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A Study of Hydrogen as I.C. Engine Fuel and Theoretical modifications required in a Hydrogen ic Engine

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Abstract: Hydrogen is seen as a viable fuel alternate and its development work is carried-out under two sects, viz., fuel cells and Hydrogen IC Engines. While the researches on Fuel cell technology have borne fruit through co-ordination and integration, Hydrogen IC Engine researches are isolated to discrete domains.
This paper is an analysis paper focusing on evaluation of Hydrogen as a fuel for IC Engine. Besides introducing Hydrogen as IC Engine fuel, the technical feasibilities of various technologies under research have been analyzed and a theoretical IC Engine working on Hydrogen has been evolved.
The right combination of features of the engine has been selected through the available literature on this subject and expert opinions. The various areas analyzed include properties of Hydrogen, combustion properties of hydrogen, design and Modeling aspects of Hydrogen IC Engines. Further a discussion on various applications of this technology has been done. This work of analysis leaves openings for continuation as in the form of simulations and practical analyses.
Keywords: alternative fuel, hydrogen, Model development, application discussion.

I. INTRODUCTION

The earliest attempt at developing a hydrogen engine was reported by Reverend W. Cecil in 1820. Cecil presented his work before the Cambridge Philosophical Society in a paper entitled “On the Application of Hydrogen Gas to Produce Moving Power in Machinery.” The engine itself operated on the vacuum principle, in which atmospheric pressure drives a piston back against a vacuum to produce power.
The vacuum is created by burning a hydrogen-air mixture, allowing it to expand and then cool. Sixty years later, during his work with combustion engines in the 1860s and 1870s, N. A. Otto (the inventor of the Otto cycle) reportedly used a synthetic producer gas for fuel, which probably had a hydrogen content of over 50%. Otto also experimented with gasoline, but found it dangerous to work with, prompting him to return to using gaseous fuels. The development of the carburetor, however, initiated a new era in which gasoline could be used both practically and safely, and interest in other fuels subsided. Hydrogen has since been used extensively in the space program since it has the best energy-to-weight ratio of any fuel. Liquid hydrogen is the fuel of choice for rocket engines, and has been utilized in the upper stages of launch vehicles on many space missions including the Apollo missions to the moon, Skylab, the Viking missions to Mars and the Voyager mission to Saturn.
The properties of Hydrogen that contribute to its use as a combustible fuel are its:

A. Wide Range of Flammability

Hydrogen has a wide flammability range in comparison with all other fuels. As a result, hydrogen can be combusted in an internal combustion engine over a wide range of fuel-air mixtures. A significant advantage of this is that hydrogen can run on a lean mixture. There is a limit to how lean the engine can be run, as lean operation can significantly reduce the power output due to a reduction in the volumetric heating value of the air/fuel mixture.

B. Low Ignition Energy

Hydrogen has very low ignition energy. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition. Unfortunately, the low ignition energy means that hot gases and hot spots on the cylinder can serve as sources of ignition, creating problems of premature ignition and flashback. Preventing this is one of the challenges associated with running an Engine on hydrogen.

C. Small Quenching Distance

Hydrogen flames travel closer to the cylinder wall than other fuels before they extinguish. Thus, it is more difficult to quench a hydrogen flame than a gasoline flame. The smaller quenching distance can also increase the tendency for backfire.

D. High Auto ignition Temperature

Hydrogen has a relatively high auto ignition temperature. This has important implications when a hydrogen-air mixture is compressed. The auto ignition determines what compression ratio an engine can use, since the temperature rise during compression is related to the compression ratio.

E. High Flame Speed

Hydrogen engines can more closely approach the thermodynamically ideal engine cycle. At leaner mixtures, however, the flame velocity decreases significantly.

F. High Diffusivity

Hydrogen has very high diffusivity. It facilitates the formation of a uniform mixture of fuel and air. Secondly, if a hydrogen leak develops, the hydrogen disperses rapidly.

G. Low Density

Hydrogen has very low density. Hence a very large volume is necessary to store enough hydrogen to give a vehicle an adequate driving range.

Depending the method used to meter the hydrogen to the engine, the power output compared to a gasoline engine can be anywhere from 85% (intake manifold injection) to 120% (high pressure injection). Because of hydrogen's wide range of flammability, hydrogen engines can run on A/F ratios of anywhere from 34:1 (stoichiometric) to 180:1.

II. PURE HYDROGEN IC ENGINES

A. Introduction

There is currently an expanding market for this technology as worldwide entities attempt to convert to hydrogen, but cannot accept the current economics of fuel cells. Utility companies, both natural gas and electric and both U.S. and abroad, are investigating the economics of being hydrogen suppliers and implementers. However, the advantages of simple conversions of IC engines with HCNG cannot be easily adopted when dealing with pure hydrogen. Without the combustion modifying effects of methane, hydrogen combustion is extremely rapid and difficult to control in an IC engine.

B. Under lying Principles and Concepts

To be able to run a hydrogen engine, the mixture formation of air and hydrogen does not need precise control (Das, 1990).Consequently; simple systems such as an external mixture system with a gas carburetor (venturi type) can be used for the fuel supply. However, a complete control of the combustion process is only possible with an injection system and an electronic control unit (electronic management system), as used for all new gasoline and diesel engines. Therefore, the carburetor is discarded to be replaced by a low-pressure gas injection system in the inlet manifold, allowing multi-point sequential injection of the gaseous hydrogen fuel in each inlet channel just before the inlet valve. Such an injection system, as applied to liquid fuels (gasoline, liquid LPG, …) has several advantages including the possibility to tune the air-fuel ratio of each cylinder to a well-defined value, increased power output and decreased cyclic variation of the combustion process in the cylinders. Timed injection also has an additional benefit for a hydrogen fuelled engine, as it implies a better resistance to backfire. All these advantages are well known (Sorusbay and Veziroglu, 1988), (Kondo et al., 1996), (Lee et al., 1995), (Guo et al., 1999).

C. Pre-Ignition Problems

The primary problem that has been encountered in the development of operational hydrogen engines is premature ignition. Premature ignition is a much greater problem in hydrogen fueled engines than in other IC engines, because of hydrogen's lower ignition energy, wider flammability range and shorter quenching distance. Premature ignition occurs when the fuel mixture in the combustion chamber becomes ignited before ignition by the spark plug, and results in an inefficient, rough running engine. Backfire conditions can also develop if the premature ignition occurs near the fuel intake valve and the resultant flame travels back into the induction system.

Pre-ignition is caused by hot spots in the combustion chamber, such as on a spark plug or exhaust valve, or on carbon deposits. Other research has shown that backfire can occur when there is overlap between the opening of the intake and exhaust valves.

The pyrolysis (chemical decomposition brought about by heat) of oil suspended in the combustion chamber or in the crevices just above the top piston ring can contribute to pre-ignition. This pyrolysed oil can enter the combustion chamber through blow-by from the crankcase (i.e. past the piston rings), through seepage past the valve guide seals and/or from the positive crankcase ventilation system (i.e. through the intake manifold).

III. MODIFICATIONS REQUIRED IN DESIGN

The high auto ignition temperature of hydrogen allows larger compression ratios to be used in a hydrogen engine than in a hydrocarbon engine. This higher compression ratio is important because it is related to the thermal efficiency of the system as presented. On the other hand, hydrogen is difficult to ignite in a compression ignition or diesel configuration, because the temperatures needed for those types of ignition are relatively high.

A. Fuel Delivery Systems

Adapting or re-designing the fuel delivery system can be effective in reducing or eliminating pre-ignition. Hydrogen fuel delivery system can be broken down into three main types: central injection (or “carbureted”), port injection and direct injection. Central and port fuel delivery systems injection forms the fuel-air mixture during the intake stroke. In the case of central injection or a carburetor, the injection is at the inlet of the air intake manifold. In the case of port injection, it is injected at the inlet port.

Direct cylinder injection is more technologically sophisticated and involves forming the fuel-air mixture inside the combustion cylinder after the air intake valve has closed.

The simplest method of delivering fuel to a hydrogen engine is by way of a carburetor or central injection system. This system has advantages for a hydrogen engine. Firstly, central injection does not require the hydrogen supply pressure to be as high as for other methods. Secondly, central injection or carburetors are used on gasoline engines, making it easy to convert a standard gasoline engine to hydrogen or a gasoline/hydrogen engine.

The disadvantage of central injection is that it is more susceptible to irregular combustion due to pre-ignition and backfires. The greater amount of hydrogen/air mixture within the intake manifold compounds the effects of pre-ignition.

B. Port Injection Systems

The port injection fuel delivery system injects fuel directly into the intake manifold at each intake port, rather than drawing fuel in at a central point. Typically, the hydrogen is injected into the manifold after the beginning of the intake stroke. At this point conditions are much less severe and the probability for premature ignition is reduced.

In port injection, the air is injected separately at the beginning of the intake stroke to dilute the hot residual gases and cool any hot spots. Since less gas (hydrogen or air) is in the manifold at any one time, any pre-ignition is less severe. The inlet supply pressure for port injection tends to be higher than for carbureted or central injection systems, but less than for direct injection systems.

The constant volume injection (CVI) system uses a mechanical cam-operated device to time the injection of the hydrogen to each cylinder.

The electronic fuel injection (EFI) system meters the hydrogen to each cylinder. This system uses individual electronic fuel injectors (solenoid valves) for each cylinder, which are plumbed to a common fuel rail located down the center of the intake manifold. Whereas the CVI system uses constant injection timing and variable fuel rail pressure, the EFI sys-tem uses variable injection timing and constant fuel rail pressure.

C. Direct Injection Systems

More sophisticated hydrogen engines can utilize direct injection into the combustion cylinder during the compression stroke. In direct injection, the intake valve is closed when the fuel is injected, completely avoiding premature ignition during the intake stroke. Consequently the engine cannot backfire into the intake manifold. The power output of a direct injected hydrogen engine is 20% more than for a gasoline engine and 42% more than a hydrogen engine using a carburetor.

While direct injection solves the problem of pre-ignition in the intake manifold, it does not necessarily prevent pre-ignition within the combustion chamber. In addition, due to the reduced mixing time of the air and fuel in a direct injection engine, the air/fuel mixture can be non-homogenous. Studies have suggested this can lead to higher NOx emissions than the non-direct injection systems. Direct injection systems require a higher fuel rail pressure than the other methods.

D. Thermal Dilution

Pre-ignition conditions can be curbed using thermal dilution techniques such as exhaust gas recirculation (EGR) or water injection. As the name implies, an EGR system re-circulates a portion of the exhaust gases back into the intake manifold. The introduction of exhaust gases helps to reduce the temperature of hot spots, reducing the possibility of pre-ignition. Additionally, recirculation exhaust gases reduce the peak combustion temperature, which reduces NOx emissions. Typically a 25 to 30% recirculation of exhaust gas is effective in eliminating backfire. On the other hand, the power output of the engine is reduced when using EGR. The presence of exhaust gases reduces the amount of fuel mixture that can be drawn into the combustion chamber.

Another technique for thermally diluting the fuel mixture is the injection of water. Injecting water into the hydrogen stream prior to mixing with air has produced better results than injecting it into the hydrogen-air mixture within the in-take manifold. A potential problem with this type of system is that water can get mixed with the oil, so care must be taken to ensure that seals do not leak.

The most effective means of controlling pre-ignition and knock is to re-design the engine for hydrogen use, specifically the combustion chamber and the cooling system. A disk-shaped combustion chamber (with a flat piston and chamber ceiling) can be used to reduce turbulence within the chamber. The disk shape helps produce low radial and tangential velocity components and does not amplify inlet swirl during compression. Since unburned hydrocarbons are not a concern in hydrogen engines, a large bore-to-stroke ratio can be used with this engine. To accommodate the wider range of flame speeds that occur over a greater range of equivalence ratios, two spark plugs are needed. The cooling system must be designed to provide uniform flow to all locations that need cooling. Additional measures to decrease the probability of pre-ignition are the use of two small exhaust valves as opposed to a single large one, and the development of an effective scavenging system, that is, a means of displacing exhaust gas from the combustion chamber with fresh air.

E. Ignition Systems

Due to hydrogen's low ignition energy limit, igniting hydrogen is easy and gasoline ignition systems can be used. At very lean air/fuel ratios (130:1 to 180:1) the flame velocity is reduced considerably and the use of a dual spark plug system is preferred.

Ignition systems that use a waste spark system should not be used for hydrogen engines. These systems energize the spark each time the piston is at top dead center whether or not the piston is on the compression stroke or on its exhaust stroke. For gasoline engines, waste spark systems work well and are less expensive than other systems. For hydrogen engines, the waste sparks are a source of pre-ignition.

Spark plugs for a hydrogen engine should have a cold rating and have non-platinum tips. A cold-rated plug is one that transfers heat from the plug tip to the cylinder head quicker than a hot-rated spark plug. This means the chances of the spark plug tip igniting the air/fuel charge is reduced. Hot-rated spark plugs are designed to maintain a certain amount of heat so that carbon deposits do not accumulate. Since hydrogen does not contain carbon, hot-rated spark plugs do not serve a useful function. Platinum-tip spark plugs should also be avoided since platinum is a catalyst, causing hydrogen to oxidize with air.

F. Crankcase Ventilation

Crankcase ventilation is even more important for hydrogen engines than for gasoline engines.

As with gasoline engines, unburnt fuel can seep by the piston rings and enter the crankcase. Since hydrogen has a lower energy ignition limit than gasoline, any unburnt hydrogen entering the crankcase has a greater chance of igniting. Hydrogen should be prevented from accumulating through ventilation. Ignition within the crankcase can be just a startling noise or result in engine fire. When hydrogen ignites within the crankcase, a sudden pressure rise occurs. To relieve this pressure, a pressure relief valve must be installed on the valve cover Exhaust gases can also seep by the piston rings into the crankcase. Since hydrogen exhaust is water vapor, water can condense in the crankcase when proper ventilation is not provided. The mixing of water into the crankcase oil reduces its lubrication ability, resulting in a higher degree of engine wear.

G. Ignition Timing

The ignition advance is normally set to the minimum value for best torque (MBT timing). This is the compromise between a high power output (necessary due to the losses in volumetric efficiency) and a minimum ignition advance to decrease NOx values. For

lean mixtures (low loads and speeds), the optimum ignition timing is early, up to 50° ca BTDC (power cycle). The engine load is the main influence. For high loads and speeds (maximum power output) the optimum ignition timing is about 20° BTDC.
The efficiency of a hydrogen fuelled engine is very dependent on optimally adjusted ignition timing as a function of the richness of the mixture (i.e. the load, as mentioned above).

H. Injection Pressure

When the injection pressure is raised, the power output will rise due to the higher amount of hydrogen in the engine (if injection durations are fixed). However, the possibilities of Variations in injection pressure are limited according to the chosen means of storage of the hydrogen. When the hydrogen is stored in liquid form, the pressure in the cryogenic tanks is restricted. For this reason, a constant injection pressure of 3 bar is respected. In case of gaseous storage in pressurized form, it would be possible to vary the injection pressure according to the desired power output (but keeping the limitations of the air to
Fuel ratio γ=2).

I. Injection Duration

The engine is operated as a diesel engine: it is a spark ignited engine but load variations are captured through variations in the richness of the hydrogen-air mixture. As a consequence, the injection duration (in degrees crank angle) is proportional to the engine load.

J. Injection Timing

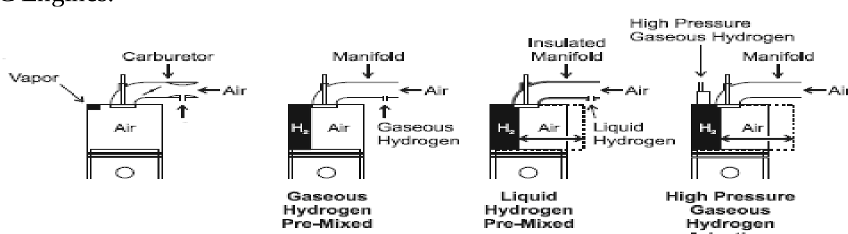
This parameter has a great impact in the lower range of engine loads and speeds. In this region, differences in power output, by varying the injection timing, of up to 20% are no exception. All optimum injections start at or before TDC (gas exchange), and should be advanced with speed increase. For example, during idling conditions (low speed) the injection starts at TDC and in high speed conditions the injection timing is advanced up to 105° c.a. BTDC (thus before the inlet valve opens, because of the time needed for the fuel to travel from the injector to the inlet valve, as a consequence the injection ends well before the inlet valve closes

K. Ignition Characteristics

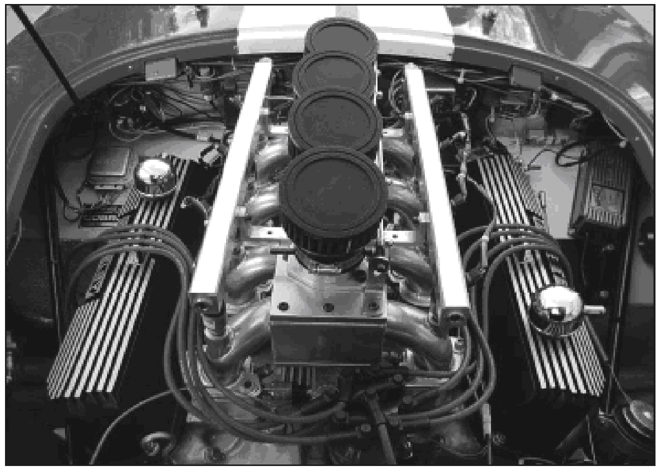
Hydrogen under high pressure is commonly used as an insulator (e.g. in the alternator of a Power plant). This results in a high ignition voltage of the hydrogen-air mixture. This is solved by choosing the spark plug gap smaller than usual in classic gasoline engines (Payvey, 1988). This is possible because of the smaller amount of deposits on the electrodes (only from impurities and lubricating oil). Measurements are done to define the optimal spark gap to cover the full load and speed range: testing during idle run is necessary to ensure a stable idle run, testing during full load has to be done to make sure the arc is not blown out. The spark plug gap corresponding to the most stable combustion is considered optimal. An optimum of 0.4 mm is calculated in comparison with the spark gap of 0.9 mm for normal spark plugs. This previous setting of 0.9 mm would create problems due to spark discharges through the air outside the cylinders. The voltage peaks on the secondary side (> 40 kV) exceeds the insulation possibilities of the spark plug cables, causing spark discharges between the spark plug heads and the cylinder head. These problems can completely be solved with the optimized spark gap. A discussion of other components of Engine is not needed as no significant modifications are required. The models and designs proposed are just theoretical and there is no evidence whatsoever to ensure the results. Any way these may be taken as indicative and further developmental researches may be under taken.

L. N. B.,

The authors however, are involved in the Engine Modification for Hydrogen added CNG fuel and Exhaust, Noise Analysis and comparison of Hydrogen IC Engines.

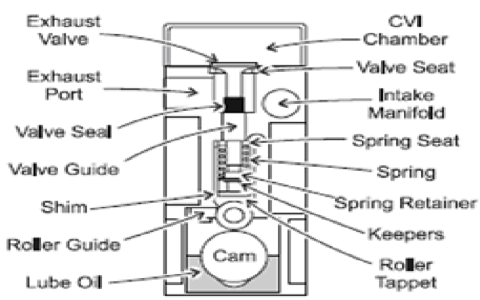


A CAD Drawing showing Hydrogen Combustion in IC Engine



Commercial Model developed by Ford

IV. PROPOSED DESIGN OF COMPONENTS



An AutoCAD drawing showing proposed fuel Injector design

V. CONCLUSION

In this project the hydrogen used as the primary fuel was less in emission and it can easily manufacture, so that the emission produced is very less and the by product could h2o hence that the modification in this engine will help to reduce the emission that produce green house effect and harmful poisonous gases to the environment, not only with that it increase the efficiency of the engine.

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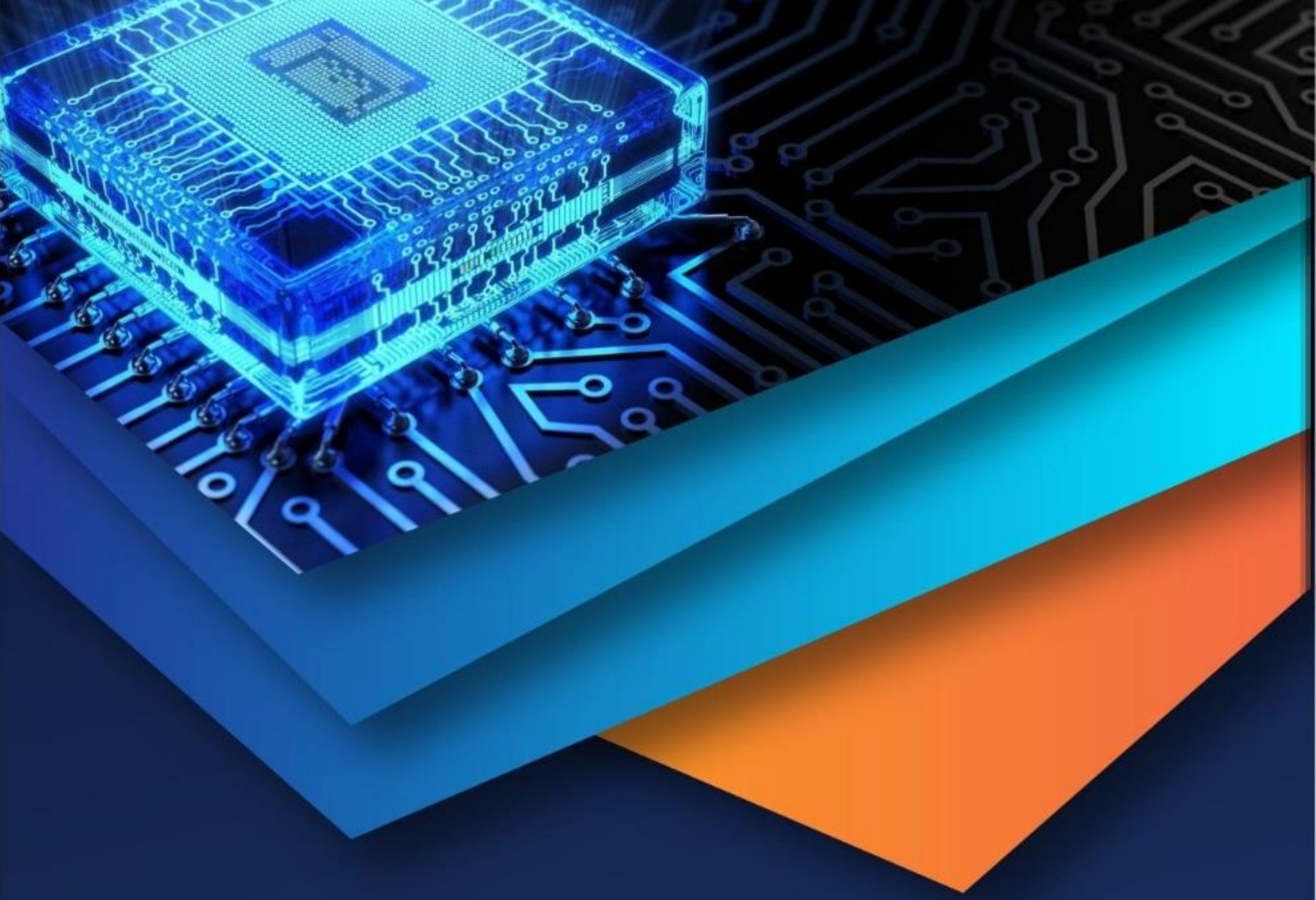

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