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Experimental Analysis and Mitigation of Soft Foot in Induction Motors

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Abstract: ***In a power plant pump and motors are the critical assets, pumps and their driving motors serve as vital components for efficient, continuous operation. Pumps transfer fluids across critical systems such as feedwater, condensate, cooling, lubrication, fuel, and ash/slurry handling. A major reliability concern in such high-power rotating machinery is excessive vibration, often stemming from misalignment and foundational issues this causes the secondary damage and catastrophic failure of the equipment.***

One prevalent cause is "soft foot" this is the condition where one or more motor feet do not sit flat on the base, different soft foot cause the different effects on machine like stator distortion and eccentricity, rotor issue like rotor bar loose, motor air gap issue and bearing misalignment leading to machine frame distortion. This can result in increased vibration, bearing wear, and even rotor-stator misalignment in electric motors. A detailed investigation into high vibration and noise from the service water pump motor revealed dominant 2X line frequency components, which is typical soft foot condition causing distortion in rotor and stator and its eccentricity indicative of electrical imbalance caused by soft footing. Blue matching and phase analysis confirmed soft foot presence which was found up to 0.65 mm during physical measurement through filler gauge, contributing to rotor-stator eccentricity and magnetic force imbalance. After corrective measures including proper blue matching, shimming, alignment, and foot surface correction, vibration levels reduced significantly from 12.8 mm/s to 0.8 mm/s. This case study highlights the critical role of soft foot detection and correction in ensuring machine reliability, especially in high-power electrical motors.

Keywords: Soft foot, Stator distortion, Eccentricity, Stiffness,Motor air gap, Blue matching, Magnetic force imbalance,Bearing misalignment.

I. INTRODUCTION

The Hindalco Mahan plant operates a captive power facility comprising six units of 150 MW each, dedicated to providing a continuous power supply to the smelter. Machine alignment is the act of making sure the moving parts of a machine, like rotating shafts, are properly lined up with each other, It refers to the process of positioning moving components—especially rotating shafts—so that they are correctly aligned with one another, High vibration in rotating machine is major concern, High vibration in machinery or structures due to soft footing is a common issue that can cause operational inefficiency, equipment damage, or even structural failure over time. Let's break down what's happening and how you can address it.

Soft foot refers to a condition where the machine does not sit evenly on all its mounting points. This uneven support can also be described as machine frame distortion This is a term we often use when we talk about shaft alignment. In fact, you must always perform a soft foot check before the actual alignment work can start; it is an essential part of securing a reliable installation. Let's go through the different types of soft foot and why they occur, why do we need to check and correct soft foot? Can it be that big a problem if there is a tiny gap underneath one machine foot or a little pile of dirt under another? Well, yes. Because if the machine is not standing perfectly flat on the machine base, you can (and most likely will) run into problems such as shaft deflection, increased vibrations, bearing failure – and, in the end, machine breakdown. And that will be a lot more expensive than fixing the soft foot problem in the first place! Luckily, all Easy-Laser shaft alignment systems come with a program for soft foot check that tells you which feet you need to adjust and how much.

We can take the example of chair which four foots are not equal one foot is not touching to ground in normal condition this gap creates the soft footing condition in chair like this this happens in the machine which having 4 nos legs of base frame any uneven gap in any foot creates this condition and responsible for many other condition and problems in machine.

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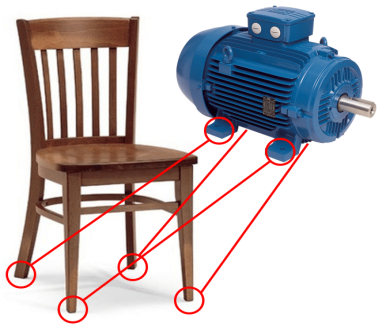

Fig-1: Soft foot(chair vs motor)

Common causes of soft foot
A combination of the following generally causes soft foot:
Twisted, bent or warped frame or base plate
Uneven or damaged foundation
Twisted, bent, dented or damaged machine feet
Too many shims under a foot
Bent or deformed shim
Dirt or debris under the feet
There are four types of soft foot which all have one thing in common

A. Parallel soft foot

Parallel soft foot means that not all four feet are on the same plane. Think of a wobbly table at a restaurant, where you can rock it back and forth. In this case, the laser system software will show high readings (>0,05 mm) for soft foot at opposite corners. With a feeler gauge, you can determine which foot or feet you need to shim and how much.

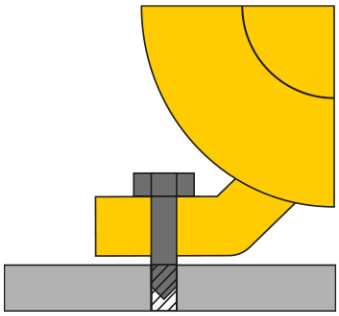

Fig-2: Parallel Soft footing

There are three possible reasons for parallel soft foot:

- When the leg is too short.
- When base plate or mounting pads are not coplanar.
- Shims under one or more feet missing.

For correction of parallel soft foot, you add enough shims to remove the rocking effect (use as few as possible, and no more than four shims).

B. Angled soft foot

This is a common type of soft foot that occurs when the foot's bottom is at an angle relative to the base. In this case, the laser system will show a high soft foot reading at three or four feet. The foot with the highest soft foot reading will show a tapered air

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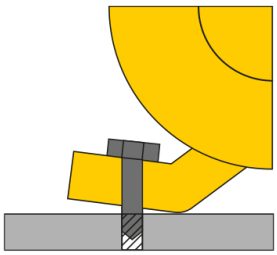


Fig-3: Angled soft foot

gap from one corner of the foot to another.

There can be several reasons for this condition, for example:

- If machinery has been dropped or roughly handled.
- When base plates are bent or poorly machined.
- There's a severe vertical angular misalignment.
- If the feet are welded.

C. Squishy foot

Squishy foot is sometimes also known as spring foot. With squishy foot, the feeler gauge won't detect any gap underneath the foot. Instead, the problem is usually that the space between foot and base is filled with too many shims from a previous attempt to fix soft foot. There may also be a build-up of other unwanted material such as dirt or rust under the foot.

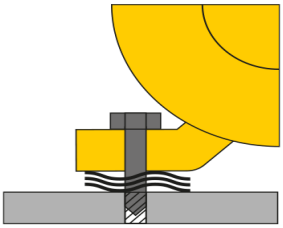


Fig-4: Squishy foot

Reasons for squishy soft foot may be:

- This due to Dirt, grease, paint, or rust between the foot and the base.
- If using too many shims (we should not use more than four shims per foot).
- Bent shims.
- Shims with burrs or thread marks.

To get rid of this problem you need to thoroughly clean the area around and underneath the foot, and replace old shims with new, crush-resistant ones.

D. Induced soft foot

Induced soft foot is caused by external forces that affect the machine frame, and it can be hard to detect. The laser system will indicate more than one soft foot, usually on the same side or the same end of the machine. The feeler gauge will find a gap, usually parallel or nearly parallel.

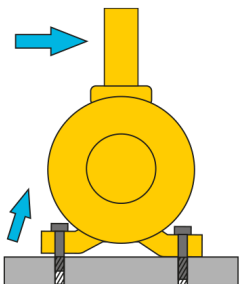


Fig-5: Induced soft foot

1) Soft footing issues in electrical motors

Soft foot in an electric motor, a condition where the mounting feet are not all level on the base, can cause significant issues.

It leads to stator It leads to stator distortion, which can create unbalanced magnetic forces between the rotor and stator there are some problems associated in electrical motors.

2) Stator Distortion and eccentricity

Soft foot causes the motor frame to distort, twisting the stator. This distortion affects the magnetic field, creating unbalanced magnetic forces between the rotor and stator.if the motor frame is distorted, it can cause the stator to deform eccentrically, or to position the rotor eccentrically. This will typically cause electrically-related vibration at 2x line frequency (120 Hz in the US), because the rotor.

3) Rotor Issues

The uneven magnetic field can induce vibrations and potentially lead to rotor damage or even rotor-to-stator contact in extreme cases.

4) Air Gap Issues

Soft foot can also affect the rotor's air gap, which is the space between the rotor and stator. Uneven air gaps can lead to further magnetic imbalances and increased vibration.

5) Bearing Misalignment

If the soft foot in a motor is excessive, misalignment of the motor bearings can occur. This happens due to stator distortion, or "twisting" of the motor frame because of the soft foot. This distortion misaligns the end bells of the motor, and increases radial and axial loading of the bearings. Overheating is common.

6) Broken Feet, Broken Hold Down Bolts, or Loosening Shims

Excessive forces on the feet due to a soft foot condition can crack or break motor feet, or stretch bolts until they weaken or shear. Another common problem is shims which appear to "walk out" from under motor feet. This is usually thought to be because the bolt was not tightened, but is caused by the foot flexing, which tends to work the shim(s) out from underneath the foot.

Hindalco Mahan service water pump was having high vibration issue and heavy noise reported from motor side this motor sound was very high, so motor no load trial was taken even at motor no load condition vibration level was very high and sound was also coming from motor inside and high vibration amplitude at motor side was observed 12.8 mm/s in no load condition.

Motor coast down test was done in which motor vibration was observed during running 12.8 mm/s but as motor power was stopped this vibration immediately down to 1.5 mm/s which indicated the electrical issue with motor.

Fig-1(Service water pump)

Service Water Pump (Solo trial)

V_{rms}**(mm/s)**

	H.	V	A
Motor NDE	**10.6**	3.0	4.9
Motor DE	**12.8**	6.5	4.9

Table-1(Motor vibration at no load)

This issue was related to motor stator and rotor issue as per vibration spectrum analysis motor 2X line frequency was observed (100 hz) as shown in fig-1 and Fig-2.

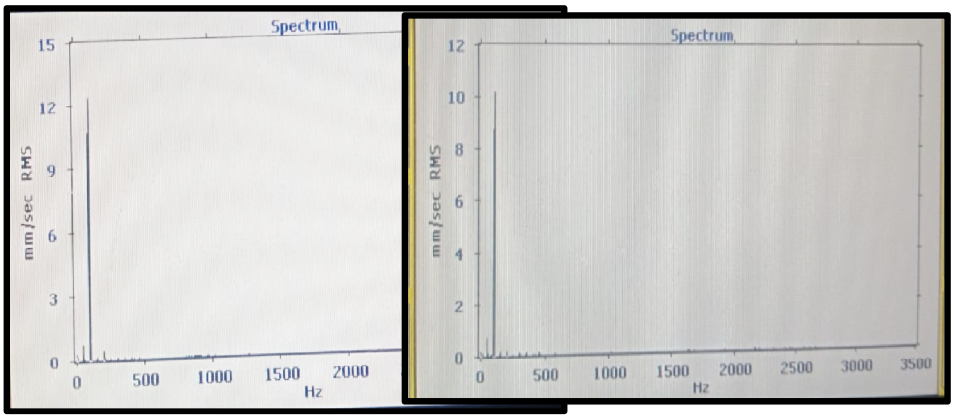


Fig-2(Motor DE side spectrum) Fig-3 (Motor NDE side spectrum)

This 2X line frequency many times observed in case of soft footing condition with equipment so equipment soft footing and blue matching was observed missed at some locations during inspection.

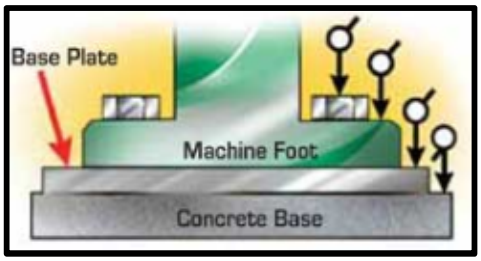


Fig-4 (Motor base vertical phase measurement)

Phase analysis showing 90 to 180 deg phase measurement between vertical measurements at bolts, motor foot, base plate and concrete base.

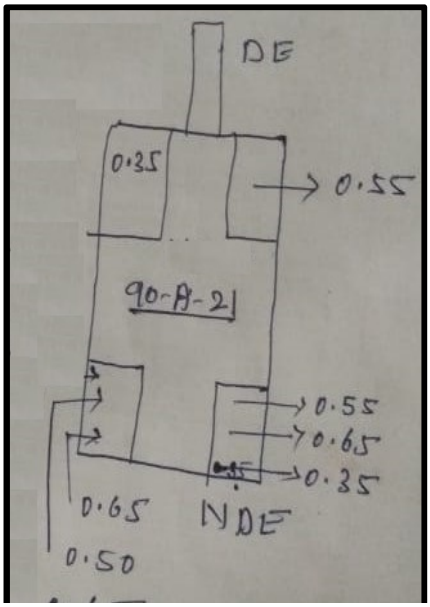


Fig-5 (Motor base blue matched readings)

Fig-6 (Motor all 4 foots blue matching)

As shown in Fig-4 and Fig-5 it is very clear that soft footing was inspected through blue matching of motor foot which is not accurate and is found out of limit at many location Max. blue matching out was observed 0.65 mm at 2 locations which was creating the heavy soft footing and due to this rotor and stator air gap become uneven and magnetic field become uneven resulting high vibration and noise at motor in no load condition.

Fig-7 (Master level of motor)

Master level atmotor foots and motor base was also observed out that was 0.8 mm.

II. METHODOLOGY

With vibration spectrum and signature analysis it was clear that 2X line frequency was dominant which is the indication of motor stator and rotor issue, During blue matching test blue matching was out 0.65 mm at 2 locations due to this soft footing was there and soft footing was reason for this rotor and stator condition.

During phase analysis at motor base it was 180 Deg and vibration at different foots was observed different which was the indication of severe misalignment and soft footing condition and causing the magnetic force imbalance in motor resulting high vibration and noise at motor side.

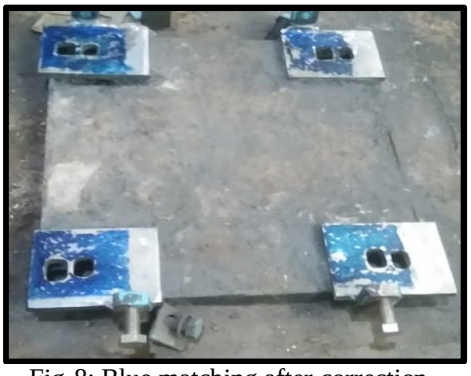


Fig-8: Blue matching after correction

Fig-9: Alignment work

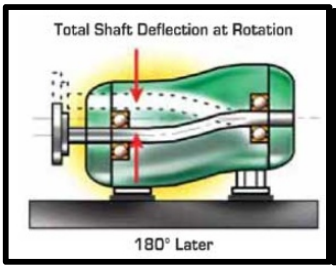
As shown in Fig-8 and Fig-9 blue matching was corrected and proper alignment was done.

- Factor influence the soft footing condition:

Uneven Mounting Surface
If the baseplate or foundation where the motor is mounted is not flat, one or more feet may not make solid contact.
Weld splatter, corrosion, or debris under the feet can also cause unevenness.
Motor Foot Deformation
Motor feet may be bent during shipping, handling, or installation.
Cast iron feet are particularly prone to cracking or deformation under stress.
Improper Shimming
Incorrect or inconsistent use of shims when levelling the motor can result in soft foot.
Over-tightening bolts without proper shimming can bend the motor frame.
Thermal Expansion
Unequal heating and expansion of the motor and base (especially in large motors) can cause a temporary or permanent soft foot condition.
Improper Grouting or Base Preparation
Concrete bases that have not cured properly or lack solid grouting can settle or deform under load, affecting motor alignment.
High Vibration and stress due to Operation
Long-term exposure to vibration can loosen bolts or shift the motor, introducing soft foot over time.
Machine Tolerances
Some motors may leave the factory with slight discrepancies in foot heights due to casting or machining variances.

- Why Soft footing causes High vibration and Noise in electrical motors:

Soft foot is the condition in motors when the feet of the machines and the platform they are mounted on are not on the same plane
In electric motors, soft foot distorts the frame, which in turn can distort the stator magnetic field. This creates unbalanced electrical forces between the rotor and the stator magnetic field this unbalance force between rotor and stator causes high vibration and heavy noise this unbalance force is due to uneven air gap because rotor centre line and stator centre line does not coincide as shown in fig-10 and Fig-11.



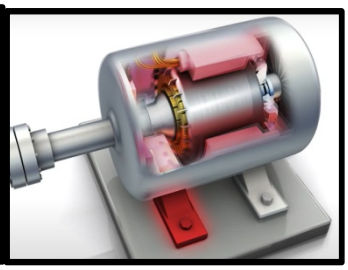


Fig-10 (Rotor shaft deflection at rotation) Fig-11(Uneven Air gap and magnetic field)

This is the reason why soft footing causes distortion in rotor, unbalance magnetic field, Air gap and heavy noise.

III. RESULTS

After correcting the soft footing condition and proper blue matching as shown in Fig-8 vibration level reduces from 12.8 mm/s to 0.8 mm/sec at motor DE side and 10.8 mm/s to 1.8 mm/s at motor NDE side location.
The high noise observed from motor inside become normal so equipment overall health condition improved from critical to Normal.

After correction, vibration readings were Normal-
Service Water Pump(Solo trial)

	V_{rms} (mm/s)		
	H.	**V**	**A**
Motor NDE	**1.8**	1.9	1.9
Motor DE	0.8	1.8	1.9

Table-2 (Vibration readings after correction)

This shows that soft footing is very critical for equipment reliability there are several techniquees which can resolve this problem with correction that is laser alignment technique which is powerful tool for resolving these types of problems.

IV. CONCLUSIONS

The reliability issues at Hindalco's Mahan plant clearly show that soft foot—a condition where one or more motor feet fail to fully contact the base—poses a major threat to high-power rotating machinery. Symptoms such as increased 2× line frequency vibration, stator and rotor distortion, bearing misalignment, and frame deformation are all classic indicators of soft foot
Blue matching, phase analysis, and filler-gauge measurements (showing up to 0.65 mm foot lift) confirmed the presence of soft foot. These were strongly correlated with diagnostic signals: notably a dominant 2X electrical frequency peak and mechanical vibration—hallmarks of eccentric stator–rotor interaction and magnetic force imbalance Following corrective alignment—blue matching, shimming, bolt torque control, and foot surface correction—vibration dropped dramatically from 12.8 mm/s to 0.8 mm/s (According to ISO10816), underscoring the effectiveness of the intervention.
By addressing the root mechanical issue of soft-footremoving foot imperfections, ensuring proper blue-matching, and aligning the shafthe root cause of vibration and noise in the service water pump motor was eliminated. This restored motor health, extended bearing and rotor life, and prevented costly downtime. Ensuring proper footing and alignment is critical to reliable motor operation in industrial power plants.

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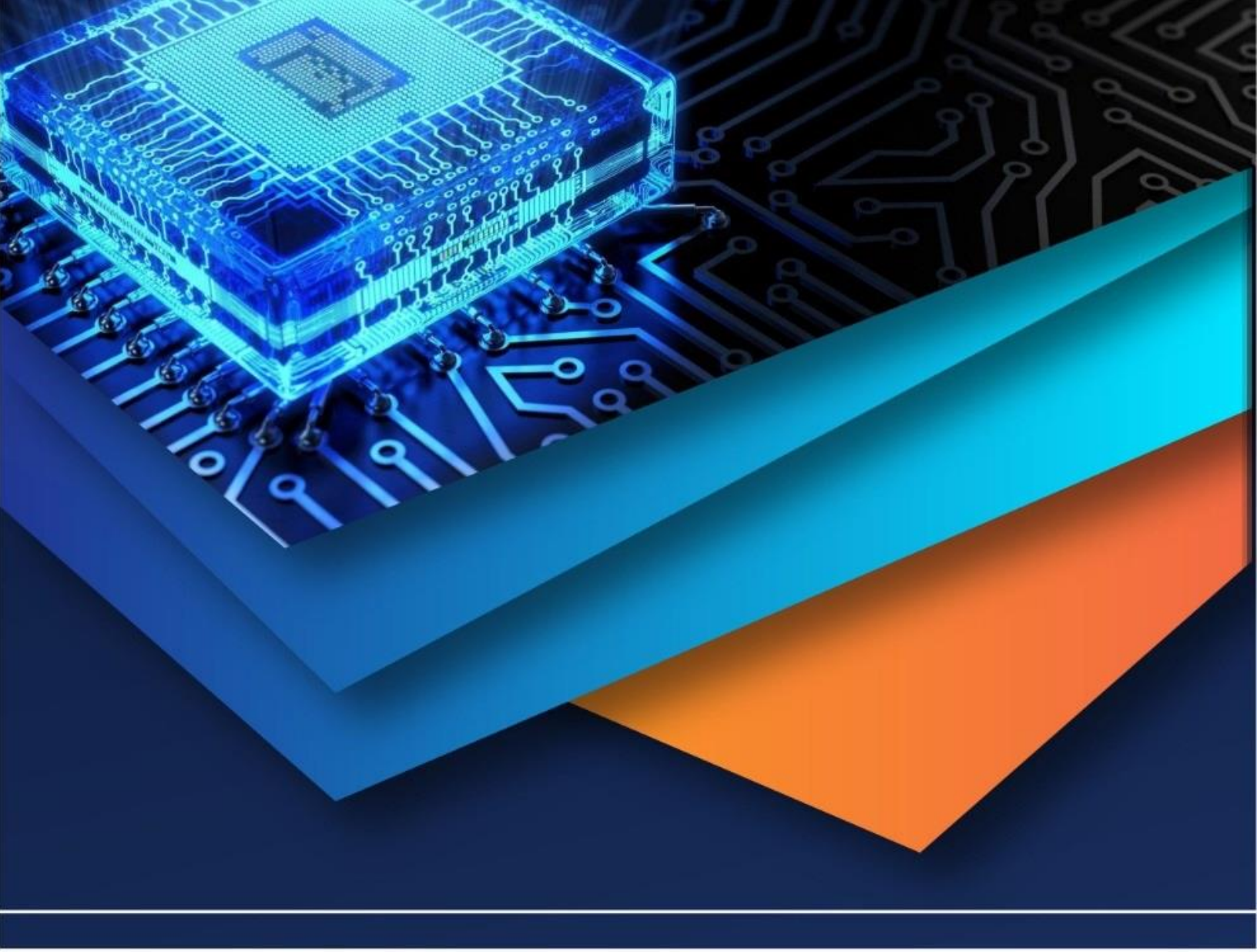

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