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Design and Development of Particle Friction and Impact Damping for Spur Gear Drive

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Abstract: ***Gear transmission system plays an important role in many of the mechanical systems. Vibration is the major problem and unavoidable in gear transmission system because high speed and heavy loading condition. High temperature and harsh working condition limits the other vibration absorption methods. Particle friction & impact damping is passive method of vibration absorption. Ordinary particle damping method gives the random movement of particles. In this research holes are provided to the gear and put cylindrical impact particles in particular hole gives the friction and impact effect to absorb the vibration. The mathematical analysis is formulated for the system also run MATLAB program and found out plot for displacement v/s time. DEM simulation carried out using EDEM software which is used to perform simulations at different speed and to analyze the energy dissipation during particle collisions and compared the energy absorbed by the particles of different materials for varying speed.***
Keywords**:** ***Impact damping, gear transmission, vibration absorption, DEM simulation***

I. INTRODUCTION

Vibration is the major problem of most of the mechanical engineering applications and there are different methods to control vibration. For attenuating the resonant vibrations of system Active and passive damping techniques are used. Passive vibration control systems function without external supply source, e.g., they do not require a power source, simply because they are driven by the vibration itself. In most cases, they offer the cheapest and simplest solution to the problem. They require less or no maintenance, and installation is relatively very simple [5]. Active vibration control systems are mostly more complicated and expensive than passive systems, require more maintenance, and there is a higher possibility of failure. There are several passive damping techniques such as friction devices, viscoelastic materials applications, tuned dampers, isolators, impact dampers. However, performance of all above damping methods depends on operating temperature. Viscoelastic materials are used for increasing damping in structures. However, they lose their effectiveness in low and high temperature environments and degrade over time period. Hence there is a need of damping mechanism which can operate in harsh environment for a long period of time [3]. Particle impact damping offers the potential for the design of an extremely robust passive damping technique with minimal impact on the strength, stiffness and weight of a structure. With a proper choice of particle materials (for example: copper, steel, aluminium etc.). This technique is essentially independent of temperature [4].

II. METHODOLOGY

In particle damping method holes are provided to the structure then put the particles into it and finally seal pack the hole. Vibration absorption using particle damping work on principle of friction between particle-particle and particle- internal casing of the hole and impact of particles at extreme ends of the hole. Hence, both the combination of friction & impact absorb the vibration of the structure [1]. Vibration is major problem in a 'Gear transmission system'. In case of gear system, the vibration transfer path is as follows: 'Gear teeth surface- holes in gear- Shaft- Bearing'

As gear transmission need to work on high-speed, heavy-duty, and high-reliability, more severe demands for the dynamic performance of the gear transmission are put forward. The main source of the noise for most machinery and equipment is vibration of the system Therefore, to find out how to control the vibration and noise of gear transmission will play a significant influence on the performance, precision and life of the machinery, the protection for operators [2]. After study number of research papers in same field it is understood that ordinary particle damping concept using the method in which they put number of small particles into the single big hole for dissipation of vibration energy. This method gets better effect in vibration absorption but the major drawbacks is as they put number of small particles in single hole makes random behavior or movement of the particles & it is very difficult to predict particular movement of particles that's the reason that in every research paper every author use trial and error method only, Means changing the materials of particles & changing the size of the particles.

Rather than using single hole with multiple particles it is provided that number of small cylindrical holes having same diameter as particle diameter. As we get friction effect between particle & internal casing of hole and impact effect at the extreme ends of the hole. One of major advantage of this method is single cylindrical particles move in the particular hole. Therefore we can get particular mathematical analysis, software analysis and can predicted the material for particular frequency of vibration.

A. *Design of Gear*

The proposed work is regarding vibration absorption using particle impact damping in gear transmission system. Hence, it is required to select all the parameters of gear pair. These parameters used to design proper gear pair which further used for software simulation. For designing the gear pair it is required to specify some input parameters, electric motor having power 1HP has been selected.

Motor speed = 1500 rpm, Central distance = 120 mm, Shaft diameter = 30mm

Table 1: Gear pair design parameters of model 1

Parameters	Driving gear	Driven gear
Material	Stainless steel	Stainless steel
Module	4 mm	4mm
Number of teeth	30	30
Diameter	120	120
Pressure angle(degree)	20	20
Tooth width	40 mm	40 mm

B. *Arrangement of Particles & Gear with Hole*

It is seen into the fig.1 that the 6 number of cylindrical particles which will insert into the holes provided into the gear. Therefore total 12 holes on gear pair. After seal pack of holes, cylindrical particles move in particular hole & absorb the vibration.

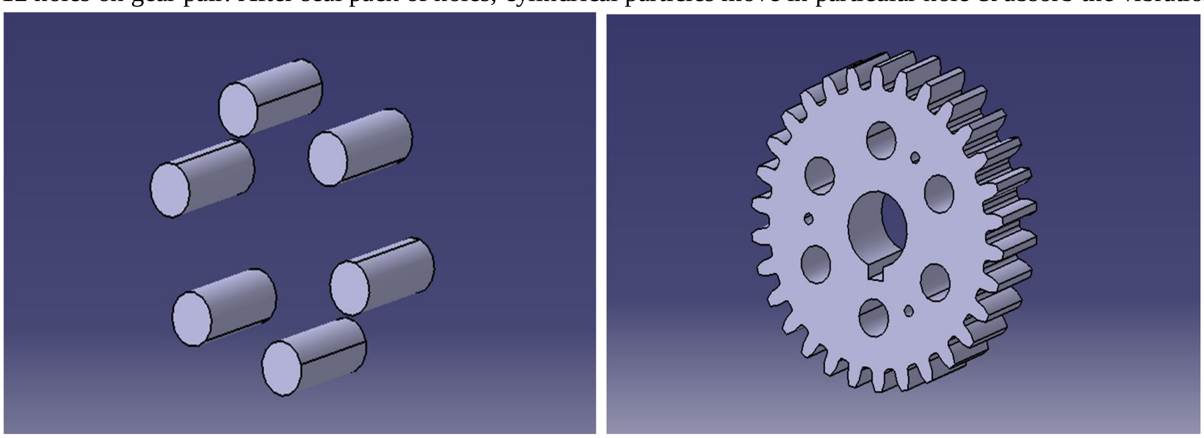


Fig.1 Arrangement of particles with the holes

C. *Mathematical Analysis*

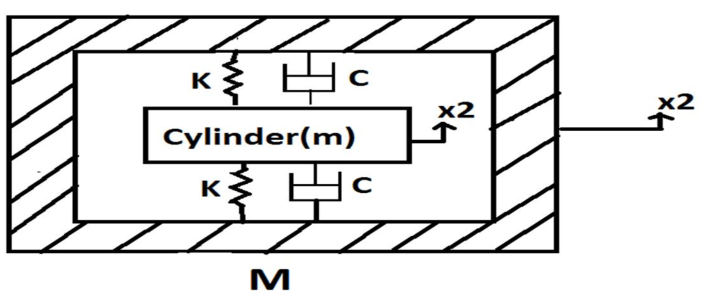


Fig.2 Spring mass damper system

Here,
m = Mass of the cylindrical particle M = Mass of the gear
According to the principle of momentum for impact between the particle & gear

$$\mathrm{mu}_1 + \mathrm{Mu}_2 = \mathrm{mv}_1 + \mathrm{Mv}_2 \qquad (1)$$

We know the coefficient of restitution

$$\alpha \mathrm{u}_2 - \alpha \mathrm{u}_1 = \mathrm{v}_1 - \mathrm{v}_2 \qquad (2)$$

Divide equation 1 by 'm' we get

$$\mathrm{u}_1 + \frac{\mathrm{M}}{\mathrm{m}}\mathrm{u}_2 = \mathrm{v}_1 + \frac{\mathrm{M}}{\mathrm{m}}\mathrm{v}_2$$

Let's consider, $\mu = \frac{M}{m}$ we get,

$$\mathrm{u}_1 + \mu \mathrm{u}_2 = \mathrm{v}_1 + \mu \mathrm{v}_2 \qquad (3)$$

Solving equation 2 & 3 we get,

$$\mathrm{v}_2 = \left(\frac{1+\alpha}{1+\mu}\right)\mathrm{u}_1 + \left(\frac{\mu-\alpha}{1+\mu}\right)\mathrm{u}_2$$

Putting above value in equation 2
We get,

$$\mathrm{v}_1 = \left(\frac{1+\alpha}{1+\mu} - \alpha\right)\mathrm{u}_1 + \left(\frac{\mu-\alpha}{1+\mu} + \alpha\right)\mathrm{u}_2$$

For impact of the two particles via discrete element method, the force among the particle is based on contact behaviour.
According to the Hertz contact theory,
Contact force between cylindrical particle & internal wall of hole is

$$f_n = k_n \delta_n + 2\xi\sqrt{m k_n}\,\dot{\delta}_n$$

Elastic coefficient of contact is given as

$$K_n = \frac{4}{3}\sqrt{r_i}\,\frac{E_i E_w}{(1-\mu_w^2)E_i + (1-\mu_i^2)E_w}$$

Here, E_i & E_w are the young's modulus and μ_i & μ_w are the poisons ratio cylindrical particle & gear respectively
Damping coefficient can be taken as

$$C_n = \alpha\sqrt{m_i K_n}\,\delta_n^{\frac{1}{4}}$$

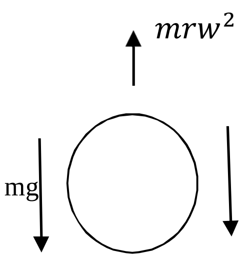
Where, δ_n = normal relative displacement between the particles
n= unit vector from centre of the particle towards the wall.
In case of contact between cylindrical particle & inner casing of the hole the normal displacement can be expressed as

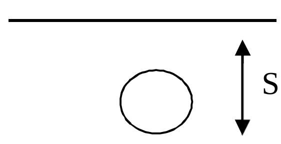
$$\delta = r_i - d_i$$

Where, r_i= Radius of the cylindrical particle
d_i= Distance between particle & inner surface of cavity
The tangential component of force can be expressed as

$$f_t = -\mu f_{nij}\frac{|U_t|}{U_t}$$

U_t= Relative velocity in tangential direction
According to Newton's law of motion,





$$mrw^2 = \mathrm{mg} + \mathrm{ma}$$
$$\mathrm{a} = rw^2 - g$$

Where, r = distance of mass from centre of rotation of gear

We know, $V^2 = U^2 + 2as$

$V = u_1 = \dot{y}$

Initially $U = 0$

Therefore $\dot{y} = u_1 = \sqrt{2as}$

Here, we have considered the relative displacement between M & m.

$$x_2 - x_1 = y$$
$$\dot{x}_2 - \dot{x}_1 = \dot{y}$$
$$\ddot{x}_2 - \ddot{x}_1 = \ddot{y}$$

According to the Newton's second law of motion

$$\dot{m}\ddot{y} = \sum f$$
$$m\ddot{y} + C\dot{y} + ky = f_n$$
$$m\ddot{y} + \frac{C}{m}\dot{y} + \frac{k}{m}y = \frac{f_n}{m}$$

It is a non-homogeneous second order differential equation & its solution is

$$y = y_{comp} + y_{part}$$

Solution for y_{comp} is

$$m\ddot{y} + \frac{C}{m}\dot{y} + \frac{k}{m}y = 0$$
$$D^2 + \frac{C}{m}D + \frac{k}{m} = 0$$

Roots of the equation becomes

$$m_1, m_2 = -\frac{C}{2m} \pm \sqrt{\frac{C^2}{4m^2} - \frac{k}{m}}$$

Then equation becomes,

$$m_1, m_2 = -\xi w_n \pm \sqrt{(\xi w_n)^2 + (w_n)^2}$$

Consider under damped system

$$m_1, m_2 = -\xi w_n \pm w_n\sqrt{1-\xi^2}i$$

We know, Damped natural frequency

$$w_d = w_n\sqrt{1-\xi^2}$$
$$m_1, m_2 = -\xi w_n \pm w_d\, i$$
$$y = e^{-\xi w_n t}(A\cos w_d t + B\sin w_d t)$$

Applying boundary conditions

At t=0 $y = y_0$

$$\dot{y} = \dot{y}_0$$

Put $y_0 = A$

$$\frac{dy}{dt} = -\xi w_n e^{-\xi w_n t}(y\cos w_d t + \mathrm{B}\sin w_d t) + e^{-\xi w_n t}(-y_0 \sin w_d t + B\cos w_d t)w_d$$
$$\left|\frac{dy}{dt}\right|_{t=0} = \dot{y}_0$$
$$\dot{y}_0 = -y_0\xi w_n + Bw_d$$
$$B = \frac{\dot{y}_0 + y_0\xi w_n}{w_d}$$

Equation becoming,

$$y_{comp} = e^{-\xi w_n t}\left(y_0\cos w_d t + \frac{\dot{y}_0 + y_0\xi w_n}{w_d}\sin w_d t\right)$$

$$y_{part} = Ye^{w_n t}$$

Where,

$$Y = \frac{f_n/k_n}{\sqrt{\left(1-\left(\frac{w}{w_n}\right)^2\right)^2 + \left(2\xi\frac{w}{w_n}\right)^2}}$$

$$y(t) = e^{-\xi w_n t}\left(y_0 \cos w_d t + \frac{\dot{y}_0 + y_0 \xi w_n}{w_d}\sin w_d\, t\right) + \frac{f_n/k_n}{\sqrt{\left(1-\left(\frac{w}{w_n}\right)^2\right)^2 + \left(2\xi\frac{w}{w_n}\right)^2}} e^{w_n t}$$

This is the equation for response of the system for particle friction and impact damping. Fig.3 shows the plot of displacement vs time using MATLAB and it is seen that as time increases the amplitude of the vibration goes on decreases for the system.

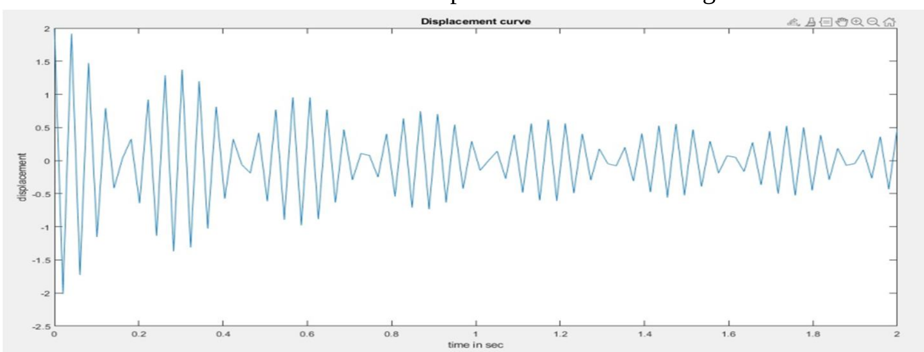


Fig.3 Displacement vs time curve using MATLAB

III. DEM SIMULATION

The discrete element method precisely includes discrete approach which has abilities to numerically calculate finite particle displacements and automatically perform contact detection for an assembly of particles. Using contact detection algorithms and suitable contact models, DEM simulations are capable of calculating forces acting on particles. Velocities, Accelerations and positions are then computed using Newton's laws of motion and numerical integration.

EDEM is one of the state of art discrete element modelling technology. EDEM simulation software simulates process and analyses the behaviour of particles such as mined ores, tablets and powder. EDEM have features such as it simulates any material, any shape.

A. Formulation of Cylindrical Shape Particle

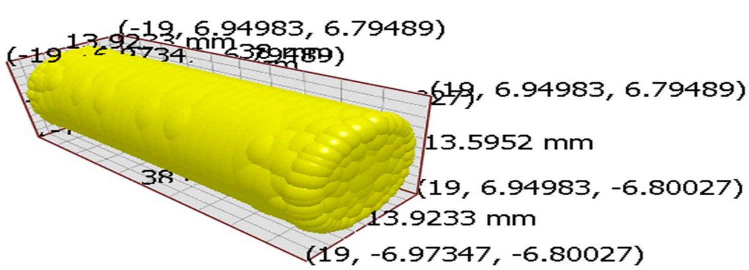


Fig.4 Cylindrical shape created by multiple ball particles

Fig.4 shows the cylindrical shape particle made from multiple small spherical balls. In EDEM software only spherical shaped particles are default are available. If different shape particles required then first import cad file of shape then after following certain steps the required shape get formed.

B. Simulation of the System

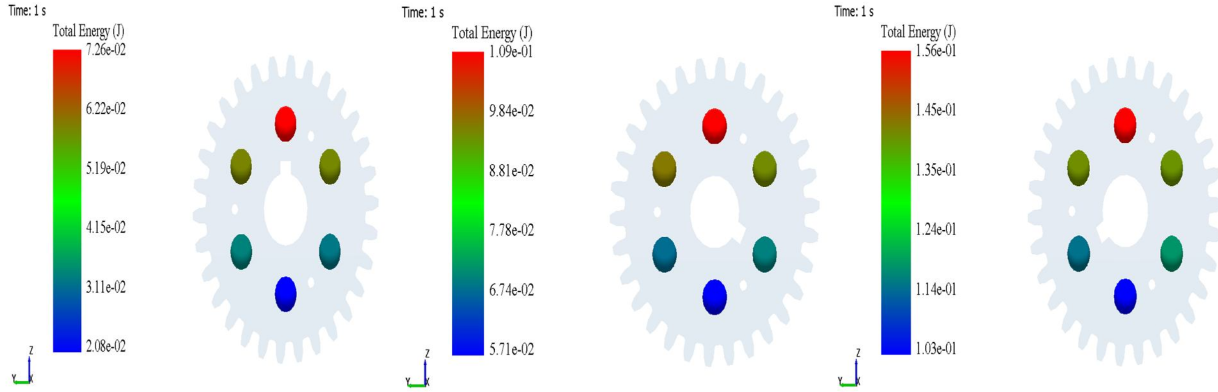
For simulation purpose three materials selected on the basis of material properties and the literature studies - 1) Steel 2) Copper 3) Aluminium

For research work the test setup run on three rpm

1)300 rpm 2) 400rpm 3) 500rpm

Simulation run for all above materials for varying speed is as follows

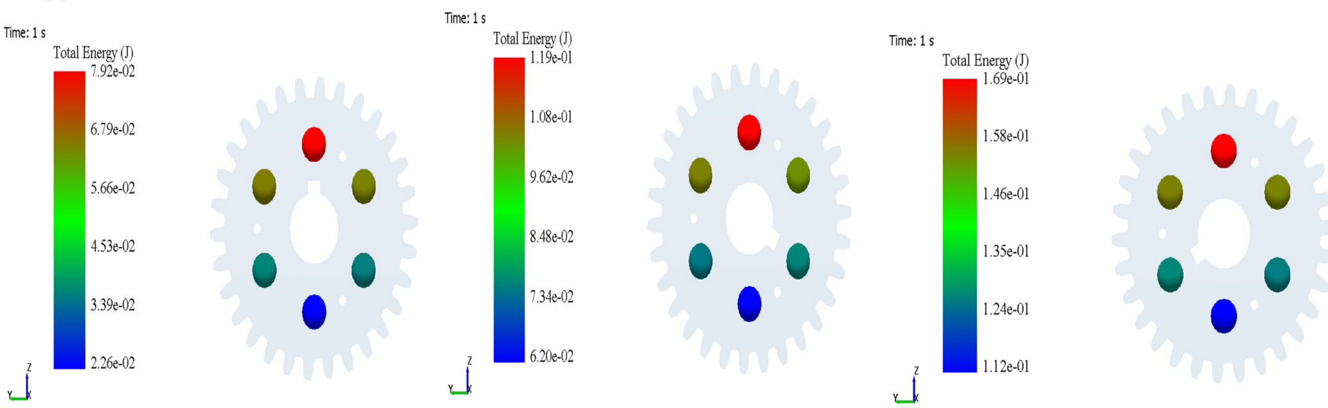
1) Steel



300rpm 400rpm 500rpm

Fig.5 Total energy absorbed for steel

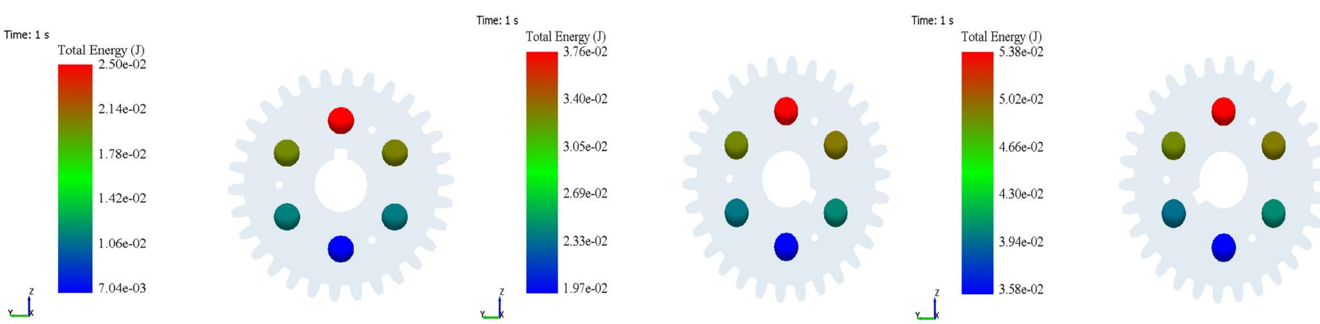
2) Copper



300rpm 400rpm 500rpm

Fig.6 Total energy absorbed for copper

3) Aluminium



300rpm 400rpm 500rpm

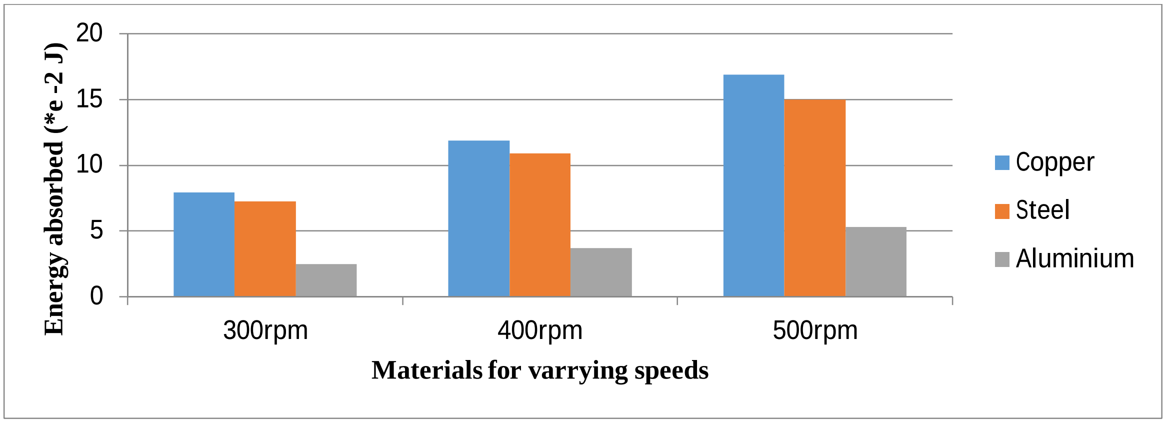
Fig.7 Total energy absorbed for Aluminium

IV. SIMULATION RESULTS

Table 2: EDEM simulation Results

Material of cylindrical particle	Density $\left({}^{kg}/{}_{m^3}\right)$	Viscous damping ratio	Energy absorbed (J)		
			300rpm	400rpm	500rpm
Steel	7800	2×10^{-4}	$7.26e^{-2}$	$1.09e^{-1}$	$1.5e^{-1}$
Copper	8960	10^{-3}	$7.92e^{-2}$	$1.19e^{-1}$	$1.69e^{-1}$
Aluminium	2700	0.5×10^{-4}	$2.5e^{-2}$	$3.76e^{-2}$	$5.38e^{-2}$

From above table It is seen that the energy absorbed by the system for steel is more than the aluminium and less than that of copper. The graphical representation of results is shown in below fig.8



V. CONCLUSION

A. Studied the approach of particle friction and impact damping for spur gear drive.
B. From the mathematical analysis and the displacement vs time curve, it is concluded that the vibrations of the system decrease using particle friction and impact damping. It gives better performance to absorb the vibration of the system.
C. From the results of EDEM simulation, it is observed that by selecting the material having more density and viscous damping ratio value gives the better damping effect. It means Steel have better damping effect than aluminium but less than copper.
D. With increase in the speed of rotation of gear pair, a simulation result shows that total energy dissipation increases.

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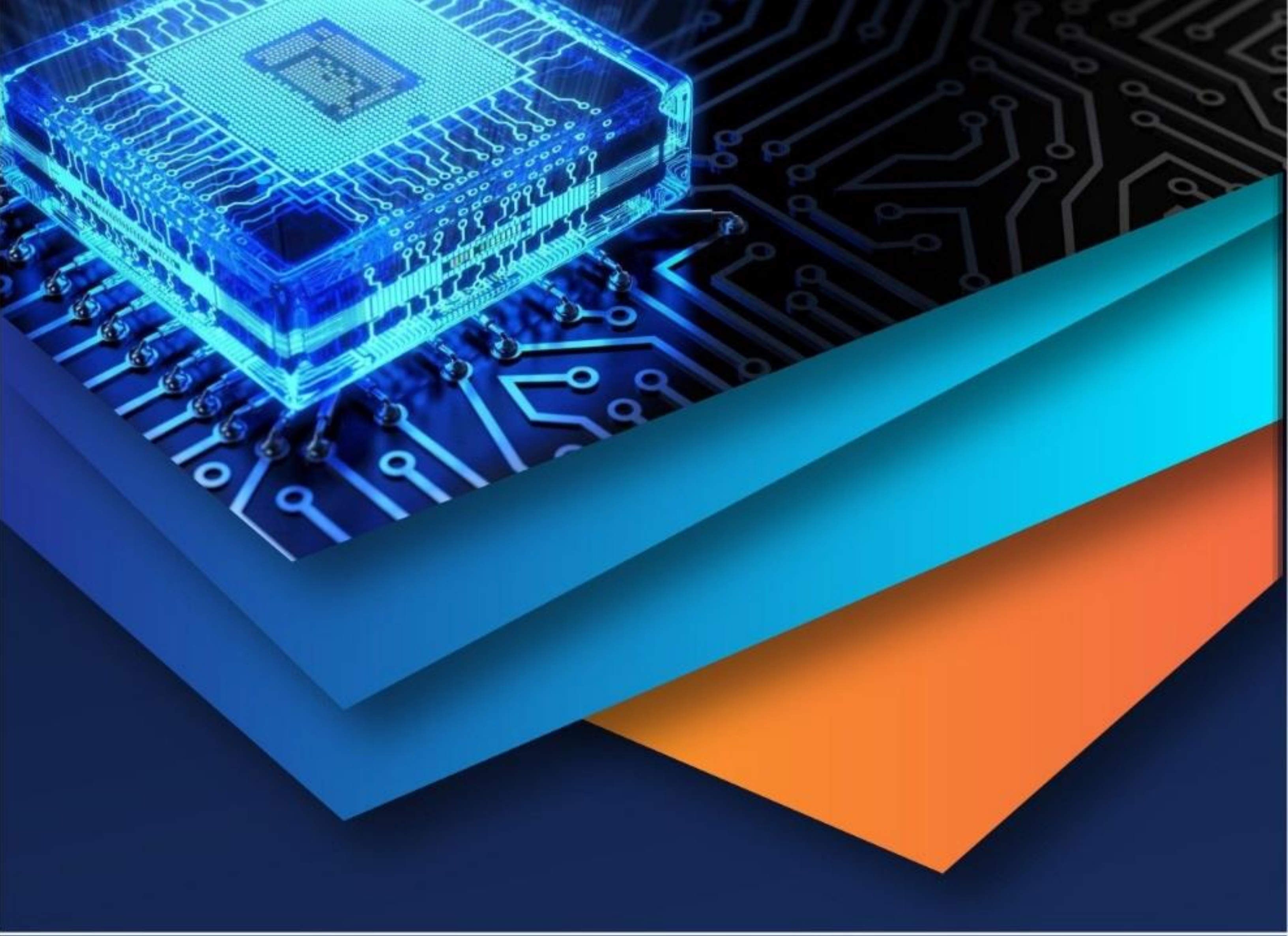

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