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Kickback Prevention Using Three Trigger Tooth Magneto System

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Abstract: Single cylinder engines which run in carburettors uses Electronic control unit to produce spark at variable desirable timing. Most of the present day single cylinder engines have magneto with single trigger tooth to sense the engine rpm/speed and to understand the position of the magneto. As the number of trigger tooth is only one, speed calculation and determination of engine piston position is not accurate and this leads to inaccurate determination of engine speed and reverse rotation of the piston in the engine under kickback/reversal condition. Proposed design address kickback issue and inaccurate speed calculation in the engine using three trigger tooth magneto system and control logic.
Keywords: Kickback prevention, Single cylinder engine, three trigger tooth magneto system, Electronic control unit, Reversal.

I. INTRODUCTION

Engine Reversal / Kick back is a serious issue in the two wheeler and three wheelers. Kick back or engine reversal is a phenomena where the engine struggles to rotate in forward direction during compression cycle and reverses. When kickback/reversal occurs, damage due to reversal impact which will occur on the starting system is huge. Sprag clutch or one way clutch, gears in the starting system and the starter motor will tend to damage and fail. This failures will increase the warranty cost of the components and reputation of the company/organization will be spoiled. The advancement in the microcontroller technology and the engine reversal issue which exists for a long time motivated to rethink on the need of the solution. Moreover advancements also help to detect acceleration and deceleration with minimum number of tooth in ACG. There are other solutions available to minimize/eliminate the reversal but with more no of tooth requirement in ACG. A new idea was proposed to resolve the issue with a minimum three number of trigger tooth[4] in the magneto/ACG and ignition system(alternator current generator) which has transistors to drive ignition coil. The proposed method is now extended with experiments and results.

II. SYSTEM MODEL

Ignition circuit consists of the components such as magneto, crank position sensor, Electronic control unit(ECU unit), throttle position sensor and battery as shown in Fig 1.

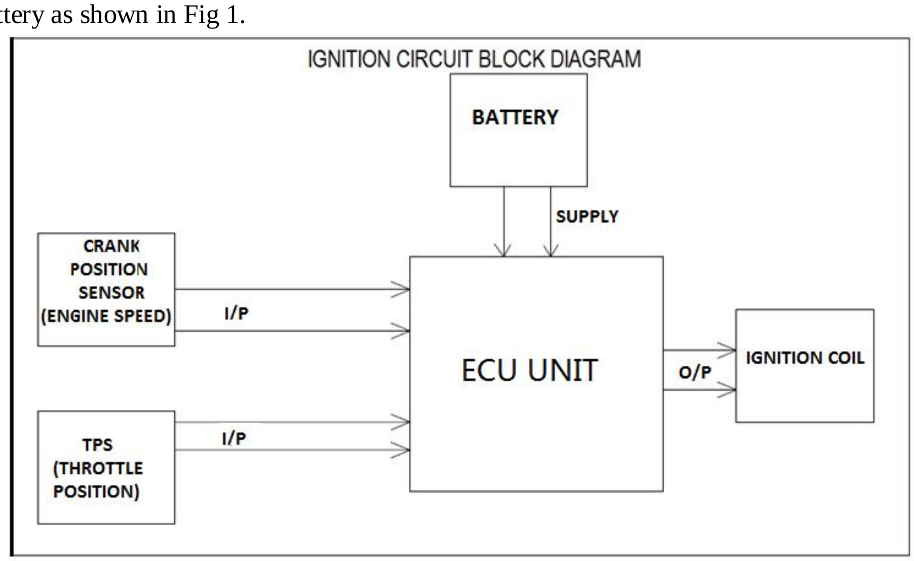

Fig 1 Ignition circuit block diagram

A. Magneto

Magneto or Alternator current generator generates ac power which would be converted to DC power and used for the electrical loads in the vehicle. In addition to the generation of electrical power it also helps in sensing engine speed. Magneto has rotor and stator, where the rotor rotates inline with engine speed and stator remains static. AC output power generated by the magneto is taken out from stator windings. Rotor surface of the magneto has trigger tooth and when the trigger tooth crosses the crank position sensor, voltage pulse is generated which inturn would be used to calculate engine speed.

B. Electronic Control Unit

Electronic Control Unit is used to calculate the ignition timing and take action as to how and when ignition shall occur. It takes input of engine speed and throttle position from crank position sensor and throttle position sensor respectively. ECU decides the ignition timing based on this two inputs and give signal to inductive ignition coil to produce spark. This spark is used to burn air-fuel mixture and run the engine.

C. Crank position sensor

Crank position sensor senses the engine rpm/speed by producing voltage pulses based on the number of trigger tooth available in the rotor. Crank position sensor is placed in such a way that trigger tooth of the rotor comes to close proximity during rotation. For any trigger tooth, positive and negative voltage pulse is generated when it crosses crank position sensor completely. During the rotation of the rotor, positive voltage pulse is generated when leading edge of trigger tooth crosses the crank position sensor and negative voltage pulse is generated when trailing edge of trigger tooth crosses crank position sensor. Crank position sensor works on reluctor sensor principle wherein the rate of change of flux occurs when the trigger tooth comes closer to sensor. Peak positive or negative pulse is generated due to buildup or decay of flux respectively.

D. Ignition coil

An ignition coil[3] is an inductive coil similar to a transformer that transforms the battery's 12Volts to thousands of volts needed to create an electric spark in the spark plugs to ignite the fuel. An ignition coil consists of a laminated iron core surrounded by two coils of copper wire for primary and secondary. The Primary winding has relatively few turns of heavy wire as compared to secondary and the secondary winding consists of thousands of turns of smaller wire, insulated from the high voltage by enamel on the wires. Voltage is stepped to thousands of voltage when the Electronic control unit drives the coil to charge and discharge. Primary of the ignition coil is energized by giving supply through Electronic control unit and the coil starts charging. By the time supply is stopped to primary of ignition coil, magnetic flux gets collapsed and induces huge voltage in the secondary of the coil which would be used to produce spark. The time to charge primary of the ignition coil is called dwell time.

E. Throttle position sensor

A throttle position sensor (TPS) [2] is a sensor used to monitor the throttle position of a vehicle. The sensor is usually located on the butterfly spindle/shaft so that it can directly monitor the position of the throttle.

III. POTENTIAL CAUSES FOR KICKBACK ISSUE

Kickback can be caused by [1]

1) Improper magneto to engine timing or improper internal magneto timing.
2) A magneto switch improperly set for starting.
3) Improperly functioning impulse couplings on magnetos.
4) Improper priming or throttle control.
5) Low battery voltage resulting in slow or sluggish starting RPM. The above causes can be eliminated by doing service and adjustments in the engine. However reversal during running or near idling speed need to be understood and eliminated by the proper method.

IV. OBSERVATION AND CHALLENGES OF KICKBACK ISSUE

A. Typical Reversal cycle in Present single trigger tooth Magneto system

Initially reversal phenomena was studied in present single trigger tooth magneto system. Kickback condition was simulated in engine running condition and oscilloscope was used to observe the phenomena of the reversal/kickback. Engine speed and Ignition coil output was measured and captured in the oscilloscope from crank position sensor and ignition coil respectively. During engine running condition, ignition spark was produced for every revolution of the engine to continue to run. However, ignition spark was produced even during kickback/engine reversal under simulated condition.

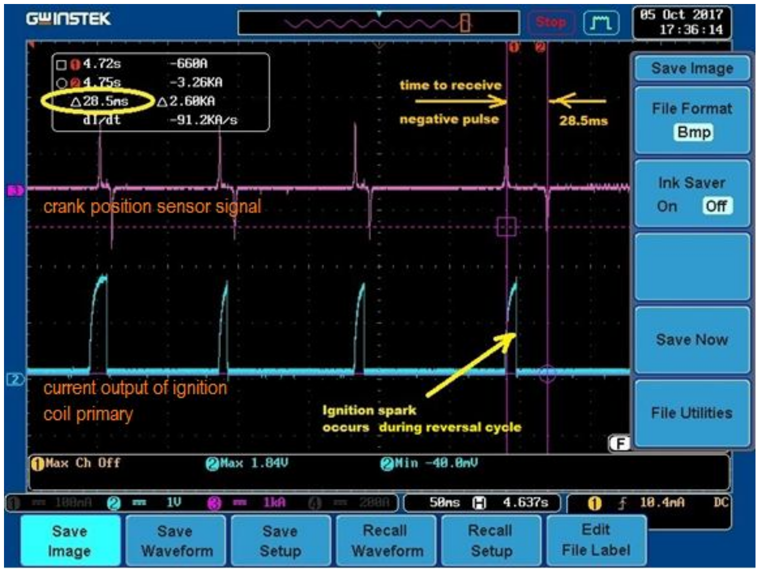

Fig 2 – Waveform of Reversal cycle in Present single tooth Magneto system

Figure 2 shows the waveform where ignition occurred during reversal cycle. Falling edge of the blue pulse indicates the occurrence of the ignition. The falling edge occurred not only in normal rotation but also in reverse rotation. When the ignition occurred during reversal cycle, combustion of the fuel have also occurred which has made piston to run in reverse direction with huge force, thereby heavy damage has occurred to the parts which were linked to the crankshaft and starting system especially sprag clutch or one way clutch, starter motor gears and starter motor.

B. Challenges in addressing reversal issue

1) Engine rpm/speed need to be calculated on the present revolution unlike using previous revolution.
2) Spark shall be cut-off only during reversal rpm/speed and not on normal non-reversal rpm/speed.
3) Reversal need to be identified using correct logic.

V. PROPOSED THREE TRIGGER TOOTH MAGNETO SYSTEM

In the existing magneto design, single trigger tooth is available in the rotor which would be insufficient to sense engine rpm/speed precisely and detect engine reversal. In the modified design, single trigger tooth is replaced with three trigger tooth and they are placed in certain angles as shown in below Fig 3**.** In a typical method, three trigger teeth are located in the magneto in such a way that TOOTH 'B' with 15° width is located 35° from TOOTH 'C. 'TOOTH' 'C' will have 45° width. TOOTH 'A' with 15° width is located 120° from TOOTH 'C'.

Engine rpm/speed change and dwell time is calculated using time gap between three pips within a revolution. But in the existing ignition system method (single pip magneto and tci/controller unit), engine rpm/speed and dwell time of the third revolution only can be calculated using time gap between main tooth of first revolution and main tooth of second revolution. So engine rpm/speed cannot be calculated in the present revolution or within one revolution and so precise control over ignition to cut-off the spark cannot be obtained during reversal cycle.

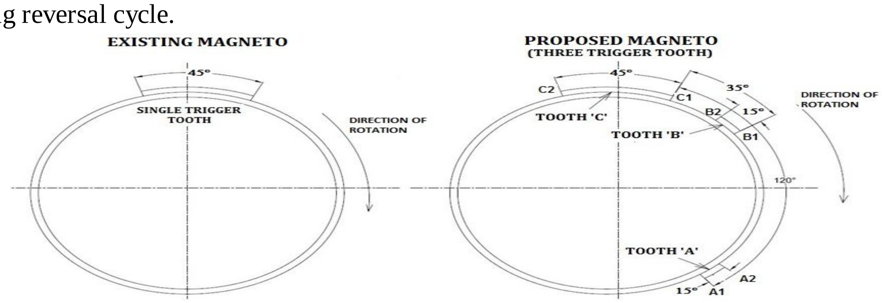

Fig 3 – Present and Proposed Magneto system

In the proposed method, time between trigger tooth edge 'C1' and 'A1' is used as a reference for the calculation of dwell time as shown in Fig 4. Dwell time is the time to charge the primary of the ignition coil to develop energy to produce spark. Time gap between trigger tooth edge 'B1' and 'C1' is used as a reference for the calculation of engine rpm/speed and ignition timing. In our method ‘C2’ position is 5deg before TDC(Top Dead Center) in the engine. Since engine rpm/speed calculation is done within one revolution, it would be accurate and helps to capture changes which occurs within one revolution/cycle.

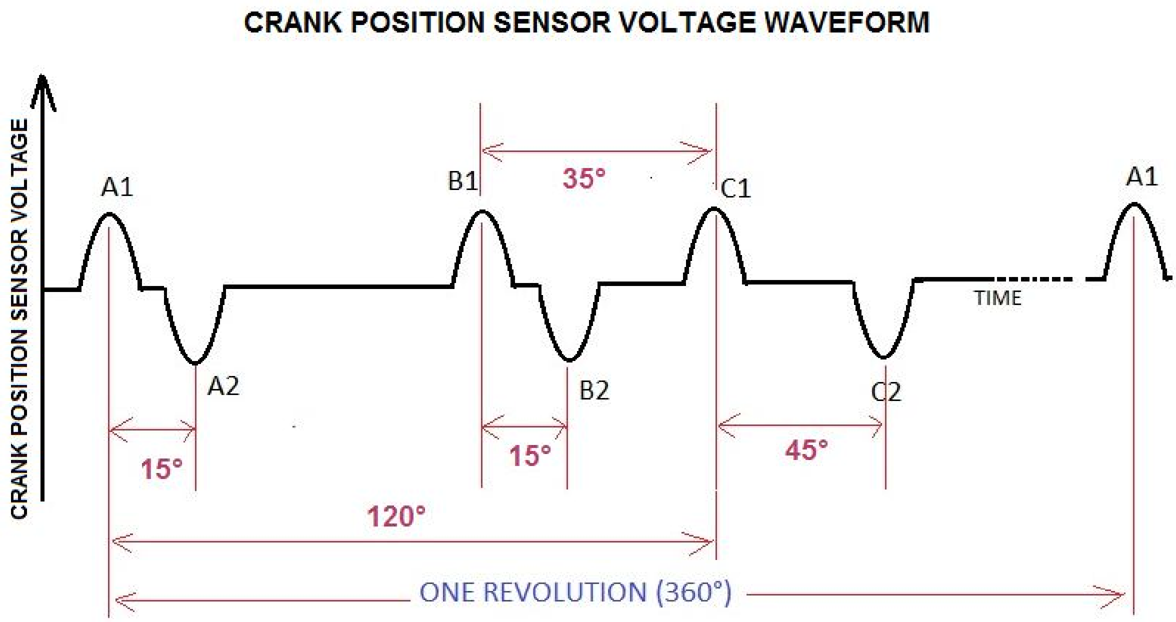

Fig 4 – Crank position sensor output for three trigger tooth magneto system

A. Simulation trials

Following simulation trials were done to identify Reversal cycle

1) Differentiate the normal engine rotation and reverse rotation using engine speed - During study it was inferred that there was no change in engine speed observed during reversal cycle and normal cycle.

2) Differentiate the normal engine rotation and reverse rotation using amplitude of the crank position sensor voltage - There was no abnormal change in amplitude of the reversal cycle observed in the crank position sensor voltage.

3) Differentiate the normal engine rotation and reverse rotation using variable ignition timings such as advance and retard. Even after changing different analog firing angles by retarding and advancing, reversal tend to have happened.

4) Differentiate the normal engine rotation and reverse rotation using firing after TDC(Top Dead Center) - Even if programmed to give ignite ‘After TDC’ from cranking /starting rpm to till idling rpm/speed i.e -2 deg to -10 deg and above, no significant improvement was observed in addressing the reversal.

5) Differentiate the normal engine rotation and reverse rotation using difference in sequence of pulse signal – Since the reversal occurs only when the piston compresses the air fuel mixture and goes closer to TDC, no difference was observed in sequence of pulse signal. Reversal occurs after the receipt of first positive pulse i.e ‘C1’ from crank position sensor signal.

6) Differentiate the normal engine rotation and reverse rotation using difference in the receipt of negative edge of the crank position sensor signal. After detailed study of reversal phenomena for more than 1000 times, it was inferred that a delay of less than 16ms was observed during normal rotation. Also a delay ranged from 25ms to 100ms was observed to receive negative edge of third trigger tooth during reversal.

So a control logic was formulated to sense the delay time and act according to our need. If delay of more than 18~22ms is observed, it is considered to be reversal and control to be provided by Electronic Control Unit to stop the ignition, thereby heavy impact to the piston and engine components can be prohibited.

VI. CONTROL METHODOLOGY

Engine reversal which occurs due to mechanical reverse rotation cannot be eliminated unless moment of inertia is optimized to the engine requirement. However impact of the reversal can be reduced in a much better way by controlling/stopping the spark during reversal cycle. When reversal occurs due to the inability of the piston to overcome the compression, piston struggles to move forward with a tendency to reverse and if the ignition occurs at that particular time, piston reverses with huge force and noise. If the ignition is stopped by any method during piston reverse rotation, impact of the reversal will be very minimal and reversal noise will become negligible. Proposed method guides us to stop the ignition during reversal cycle.

A. *Control Logics*

1) *Starting and Engine idling condition:* When the engine runs with the engine rpm/speed equal to or less than idling rpm/speed and time to receive trailing edge of trigger tooth 'C' (i.e. C2) after it receives leading edge of trigger tooth'C'(i.e. C1) is less than the predetermined time, spark shall be triggered to occur exactly at trailing edge of trigger tooth 'C2' by Controller unit. Ignition shall occur in analog mode instead of digital mode and analog firing position chosen in our method is the trailing edge or negative edge of third trigger tooth 'C2'. Controller shall wait for the trailing edge of trigger tooth'C' and as soon as trailing edge of trigger tooth 'C2 is received, it shall give the signal to produce spark. Since triggering occurs as soon as C2 is received, it is called Analog firing angle.
2) *Kickback/Reversal during starting or engine Idling condition:* When the engine runs with the engine rpm/speed equal to or less than idling rpm/speed and time to receive trailing edge of trigger tooth 'C' (i.e. C2) after it receives leading edge of trigger tooth 'C'(i.e. C1) is more than the predetermined time, spark shall be cutoff/prohibited by Controller unit.
3) *Engine rpm/speed more than idling rpm:* When the engine runs with the engine rpm/speed more than idling rpm/speed, Controller unit shall give spark based on the ignition map. Ignition shall be decided by digital mode to have variable ignition timing inorder to achieve better performance and to reduce emissions. Controller calculates ignition timing based on the engine speed and throttle position.

B. *Reversal cycle elimination using 3 tooth ACG with corresponding control logic*

Kickback condition was simulated in engine running condition and oscilloscope was used to observe the phenomena of the reversal/kickback. Engine speed and Ignition coil output was measured and captured in the oscilloscope from crank position sensor and ignition coil respectively. During engine running condition, ignition spark was produced for every revolution of the engine to continue to run. However, ignition spark was not produced even during kickback/engine reversal in three trigger tooth magneto system.

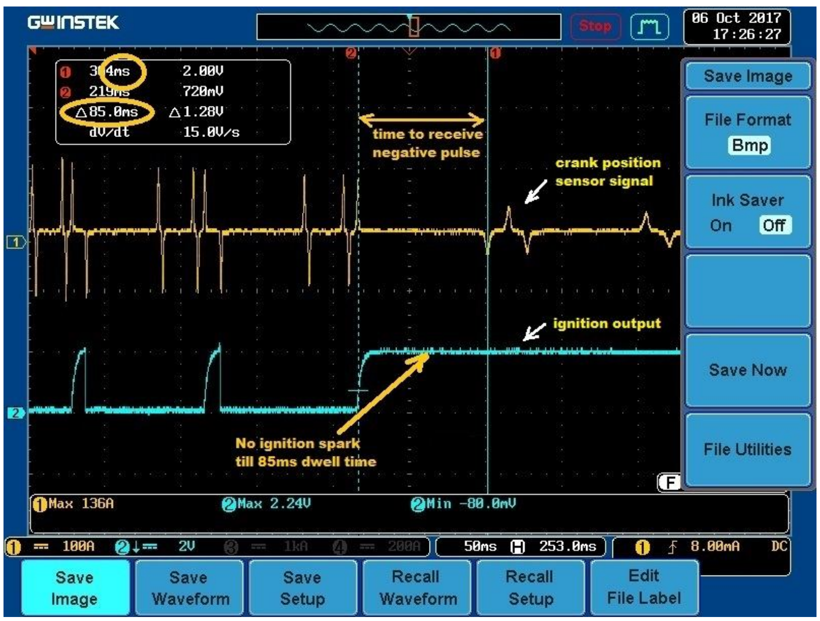

Fig 5 - Waveform for prohibition of ignition spark during kickback/reversal cycle

Waveform shown in fig 5 was captured during reversal cycle. In the above waveform, yellow pulses are signals of crank position sensor and blue pulses are output of ignition coil. As the time taken to receive the negative edge of the third pip was more than 20ms in the third revolution as shown in waveform image, Electronic control unit identified that particular cycle as reversal cycle and decided to continue to turn ON the ignition coil, thus ground signal was not given to the ignition coil to turn OFF, so there was no

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spark output, thus the engine was turned off. Turn ON time of the ignition coil during reversal cycle to be selected such that engine shall be turned off without harming the ignition coil.

C. Protect the Ignition coil from damage during kickback prevention

Once the engine is turned off, ignition coil would be kept in charged condition, which would be harmful to the coil as it would lead to heating up and burning of the coil. It shall be turned off to protect the coil and at the same time it must be ensured that vehicle is turned off during reversal cycle. Turn on duration of the ignition coil during reversal cycle is maintained as 1sec to ensure that engine will get turned off and shall not harm the coil.

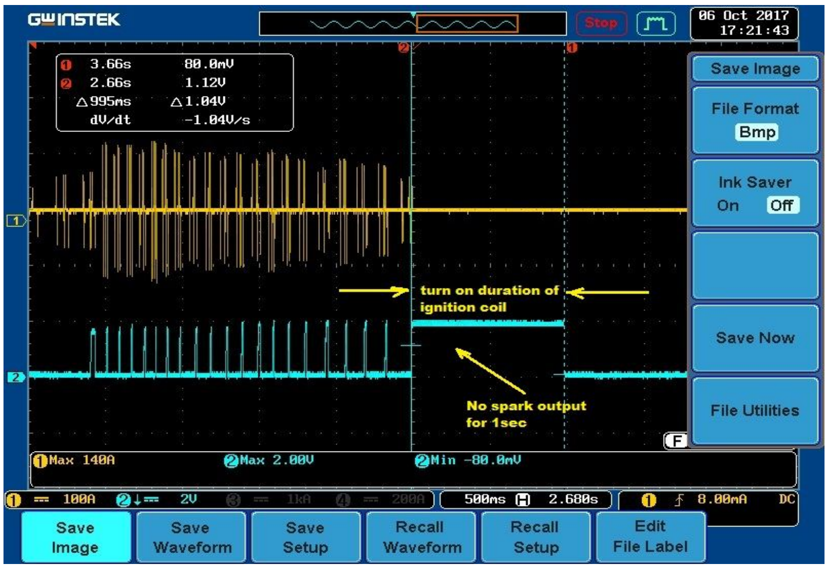

Fig 6 - Waveform for turn ON duration of ignition coil during reversal cycle

In the waveform as shown in Fig 6, it was shown that ignition coil was turned ON for 1 sec for safe operation and to meet the function.

VII. CONCLUSION

The proposed system can be used to prevent Kickback in any Internal combustion engines. Software control logic can be used in single trigger tooth magneto system[5] also to prevent kickback, however reversal/kickback determination may be inaccurate as the engine rpm was calculated using previous revolution and sudden acceleration/deceleration may mislead the determination of engine rpm. Magneto with 3 trigger tooth is able to calculate engine speed precisely at transient conditions within any particular revolution. The proposed model is applicable for two/three wheelers which has carburetor system since it needs the control of ignition only. Vehicles which has Electronic Fuel Ignition (EFI) system may require more no of trigger tooth in the alternator for the calculation and for the control of both ignition and injection. However kick back/engine reversal can be eliminated using the similar technique even in EFI system.

VIII. ACKNOWLEDGEMENT

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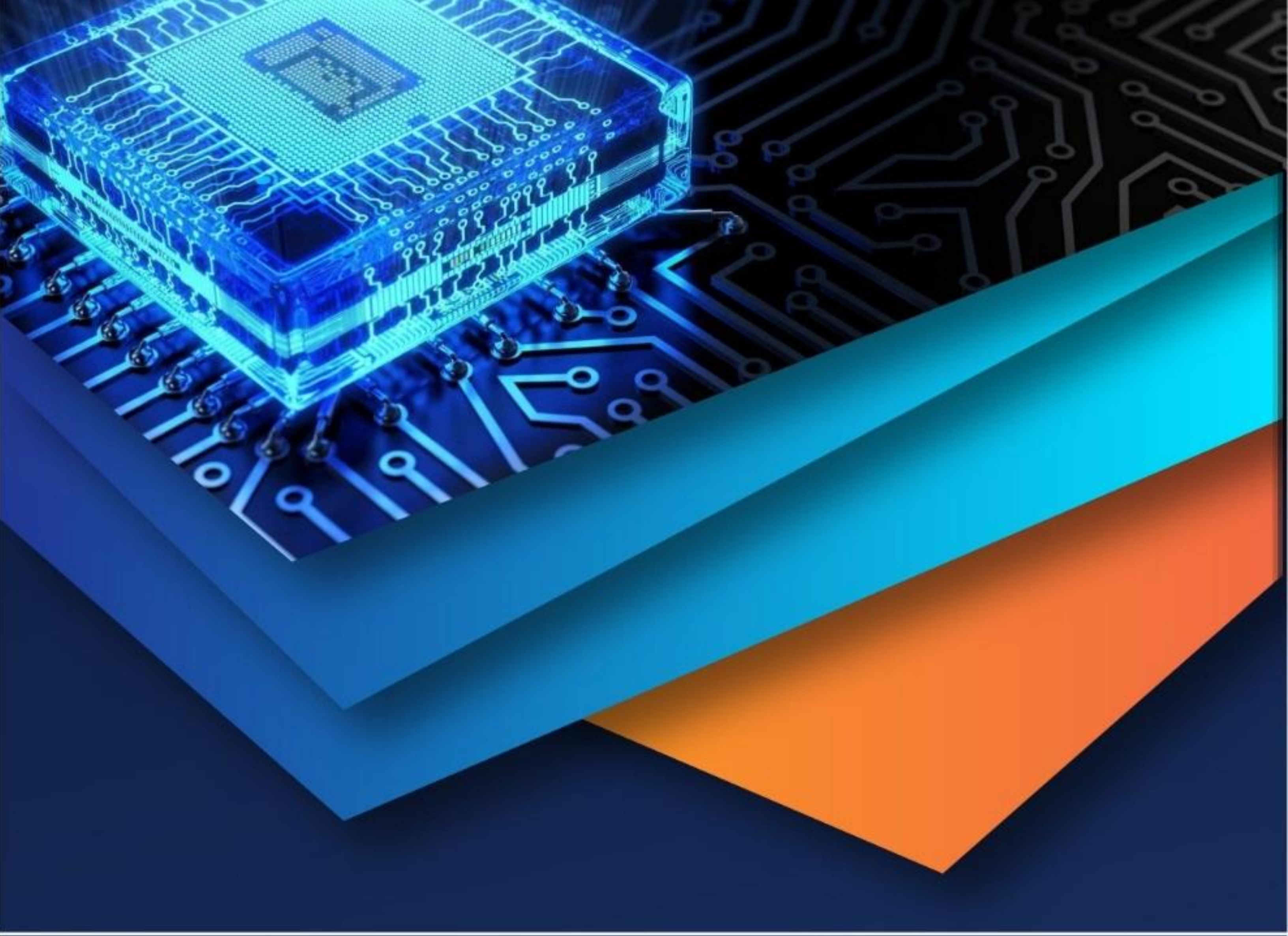

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