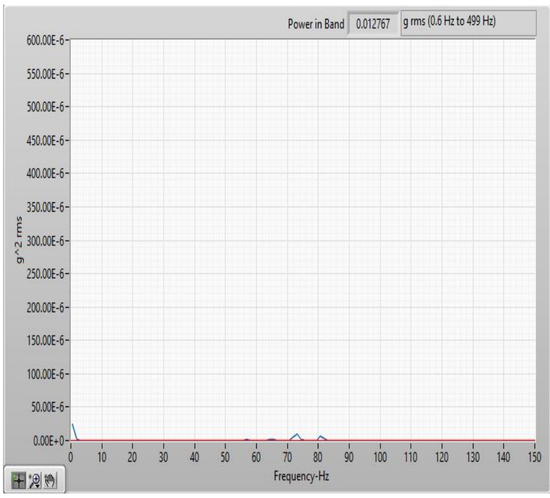


Fig 7(a): H signal at 400rpm and No-Load

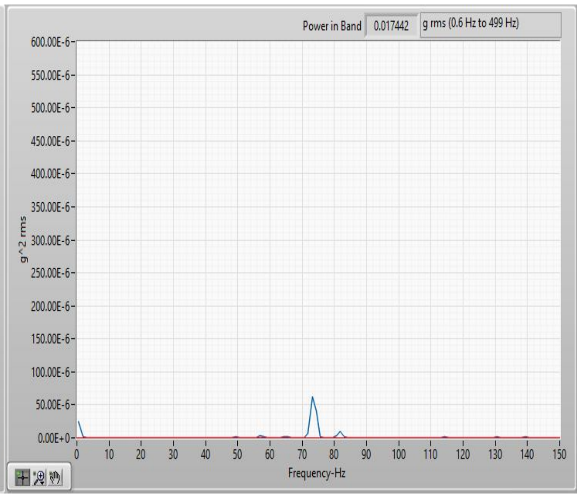


Fig 7(b): H signal at 400rpm and 25g unbalance

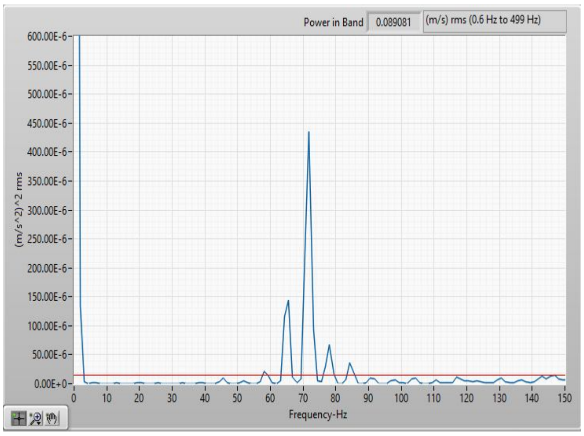


Fig 7(c): OR1 signal at 400rpm and No-Load

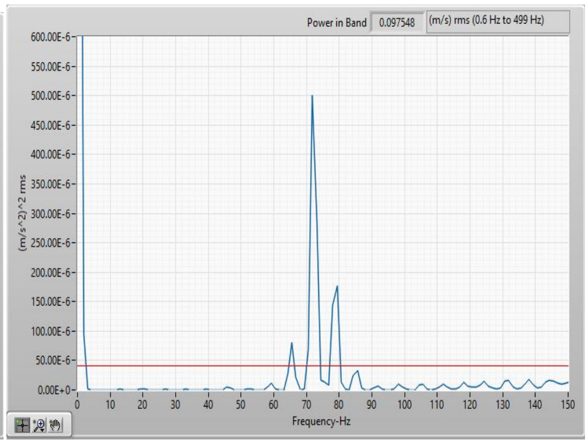


Fig 7(d): OR1 signal at 400rpm and 25g unbalance

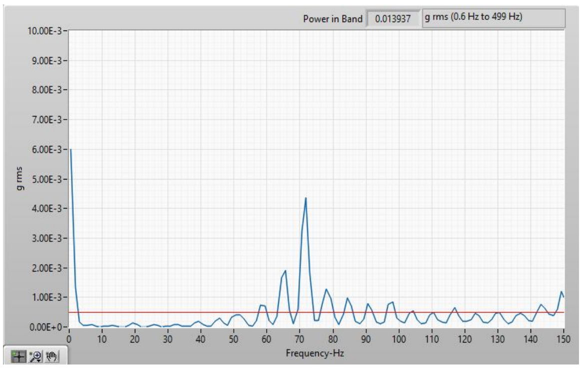


Fig 7(e): OR2 signal at 400rpm and No-Load

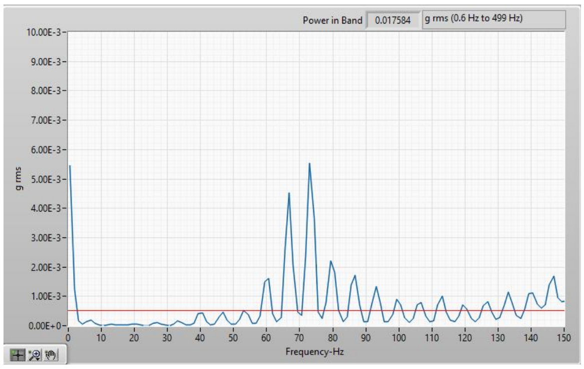


Fig 7(f): OR2 signal at 400rpm and 25g unbalance

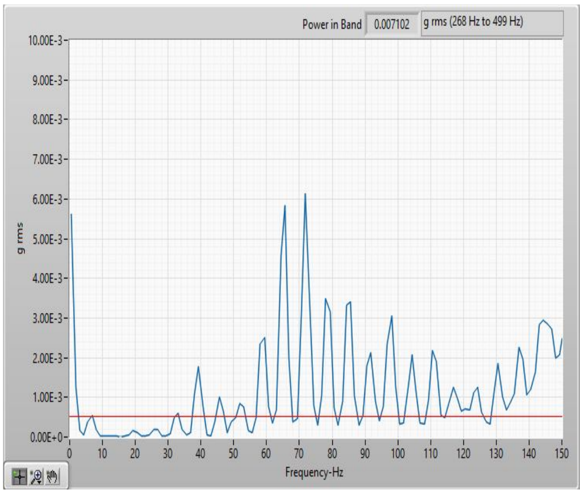


Fig 7(g): OR4 signal at 400rpm and No-Load

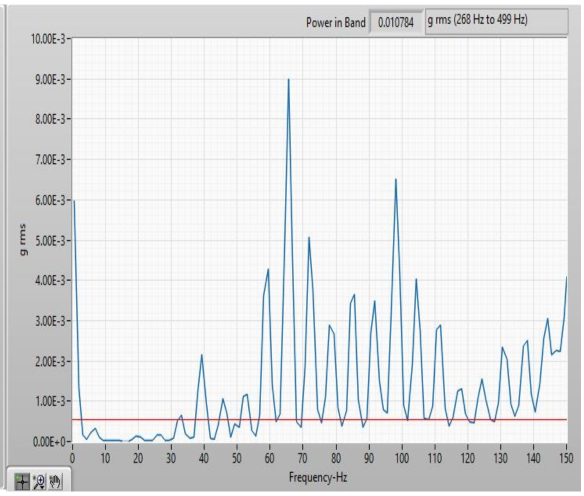


Fig 7(h): OR4 defect signal at 400rpm and 25g unbalance

Fig 7 shows the FFT signals for healthy and defective bearings at400rpm, for both no load condition and for an eccentric load of 25gms. It can be observed from the plots that in all the cases, peak amplitude is exciting around 70Hz which is close to the first natural frequency of 78Hz as observed from FRF analysis, this can be attributed to excitation of the system by harmonic of BPFO(≈20Hz) of the bearing. Also the peak amplitude is observed to increase drastically at the same frequency with the increase in number of defects. Further, number of sidebands spacing with shaft frequency are observed in case of defective bearings. Number of sidebands are also found to increase with number of defects which is a clear indication of presence of defect in the bearing. Thus the results of FFT signals are useful in identifying the quantum of defect in a bearing, while in operation.

IV. CONCLUSIONS

An attempt is made in the present work to study the vibration response of the rotating system having defective rolling element bearings. The study also aims to recognizing the presence of defect in the system using vibration signals emanuated.
The following conclusions are drawn from the present work.

A. There is distinct rise in the RMS values of the signal with increase in the number of defects, which can be helpful in identification of defects.
B. FFT signals indicate the rise in amplitude of signals at first natural frequency of the system, due to excitation by harmonics of BPFs. The sidebands present around these frequency , their number and amplitudes, are also indication of presence of defect in the bearings.

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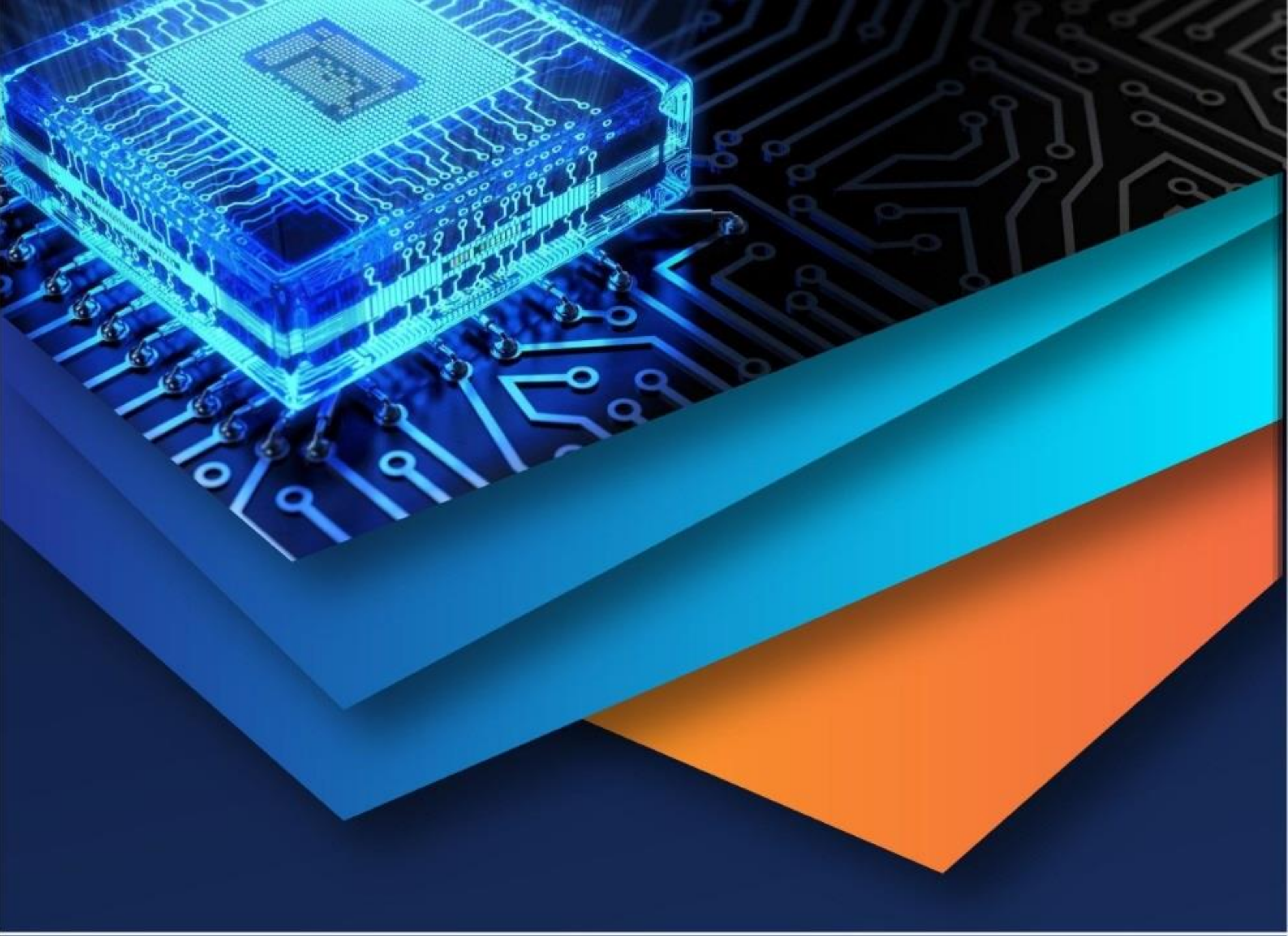

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